



06 - 08 September, 2025
Tirupati, India

Technical Partners



4th International Conference on
**Friction-Based
Processes
2025**

Souvenir



www.iapmfp.org

International Association for
Processing of Materials and
Fabrication of Products

डॉ. एस.वी.एस. नारायण मूर्ति
अध्यक्ष एवं प्रबंध निदेशक



Dr. S.V.S. Narayana Murty
Chairman and Managing Director



Message

It is heartening to note that the 4th International Conference on Friction-Based Processes (ICFP 2025), organized by several prominent Indian institutions: the Indian Institute of Technology Tirupati (IITT), the Indian Institute of Technology Patna (IITP), the Indian Institute of Technology Dharwad (IITDh), and the Indian Institute of Science Bangalore (IISc), is being held this year in the holy city of Tirupati, India from 6th -8th Sept 2025. This event brings together professionals, researchers, innovators, and thought leaders from around the world to explore the potential of friction-based processes.

This conference occupies a prominent role in achieving the honourable prime minister's vision of "Viksit Bharat-2047". To achieve this vision, there is an ever-growing demand to dynamically evolve and redefine the existing boundaries of material processing techniques using advanced technologies involving machine learning and artificial intelligence. This would also result in faster and more intelligent production of high-quality products for aerospace, defense, automotive, naval and nuclear applications to support our indigenous efforts along with enhanced forex savings.

It is a pleasure to extend our support for the ICFP 2025 conference on behalf of the Mishra Dhatu Nigam (MIDHANI) family. We believe this event will be instrumental in advancing friction-based processes and aligning with the "Viksit Bharat-2047" vision.

May this conference foster new collaborations and establish clear directives for the development of advanced friction-based processing techniques, thereby continually improving advanced products made in India.

I wish the conference a grand success.

warm Regards

Dr S V S Narayana Murty
Chairman & Managing Director

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MESSAGE

from

President of International Association for Processing of Materials and Fabrication of Products [IA PMFP]

Greetings, cheers and abundance of thanks I extend to each one of you opting to be physically present in person and to even those who may be tuning in on-line to make “valued” presence felt and concurrently participating both by way of delivering their presentation and discussion. In the last few days and weeks, I have been fortunate to receive messages from individuals, both involved and committed to investigating and understanding the impact and far-reaching implications arising from systematically studying **friction-based processes** specific to materials (to include both Science and Engineering) and Manufacturing Processes (to include Manufacturing Technologies), so as to help in promoting and furthering the prevailing knowledge base specific to the Processing of Materials as a viable outcome for the fabrication of products for use in a spectrum of applications.

This technical event on Friction-Based Processes is being held at the **S.R. Convention Hall** [Tirupati, Andhra Pradesh, India] and jointly organized by (i) **IA-PMFP**, (ii) **Indian Institute of Technology (IIT) [Tirupati]**, (iii) **IIT [Dharwad]**, (iv) **IIT [Patna]**, and (v) **Indian Institute of Science [Bangalore]** is the **FOURTH** in a series of conferences on the specific topic of “**Friction-Based Processes**”. The prime objective is to bring together engineers, technologists, and researchers from nations scattered through the globe and intimately associated with industries, universities and national/government laboratories, and committed to both studying and understanding aspects and intricacies related, relevant and applicable to friction-based processes specific to materials and products.

The topics for presentation and discussion include the following: (i) friction-based metal forming processes, (ii) friction-stir welding and allied processes, (iii) smart manufacturing, (iv) Artificial Intelligence / Machine Learning, (v) digital twin technologies, (vi) deformation mechanisms, and (vii) advanced characterization techniques. The agenda of this scholarly technical event is vital since it attempts to address the relevance of friction-based processes specific to the future of engineering with applications extending to the following sectors: (i) Aerospace and Defense, (ii) Automotive, (iii) Structural Applications, and (iv) Naval and Nuclear industries.

In net essence the “**Theme**” of this Scholarly Technical Event is to bring together a spectrum of contributions that not only highlight fundamental ideas but also conduct the research into both enabling and ensuring practical industrial solutions. The key participants are anticipated and encouraged to present and discuss their findings, observations, inferences and potentially viable outcomes culminating from their study



The earlier conferences on “**Friction-Based Processes**” were sponsored by the following three high-profile academic institutions: (i) Indian Institute of Science (India), (ii) Tsinghua University (China), and (iii) Osaka University, JWRI (Japan).

As organizers we have made every effort to ensure that each one of the participants in attendance, has an excellent experience that spans the domain of education with the prime objective of achieving the following:

- (a) Enabling and ensuring enlightenment for all of the participants and interested attendees, and concurrently
- (b) Striving to enable, encourage and promote entrepreneurship, growth and prosperity.

Giving due consideration to the scale and caliber of the qualified and intellectually inclined and inspired individuals, numbering in excess of 250 [50 of whom are international participants], that we have been able to attract, encourage, inspire and motivate to participate in this scholarly technical event the “**Fourth International Conference** on the topic of **Friction-Based Processes**” does look promising to both meeting and fulfilling the objectives specific to presenting and discussing efforts aimed at excellence in the execution of research with the ulterior objective of both enabling and ensuring entrepreneurship by way of development of both processes and products for selection and prudent use in a large number of applications.

In essence, this conference seeks to bring out excellence, while concurrently striving to both enable and promote diversity, and concurrently celebrating accomplishments and achievements made possible through both independent study and collaborative/co-operative studies. Our key objective is to both nurture and promote the overall well-being of research done by each participant, while concurrently ensuring a platform for the presentation of the research executed and accomplished with an emphasis on (i) innovations and findings, and (ii) the possibility of entrepreneurship that does necessitate the need for both stewardship and direction.

Srivatsan T S

President (IA PMFP)

Date: August 21, 2025

Prof. Kalidindi N. Satyanarayana
Director

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I am delighted to learn that the International Association for Processing of Materials and Fabrication of Products (IA-PMFP), in collaboration with the Indian Institute of Technology Tirupati, Indian Institute of Technology Patna, Indian Institute of Technology Dharwad, and the Indian Institute of Science (IISc) Bangalore, is organizing the 4th International Conference on Friction-Based Processes (ICFP 2025). The conference will be held in Tirupati, India, from 6th to 8th September 2025.

Materials and Manufacturing is one of the key thrust areas at IIT Tirupati, and the ICFP 2025 is well aligned with this focus. Continuing the legacy of the ICFP series, which began in 2014, this conference serves as a prestigious global platform to present and discuss the latest advancements in friction-based manufacturing processes—an area that is critical for a wide range of materials and industrial sectors.

The scope of the conference is broad and impactful, covering topics such as:

- Friction-Based Metal Forming Processes
- Friction Stir Welding and Allied Processes
- Friction Stir Processing and Additive Manufacturing
- Solid-State Manufacturing Techniques
- Tribology (Wear, Friction, and Lubrication)
- Smart Manufacturing
- AI/ML and Digital Twin Tools
- Deformation Mechanisms and Advanced Characterization

These themes are particularly relevant to applications in Aerospace and Defense, Automotive and Structural Engineering, and Naval and Nuclear Industries.

ICFP 2025 provides a unique opportunity for researchers, practitioners, and newcomers to engage, exchange ideas, and foster collaborations that will shape the future of friction-based processes.

I extend a warm welcome to all conference delegates and participants.

I also wish the organizers every success in hosting this important international event in association with **IIT Tirupati**.



Best Regards,
K. N. Satyanarayana



Prof. Satyam Suwas
Chairman, 4th ICFP 2025

28th Aug 2025

I am delighted and proud to serve as the Chairman for the 4th International Conference on Friction-Based Processes (ICFP 2025), organized by the International Association for Processing of Materials and Fabrication of Products (IA-PMFP) in collaboration with the Indian Institute of Technology Tirupati, Indian Institute of Technology Patna, Indian Institute of Technology Dharwad, and the Indian Institute of Science (IISc) Bangalore. The conference will be held in Tirupati, India, from 6th to 8th September 2025. I would also like to express my gratitude to Prof. Satish Vasu Kailas, who initiated this conference series 10 years ago.

Materials and manufacturing are fundamental to a nation's growth, and ICFP 2025 is closely aligned with this vision. Building on the legacy of the ICFP series that began in 2014, this conference has grown into a prestigious global platform to present and discuss the latest advancements in friction-based manufacturing processes—a field critical to a wide range of materials and industrial sectors.

The conference will cover a broad and impactful range of topics, including:

- Friction-Based Metal Forming Processes
- Friction Stir Welding and Allied Processes
- Friction Stir Processing and Additive Manufacturing
- Solid-State Manufacturing Techniques
- Tribology (Wear, Friction, and Lubrication)
- Smart Manufacturing
- AI/ML and Digital Twin Tools
- Deformation Mechanisms and Advanced Characterization

ICFP 2025 provides a valuable opportunity for researchers, practitioners, and young professionals to engage, exchange ideas, and forge collaborations that will shape the future of friction-based processes. I extend a warm welcome to all conference delegates and participants and wish the organizers every success in hosting this important international event in Tirupati.

Best Regards,

A handwritten signature in blue ink that reads "Satyam Suwas". The signature is fluid and cursive, with the first name "Satyam" and last name "Suwas" clearly distinguishable.

[Satyam Suwas]



Prof. David P. Field
(Washington State University,
Pullman, Washington,
United States of America)



Prof. Zongyi Ma
(Institute of Metal Research Chinese
Academy of Sciences, Shenyang, China)
Editors-in-Chief, Materials Characterization
Elsevier Journal

Message

We welcome submissions to Materials Characterization from participants of ICFP for the special issue on "Microstructure Development During Friction-Based Processes." We are certain that many of the papers fall in line with the scope of the journal and we look forward to receiving your submissions. The papers will be reviewed in the regular process with organizers of ICFP serving as Guest Editors of the issue. Please be aware that not all papers in the conference will fit the scope of the journal that requires an emphasis on microstructural imaging. Microstructural analysis should be emphasized using conventional and/or novel characterization techniques. It is unfortunate that we are not able to join you in person, but we hope that you have a successful and productive conference.

David Field

Zongyi Ma



I would like to sincerely thank you and the Organizing Committee for the kind invitation to contribute a message to the souvenir of the 4th International Conference on Friction-Based Processes (ICFP 2025).

It is a great honor to be associated with this important event, which brings together leading experts from academia and industry to foster innovation in the field of friction-based manufacturing. The conference, organized in collaboration with prestigious institutions such as IISc Bangalore, IIT Tirupati, IIT Patna, and IIT Dharwad, will undoubtedly serve as a vibrant platform for the exchange of knowledge and the promotion of fruitful collaborations.

I warmly congratulate the organizers for their efforts and dedication in preparing this international gathering. I am confident that ICFP 2025 will make a significant contribution to advancing scientific understanding and technological progress in the area of friction-based processes.

I wish the conference every success and look forward to its stimulating discussions and outcomes.

With my best regards,

Pr. Roxane MASSION
Université de Lorraine
France



Message

Organizing any conference is a demanding task. While the individual components may appear straightforward, they require careful attention and coordination at every step. It is indeed heartening to see the success of this endeavor, thanks to the dedicated efforts of the organizing team led by Prof. Ajay Kumar from IIT Tirupati, Prof. Devinder Yadav from IIT Patna, and Dr. Anbukkarasi Rajendran from IIT Dharwad. Their commitment, along with the valuable guidance of Prof. Satyam Suwas from IISc, has made this conference a reality. We are also grateful for the support and encouragement from the Director of IIT Tirupati, Prof. K. N. Satyanarayana, and from Prof. T. Srivatsan of the University of Akron. Their contributions have played a pivotal role in bringing this event to fruition. This conference marks the fourth in the series of the International Conference on Friction-based Processes. A notable and exciting development in this edition is the inclusion of a dedicated session on Tribology, expanding the scope of discussion and opening new avenues for interdisciplinary engagement. With a distinguished lineup of speakers and participants from around the world, we are confident that this conference will be a grand success. At the heart of any such gathering lies the opportunity to share ideas, foster dialogue, and initiate meaningful collaborations. It is our hope that this platform will spark new connections and fruitful partnerships among researchers and practitioners alike. To that end, we encourage all attendees to engage actively — to meet those from whom they seek inspiration, and to offer their own insights in return. Thoughtful exchange, proper acknowledgment, and the potential for joint publications or even patents are the true hallmarks of a successful academic gathering. Let us ensure that every participant finds value in this experience. Wishing the conference all success and lasting impact.

Satish Vasu Kailas,

Ph.D. Professor (HAG)

Surface Interaction and Manufacturing Laboratory

Department of Mechanical Engineering

Indian Institute of Science Bengaluru 560012 INDIA



Prof. Ajay Kumar
IIT Tirupati



Prof. Devinder Yadav
IIT Patna



Prof. Anbukkarasi Rajendran
IIT Dharwad

Message

On behalf of the organizing committee, we are delighted to welcome you to the 4th International Conference on Friction-Based Processes (ICFP 2025), hosted at S R Convention, Tirupati, India, from September 6–8, 2025. This conference marks a significant milestone as we bring together over 150 delegates, including more than 20 international experts, to discuss and advance the field of friction-based manufacturing processes.

ICFP 2025 is a collaborative effort of the International Association for Processing of Materials and Fabrication of Products (IA-PMFP) and esteemed institutions such as the Indian Institutes of Technology (IIT) Tirupati, Patna, and Dharwad, along with the Indian Institute of Science (IISc) Bangalore. Our collective goal is to foster interdisciplinary dialogue, promote innovative research, and address the challenges and opportunities in friction-based manufacturing.

The conference features plenary talks, parallel sessions, poster presentations, and interactive discussions, providing a platform for researchers, academicians, and industry professionals to share knowledge and collaborate. Special sessions will focus on emerging trends and the future of friction-based processes, ensuring that we remain at the forefront of technological advancements.

Beyond the technical sessions, ICFP 2025 offers a unique cultural experience in the historic city of Tirupati. Participants will have the opportunity to explore renowned temples, engage in cultural programs, and partake in a spiritual visit to the Sri Venkateswara Swamy Temple, enriching both professional and personal experiences.

We are committed to providing an inclusive and engaging environment for all attendees. Our team has meticulously planned every aspect of the conference to ensure your comfort and a memorable experience.

Thank you for your participation and contribution to the success of ICFP 2025. We look forward to meaningful discussions, fruitful collaborations, and a memorable journey together.

Warm regards,

Prof. Ajay Kumar
IIT Tirupati

Prof. Devinder Yadav
IIT Patna and

Prof. Anbukkarasi Rajendran
IIT Dharwad

Conveners, ICFP 2025
Department of Mechanical Engineering
Indian Institute of Technology Tirupati

Plenary Talks

Friction Stir Technologies – Evolution of a Disruptive Process over 30 Years

Rajiv S. Mishra^{1*}

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Abstract

The invention of friction stir welding in 1995 was the onset of a disruptive joining technology. In the beginning, it enabled solid-state joining of unweldable high strength aluminum alloys. The first evolution of this technology by Mishra et al. (1999) was given a generic name of friction stir processing. The friction stir processing broadened the scope of this solid-state technology as a microstructural refinement technique with first application to superplasticity. From that time, it has been a continuous emergence of new technologies based on the principles of friction stir process. In this overview, the pace of evolution will be presented including the most recent variants of additive friction stir deposition (AFSD) and SolidStir additive manufacturing (AM). These solid-state additive manufacturing technologies have the highest deposit rate among all the AM technologies. In addition, being solid-state process, these result in wrought microstructure and are best suited for replacing of large-scale castings and forgings. Highlights of mechanical properties using these friction stir AM processes will be presented. Both these processes are also very suitable for recycling and upcycling of metallic materials. Examples of recent progress of recycling and repair will be presented to provide guidance for emerging directions. Even after 30 years of its first application, emergence of new concepts provides exciting opportunities.

Keywords: Friction Stir Welding; Friction Stir Technologies; Additive Manufacturing; Technology Innovation; Recycling; Repair

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New Industrially Scalable Severe Plastic Deformation Processes

Satish V. Kailas
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Abstract

One of the methods to increase the strength of the material is by reducing its grain size. Getting a very fine-grained size in bulk samples by conventional methods is a challenge. Severe plastic deformation (SPD) processes are one of the methods to get ultra-fine-grained material. However, SPD processes also face the challenge of getting industrially relevant sizes of material and at speeds that are sufficient to be industrially attractive. In this talk, two new SPD processes are presented that are industrially scalable both in size as well as. The process is such that the SPD can be carried out at room temperature. The two processes are called High Pressure Compressive Reciprocating Shear (HPCRS) and Continuous Friction Assisted Lateral Extrusion (C-FALEP) process. In HPCRS, the material is enclosed in a die and pressed against a reciprocating die to impose large strains on the sample. The shear strains induced in the material are more than 60. If the deformation is done at higher frequencies, the friction between the die and the workpiece and the plastic deformation at high strain rates cause heating of the material. Temperatures of the order of 573 K are estimated for magnesium. The loads are such that sheets of the dimensions required for industrial applications can be made. In C-FALEP, a billet is pushed against a reciprocating die, and the material is squeezed out of an orifice. In this process, the advantage is that once the first billet is formed, another billet can be placed behind the earlier billet, and the SPD can continue. Here too, high shear strains of more than 25 can be imparted on the billet material when a 25 X 25 mm billet is formed into a 1 mm thick strip. Here too, the process can be adapted to make sheets or other shapes of, say, 1 m width. These two processes will be explained in detail in this talk.

A new additive friction stir deposition method

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Abstract

Additive manufacturing (AM) has emerged as a promising technique for building metal components in diverse shapes and sizes. However, conventional AM methods typically require high energy-input and extended processing time, especially for large-scale products. To overcome these issues, we developed a novel additive friction stir deposition (AFSD) method, enabling efficient and aesthetically consistent metal layer deposition. A new type of friction surfacing with a ring-jig was performed to achieve an improved solid-state additive manufacturing process. An AA6063-T5 plate, an AA6063-T6 round bar, and a JIS-SUS304 ring were used as specimens and jig. The plate was used as base metal, and the round bar was used as consumable material. The ring-jig was attached at the tip of the round bar and able to move freely along the longitudinal direction of the round bar. After starting friction, the ring-jig elevated at the same time as the layer formed. The layer was formed from the bottom of the ring-jig during the process. As a result of applying the ring-jig, the homogeneous and wider layer was formed with improved symmetry compared to that without the ring-jig. In addition, the surface of the layer was remarkably smooth. No defects were observed in the cross-section of the layer obtained with the ring-jig. Multi-layers were laminated perpendicularly to obtain an aluminum wall. Without the ring-jig, many defects were observed between the layers and the thickness of the wall decreased on the retreating side. On the other hand, with the ring-jig, no defects were observed between the layers, and symmetrically shaped layers were formed on the advancing and retreating sides. The new method using the ring-jig is expected to be an effective additive manufacturing process to obtain various metal components with high strength and reliability. Achieving this new additive friction stir deposition process leads to forming products with significantly lower energy cost.

Keywords: Additive manufacturing; additive friction stir deposition; Friction surfacing; Aluminum alloy; Ring-jig.

Keynote Talks (Online)

An Investigation into Linear Friction Welding of Steel

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and Gianluca Buffa²

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Abstract

Linear Friction Welding (LFW) is a solid state joining process where friction generated between oscillating parts, which are under normal pressure, is used to produce adequate energy and raise temperature locally at the oscillating interface in order to create favorable conditions for welding at the interface between two parts. The parts show locally large deformations as materials yield locally at high temperatures which are below the melting point of materials under study, and material extrudes from the sides of the interface. Experiments were performed with a custom built LFW welding machine to join the low-carbon, case-hardening alloy steel DIN-15CrNi6, which is used for its wear resistance, toughness, and fatigue strength. The oscillation frequency range was between 45 and 72 Hz, while the welding pressure range was between 20 and 35 MPa in the experiments while the overall process time was kept constant. Numerical modeling of the process was performed using the implicit Lagrangian code DEFORM which is designed to simulate metal forming processes. The coupled thermo-mechanical analysis investigated the effects of the processing parameters on the temperature evolution, strain, strain rate and axial shortening of the joints. For computing efficiency, the effect of changing contact area between specimens during LFW was simulated with a friction window. The association between interface temperature and welding pressure was established together with increased deformation and flash formation.

Keywords: Linear friction welding; numerical modelling; 15CrNi6 Steel; coupled thermo-mechanical model; viscoplastic material model

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Production of titanium and stainless steel-based hybrids by Friction Stir Spot Welding: Interface Properties

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Abstract

The increasingly complex industrial projects require efficient engineering approaches, which are focused on achieving increased performance with minimal waste. The joining of materials with very different physical and mechanical properties is an excellent way for meeting some of these demanding requirements. Economic engineering solutions consisting of components that combine specific properties of two or more materials can be produced. However, the joining of materials with very different properties is practically impossible through the conventional welding techniques. In turn, the solid-state welding techniques, like friction stir welding and related processes, have a strong potential for achieving high-quality hybrids. This way, the aim of the present research is to study the interfacial properties of friction stir spot welds in three distinct material combinations, i.e., copper/stainless steel (Cu/SS), titanium/stainless steel (Ti/SS) and titanium/magnesium (Ti/Mg). A wide range of welding parameters was tested for each material combination. The welds, which were produced with a pinless tool, were characterised using several experimental techniques. The chemical interaction of the materials at the weld interface has a strong influence on the overall quality of the joints, especially, on their mechanical behaviour. For some material couples, the lack of interaction is the most determining factor conditioning the success of the welding operation. This concern can be overcome with the inclusion of an interlayer material, which provides the required interaction at the interface (Figure 1). On the other hand, for other couples, the interaction of the materials at the interface results in the formation of brittle layers of intermetallic compounds (IMCs), which are very detrimental to the weld mechanical behaviour. For these cases, the materials interaction must be reduced so that thick and continuous IMC layers are not formed.

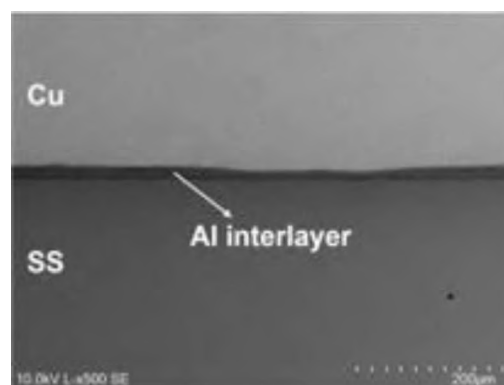


Figure 1 – Interface morphology of a Cu/SS weld produced with an Al interlayer.

Keywords: Friction stir spot welding; Titanium; Stainless steel; Hybrid; Interface; Intermetallic compounds; Microstructure; Mechanical properties

Keynote Talks

Decoding Friction in SPD: When Interfaces Drive Deformation

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Abstract

Severe Plastic Deformation (SPD) processes such as Equal Channel Angular Pressing (ECAP) and High Pressure Torsion (HPT) are key technologies for developing ultrafine-grained metallic materials with enhanced properties. However, the modeling of these processes is still limited by a complex understanding of friction mechanisms at the tool-material interface. Considered a simple adjustment parameter, friction has turned out to be a fitting variable that directly influences material flow and deformation localization.

To challenge this, a transversal research theme has emerged at LEM3 in University of Lorraine (France), combining tribology, materials mechanics, and process engineering. The need to characterize friction under extreme conditions — very high normal pressures (up to 2 GPa) and low sliding rates (<1 cm/min) — led to the design and development of original tribometers meeting the requirements in SPD processes. Two test setups have been designed in order to impose dry sliding on simple specimen geometries with different contact surface (roughness, couples of materials, orientation). The couples of materials tested are representative of those used in SPD processes such as IF steel on steel or pure copper on steel for a large range of sliding lengths, from 1 mm up to 30 mm [1-3].

These experimental tests highlighted the strong influence of the apparent normal pressure and surface roughness on static and kinetic friction coefficients. Microstructural analyses revealed highly sheared zones and the formation of third-body layers where the microstructure was ultrafine-grained. These results provide knowledge on dry friction under high pressure but also new outlook for modeling friction at the interface.

Keywords: *Friction, Severe Plastic Deformation, Quasi-static Conditions, High Pressure*

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Friction+arc assisted stir technique (fast) for joining High melting temperature materials

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Abstract

Friction+Arc Assisted Stir Technique (FAST) is a variant of Friction Stir Welding (FSW) Technique, which is a continuous, hot shear, autogenous joining process involving non-consumable rotating tool of harder material and the materials to be joined will be preheated by welding arc. When alloys are friction stir welded, phase transformations that occur during the cool down of the weld are of a solid-state type. Due to the absence of parent metal melting, the FAST is observed to offer several advantages over fusion welding. The benefits that stand out most are welding of difficult to weld, better retention of baseline material properties, fewer weld defects, low residual stresses, and better dimensional stability of the welded structure. FAST creates the weld joint without bulk melting. In addition, the extensive thermo mechanical deformation induces dynamic recrystallization and recovery that refine the microstructure of the stir region. Therefore, welds made by FAST are shown to have much improved mechanical properties than the corresponding fusion welds.

FAST is capable of joining aluminium alloys, magnesium alloys without melting and thus it can eliminate problems related to the solidification. As FAST does not require any filler material, the metallurgical problems associated with it can also be reduced and good quality weld can be obtained. Higher thermal conductivity and thermal expansion of copper result in greater weld distortion than in comparable steel welds. On the other hand, FAST process would alleviate most of the problems caused by the fusion welding processes because it does not result in the melting and resolidification of the material to be welded. FAST efforts to date have involved joining of aluminium alloys and magnesium alloys, there is considerable interest in extending the technique to other materials, including steels. FAST appears to offer several advantages over arc welding of steels. The lower apparent energy inputs of FAST are expected to minimize grain growth in the HAZ, limit distortion and residual stress in steels, eliminate welding fumes and hydrogen induced cracking etc. In this invited lecture, the challenges faced during joining of high melting temperature materials such as carbon steels, stainless steels, titanium alloys and nickel base alloys by friction assisted stir technique will be discussed. Few case studies carried out in Centre for Materials Joining & Research (CEMAJOR), Annamalai University on Interstitial Free (IF) steel, Carbon steel, High Strength Low Alloy Steel, Ferritic Steel and Titanium alloys will be presented in detail.

Keywords: Friction+Arc assisted stir technique, IF Steel, Carbon Steel, Ferritic Steel, Titanium alloy, Microstructure, Mechanical properties.

Development of SolidStir® Technologies for Upcycling and Additive Manufacturing

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Abstract

SolidStir® is an in-situ thermomechanical material process based on the fundamentals of Friction Stir Welding/Processing (FSW/P). Severe plastic deformation and material flow that happens at elevated temperature under a hydrostatic stress around the stirring tool is utilized in this technology for shear mixing, microstructural refinement, consolidation, extrusion, and deposition. Currently, SolidStir® technology is being developed for material development, upcycling, and metal additive manufacturing. SolidStir® technology comprises two primary components: the stirring tool and the processing chamber, as shown in Figure 1 and Figure 2. The stirring tool rotates within a stationary processing chamber, which features one or more feed ports and exit dies. Feedstock is introduced through the feed ports and directed against the rotating stirring tool, where it undergoes plasticization due to the generated frictional and adiabatic heat. The surface features of the stirring tool guide the plasticized material toward the exit die. In the extrusion variant of SolidStir®, the plasticized material is forced through a profiled die. In the additive manufacturing variant, the tool end extends beyond the die to weld the extruded material onto a substrate. Key process parameters include the design of the tool and processing chamber, rotation speed, and feedstock feed rate. The tool material is carefully selected based on the specific material being processed.

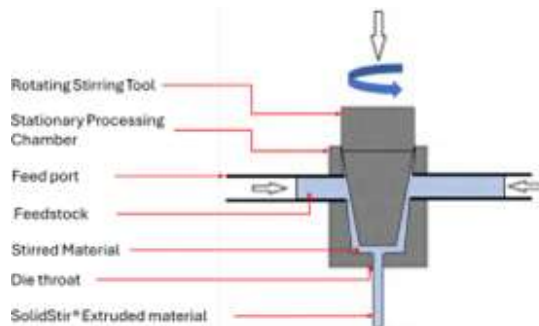


Figure 1: SolidStir®-Extrusion

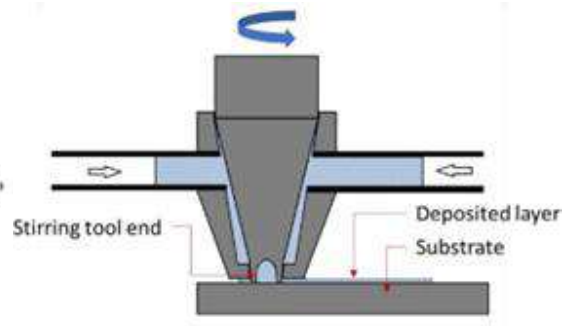


Figure 2: SolidStir®-AM

SolidStir® technologies are energy efficient as they avoid heat loss by applying energy at the point of need. Additionally, SolidStir® can consolidate and extrude materials in a single step without any length limitations. This process is feedstock-form agnostic, making it versatile for developing feedstock. The track width produced by SolidStir®-AM is independent of the feedstock size, providing greater flexibility. Moreover, the technology decouples the downward forces required for plasticization and deposition. One of the notable benefits of SolidStir® is its adaptability; conventional machine tools such as lathes and milling machines can be modified to perform material development, upcycling, and additive manufacturing using this technology. This flexibility allows for broader application across various industries, making SolidStir® a valuable tool to rapidly advance manufacturing.

Keywords: SolidStir® Technologies, Extrusion, Solid-state Material Processing, Additive Manufacturing, Sustainability, Upcycling, Energy Efficiency, and Circular Economy.

Superplasticity aided Microforming: An Approach to Manufacture Miniaturized Components

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Abstract

Microforming is an emerging micro-manufacturing technique that enables mass manufacturing of various miniaturized micro-components to serve the biomedical, MEMS, and other relevant sectors. At present, microforming technology is in a very nascent stage, limited to easy-to-deform FCC materials such as Aluminum and Copper alloys. In the present scenario, the biomedical sector is mainly dominated by Titanium (Ti) and Magnesium (Mg) alloys. To serve the emerging demand for biomedical parts and implants, the microforming of materials such as Ti and Mg alloys must be studied. Owing to HCP crystallography, the microforming of such complex materials requires deformation at elevated temperatures to activate temperature-dependent slip systems. This needs a thoughtful understanding of material design, microstructural engineering, sophisticated micro-tooling design, and process optimization. Superplasticity, a special case studied during hot deformation of Mg and Ti alloys at the macroscale, enables them to undergo extensively large plastic deformation without necking/failure. The study of superplastic microforming of complex Mg and Ti alloys can revolutionize the bio implant manufacturing sector and drastically cut down manufacturing costs. The present research aims to establish a roadmap to facilitate the superplastic microforming of friction stir processed engineered Mg and Ti alloys on developing different micro products such as micro- cups, micro-pins, micro-gears etc. The superplastic microforming knowledge base is established using various mechanical and microstructural assessments.

Keywords: Microforming, Superplastic Microforming, Friction Stir Processing, Bioimplant Manufacturing, Magnesium alloys, Titanium alloys, Biocompatibility.

Friction, Wear and Ballistic Behavior of Liquid Phase Sintered Boron Carbide Ceramics

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Abstract

Boron carbide ceramics are preferred for friction, wear and ballistic applications, owing to their unique characteristics of high hardness and abrasion resistance. However, the usage of boron carbide ceramics is restricted due to difficulties in processing and limited understanding of friction and wear mechanisms. The present study investigates the liquid-phase spark plasma sintering for boron carbide–silicon carbide ceramics with alumina and yttria additives via spark plasma sintering. In particular, the influence of liquid phase precipitates on densification and mechanical properties is discussed, followed by the friction and wear behaviour in dry sliding wear contacts. The material removal mechanisms in varying sliding conditions are explained. In addition, the ballistic performance of the sintered ceramics is investigated as a function of additive composition. The addition of alumina enhances sliding wear resistance, but does not improve ballistic performance.

Keywords: Boron Carbide, Sintering, Friction, Wear, Ballistic resistance.

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Investigating precipitation pathway and mitigation strategies for HAZ softening in friction stir welded Al-Zn-Mg-Fe alloy

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Abstract

Newly developed medium-strength-high elongation Al-Zn-Mg-Fe (HE700) cast alloys have the potential to be used as futuristic structural materials for automotive lightweighting applications [1]. An effective joining technique is essential to widen the manufacturing scope of the alloy for such applications and beyond. Due to the hot tearing susceptibility [2] and difficulties associated with fusion welding of Al-Zn-Mg alloys, friction stir welding (FSW), a well-known solid-state joining technique, was used in this research work. The evolution pathway for the microstructure and precipitation was elucidated through systematic studies involving advanced characterization. The FSW process parameters were first optimized based on the weld quality, microstructure and properties. Although the overall weld properties improved by the microstructure refinement during FSW, the heat affected zone (HAZ) got wider extending all the way to the base metal due to the thin plate thickness. The thermal cycle during FSW dissolved and/or coarsened the precipitates in the HAZ leading to softening. Therefore, a major emphasis of this investigation was to explore different strategies to minimize HAZ width and softening without compromising weld quality. In-process cooling during FSW significantly reduced the HAZ width but also degraded the weld quality. The response of the alloy to conventional post-weld heat treatment (PWHT) was not significant due to the sluggish kinetics of transition of solute nanoclusters to precipitates and the presence of pre-existing coarsened precipitates. A reversion re-aging (RRA) treatment was formulated to restore the properties of the weld, especially the HAZ. Among several treatments that were explored, a reversion at 350 °C for 2 h proved to be optimal for an effective response to RRA and PWHT. A two-stage PWHT following the reversion enabled substantial hardness recovery in the HAZ while having minimal degrading effect on the refined stir zone (SZ) microstructure. This approach facilitated a uniform distribution of precipitates within the HAZ, thus providing a feasible pathway for HAZ property restoration.

Keywords: Al-Zn-Mg-Fe alloy; Friction stir welding (FSW); Precipitation hardening; HAZ softening; Dynamic recrystallization (DRX); Reversion re-aging (RRA) heat treatment.

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Invited Talks

Non-Conventional Forming Techniques to Enhance Formability of Advanced High Strength Steels

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Abstract

Advanced high-strength steels (AHSS) have found wide applications in the automotive sector due to their superior strength-to-weight ratio. However, their adoption is often constrained by significant manufacturing challenges such as poor stretch-flangeability and limited room-temperature formability. Current research trends focus on enhancing formability without significant modifications to existing tooling and dies. Among various approaches, servo presses have considerable attention due to their ability to apply pulsating loading during forming operations. This presentation highlights the potential of pulsating loading in improving the formability of dual-phase steels. The initial discussion focuses on experimental investigations including stretch-flangeability enhancement and hydraulic bulge testing. In addition, a synergistic experimental-computational framework is employed to gain fundamental insights into pulsating loading, particularly its influence on stress relaxation and frictional behaviour.

Tribological Performance of Hybrid Nanoparticle-Infused Jatropha Oil: A Next-Generation Bio-Lubricant

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Abstract

Lubricants derived from biological sources offer a sustainable alternative to conventional petroleum-based lubricants, addressing environmental concerns and depleting non-renewable resources. This study investigates the scope of hybrid nanoparticle-infused Jatropha oil as a heavy-duty industrial lubricant. Jatropha oil, known for its biodegradability and inherent lubricity, was reinforced with a controlled dispersion of TiO₂ (80%)/Cu(II)O (20%) hybrid nanoparticles at concentrations of 0.05%, 0.1%, and 0.15% (v/v) to improve its tribological properties. The tribological properties were evaluated under both rotary action and reciprocating wear conditions using a four-ball tester and a universal tribometer, providing comprehensive insights into their lubrication performance. The results demonstrated a notable improvement in thermal conductivity, with a maximum enhancement of 2.41% compared to the base oil. Additionally, the coefficient of friction (COF) was significantly reduced by 46.77%, indicating superior friction-reducing capabilities. Though there was no considerable change in flashpoints, the hybrid nano oil samples showed a notable increase in terms of fire point and superior dispersion stability. Surface morphology analysis of wear track scars revealed that the primary lubrication mechanism was the ball-bearing effect of the hybrid nanoparticles. The prepared nano lubricants exhibited shear thinning effect as observed from rheological test. These findings suggest that the proposed hybrid nano oil is a promising next-generation bio-lubricant with improved thermal and tribological properties. This study underscores the potential of hybrid nanolubricants in advancing eco-friendly and high-performance lubrication solutions for industrial applications.

Keywords: Hybrid nanoparticles; jatropha oil; thermo-physical properties; rheology; four ball tester; reciprocating wear

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Friction stir lap welding of dissimilar aluminum alloys at different configurations: DIC-based strain measurements for strength, failure analysis

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Abstract

The present work aims to evaluate the influence of different lap configurations on mechanical performance and failure in dissimilar friction stir lap welds (FSLW) of aluminum alloy joints performed at constant tool rotation and welding speed. Three different lap weld sets are fabricated using three distinct grades of aluminum alloys, namely AA5083-H11, AA6061-T6, and AA7075-T6 of 3 mm thickness. Each of the dissimilar FSLW joint sets of AA5083-AA6061, AA5083-AA7075 and AA6061-AA7075 are further prepared with two different configurations based on the placement of the plates on top or bottom (i.e., FSLW 5/6 implies AA5083 at top and AA6061 at bottom, whereas in FSLW 6/5 the placement of plates is reversed for the AA5083-AA6061 FSLW joint, and so on). Full-field strain measurement on the thickness surface is performed by digital image correlation (DIC) to quantify and characterize the interfacial strain localization and failure progression, and correlate with the joint mechanical performance during the tensile shear test. Furthermore, detailed microstructural characterization along with nanoindentation tests are performed to appraise material flow, texture evolution, and localized mechanical properties. Local strain variation along the longitudinal direction (ϵ_{yy}) obtained from the DIC shows that, initially, an even strain accumulation takes place over the joint interface, and no weak region with unusual strain localization is noted. With further elongation, strain intensifies at the hook/cold lap region and reaches the maximum longitudinal strain, leading to failure. Microstructural characterization depicts a favorable and effective material intermixing under specific configurations of dissimilar FSLW joints.

Influence of heating cycle during layer-wise addition in friction stir additive manufacturing (FSAM) of AA2024 on microstructure and mechanical properties

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Abstract

Friction stir additive manufacturing (FSAM) is an efficient solid-state approach to manufacture high strength aluminum builds without solidifications defects. During the FSAM process, the phenomenon of reheating needs further attention as it might affect the microstructure and the resulting mechanical performance of the build. In this study, the effect of reheating during layer-wise addition in FSAM of AA2024 was studied. Four layers were added in this study and after the addition of each layer, a sample was cut from the build for microstructural analysis to investigate the reheating effects on the build. Fine grain microstructures were observed in the build with average grain size decreasing from the bottom (4.4 μm) to the top (3.8 μm). The EBSD analysis revealed that with each reheating cycle, the fraction of high-angle grain boundaries (HAGBs) and recrystallized grains were reduced, implying the possibility of annealing/static recrystallization in the lower layers. Precipitate dissolution of coarsening was noticed in SEM images at the lower layers. The hardness value was around 130-160 Hv in a freshly processed layer, and with each reheating cycle, the hardness decreased by 20-40 Hv in that layer. The tensile sample taken in the weld direction achieved an ultimate tensile strength of 370 MPa (77% build efficiency) with a 50% improvement in elongation. The sliced tensile sample from the top of the build had higher tensile strength (400 MPa), whereas the sliced tensile sample from the bottom had better elongation with reduced strength (350 MPa).

Keywords: Friction stir additive manufacturing, reheating effects, Microstructure, Precipitate, Mechanical properties, aluminium alloy, AA2024.

Aluminium Alloy-Based Gradient Composite Structures Fabricated Using Friction Stir Additive Manufacturing

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Abstract

The present study investigates the potential of FSAM in fabricating gradient composite structures using aluminium alloys grades (AA5083, AA6061, and AA7075) with and without the incorporation of various reinforcement particles. The aim is to develop advanced structural materials with tailored mechanical and functional properties for high-performance engineering applications. Initial experiments involving unreinforced gradient composites (AA5083/AA6061/AA7075) revealed excellent ductility (% elongation) but poor mechanical strength, including low yield strength (YS), ultimate tensile strength (UTS), and hardness. To overcome these limitations, different reinforcement strategies were employed. When the gradient composites were reinforced with micro-sized SiC ($d_p \sim 26 \mu\text{m}$) and Al_2O_3 ($d_p \sim 7.5 \mu\text{m}$) particles, significant improvements in YS, UTS, and hardness were achieved. However, these enhancements came at the expense of reduced ductility, highlighting the further improvement in the trade-off between strength and elongation. Therefore, to achieve a better balance of mechanical properties, nano-sized Al_2O_3 particles were introduced. The resulting composite exhibited a superior combination of tensile strength and elongation, along with enhanced tribological and corrosion resistance, making it a strong candidate for multi-functional structural applications. Furthermore, the incorporation of Zn particles as reinforcement in the gradient composite resulted in a balanced enhancement of both strength and ductility compared to micro-particle reinforced and unreinforced builds. This improvement is attributed to the solid solution strengthening mechanism, facilitated by Zn low melting point and alloying capability. In contrast, dispersion strengthening mechanisms are primarily responsible for the property improvements observed with SiC and Al_2O_3 reinforcements. Overall, the present work demonstrates that FSAM, combined with appropriate reinforcement strategies, can effectively tailor the mechanical, tribological, and corrosion properties of aluminium-based gradient composite structures. These findings expand the application scope of FSAM and provide valuable insights into the design of next-generation lightweight and high-strength materials.

Keywords: *Friction stir additive manufacturing, Reinforcement particles, Particle stimulated nucleation (PSN), Dynamic recrystallization, Dispersion strengthening, Solid solution strengthening.*

Development and Deformation Behavior of Aluminium Matrix Composites

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Abstract

Ultrafine-grained (UFG) aluminium matrix composites (AMCs) have garnered significant attention due to their enhanced mechanical properties, making them promising candidates for a wide range of engineering applications. This study focused on the development of bulk UFG AA6063 composites reinforced with 4 wt.% silicon carbide (SiC) particles of varying sizes—coarse (12 μm), fine (1 μm), and nano (45 nm)—using a novel hybrid approach combining stir casting and cryogenic deformation. This hybrid processing route, along with the incorporation of SiC particles, effectively refined the microstructure into the UFG regime and significantly enhanced the mechanical strength of the composites. The combined effects of the hybrid process and SiC particle size on the age-hardening behavior were investigated via systematic aging studies conducted over a temperature range of 100 °C to 175 °C. Results revealed accelerated aging kinetics with decreasing SiC particle size. The thermal stability of the developed and cryo-deformed AMCs was evaluated between 150 °C and 300 °C. The AMC reinforced with the nano-SiC reinforcement exhibited superior thermal stability up to 300 °C, attributed to the effective pinning of dislocations and suppression of grain boundary migration by the finely dispersed nano-SiC particles. The hot deformation behavior of the UFG composites was characterized under a temperature range of 300 °C to 450 °C and strain rates from 0.001 to 10 s⁻¹. Processing maps were developed to identify safe and optimal processing windows in terms of strain, strain rate, and temperature. The varying processing parameters were obtained for the developed composites with changing reinforcement sizes which showed the optimal properties.

Keywords: Aluminium Matrix Composites; Severe Plastic Deformation; Aging Behavior; Thermal Stability; Mechanical Properties; Microstructure.

Excellent Thermal stability of microstructure in Friction Stir Processed Aluminum

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Abstract

Severe plastic deformation processes are renowned for producing nanocrystalline (NC) or ultra-fine-grained (UFG) microstructures exploiting the grain size-dependent strengthening effect. However, the lattice defects and non-equilibrium grain boundaries associated with the NC and UFG grains lead the materials into a metastable non-equilibrium state, limiting their thermal and mechanical stability. Recent investigation into the friction stir processing (FSP) of Al powder compacts has revealed exceptional thermal stability of the microstructure up to 450 °C for one hour [1,2]. The current study delves into extending the thermal stability of microstructure in wrought Al mixed with oxide powder particle and the role of further deformation on the thermal stability of such microstructures. Commercial purity Al was melted in graphite crucible and mixed with aluminum oxide and further casted in to cylindrical mold. The cast Al was further hot forged and hot rolled to enhance the uniform distribution of oxide particles. Hot rolled sheets of 6 mm thick Al was FSPed at 1050 rpm and 1mm/min traverse speed. The microstructural investigations revealed uniform distribution of fine grain structure, having an average grain size of 5 µm. Such microstructures were found stable even after annealing at 500 °C for 2 hrs. To introduce spatially varying deformation, high-pressure torsion (HPT) was performed on the FSPed Al sample. Initially, additional deformation through HPT increased the average grain size from to ~ 10 µm after 1 turn HPT; however, it reduced to ~ 1.2 µm after 5 turn HPT. The microstructure of the FSPed sample showed thermal stability regardless of the location in the stir zone. In contrast, the HPT-5 turn samples showed notable microstructural stability at the majority of the locations but resulted in a bimodal grain size distribution after annealing at 450 °C for 1 hour. However, the HPT – 1 turn sample displayed normal grain growth, increasing the average grain size to 130 µm. This work explores the possible reasons behind the changes in thermal stability as a function of deformation. Regardless of the grain growth possibility, annealing of the sample weakens the crystallographic texture. The surface oxides of the powder particle act as a pinning agent for grain boundaries. However, with deformation, these particles undergo coarsening and/or fragmentation governed by the strain. The present study suggests that modifying the aluminium matrix with suitable reinforcements could effectively anchor grain boundaries, ensuring microstructural stability during high-temperature exposures.

Keywords: Thermal stability; grain boundary pinning; grain growth; EBSD; In-situ TEM; Aluminium

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Deformation Behaviour and Mechanical Performance of Friction Stir Welded sheets in Single Point Incremental Forming

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Abstract

Hybrid manufacturing refers to combining two or more fabrication techniques to best utilize the strengths of different processes. Friction Stir Welding (FSW) is a solid-state joining process, that enables the joining of similar and dissimilar metallic materials with minimal distortion and residual stresses compared to conventional welding [1]. Incremental Sheet Forming (ISF) is a die less forming process that produces components directly from CAD without the need for dedicated tooling [2]. Because of the localized deformation, ISF has higher formability compared to the conventional deep drawing and stamping processes. Hybridization of FSW and ISF can be easily performed with low investment [3]. In view of combining both the processes, the current work studies the advantages and challenges of hybridizing FSW and ISF processes.

First Aluminium alloy sheets (5052 and 6061) of 2 mm thickness are joined using friction stir welding. These sheets are used to form conical and pyramidal geometries by Single Point Increment Forming (SPIF). Formability in ISF greatly depends on the wall angle of the geometry. The formability of the joined sheets compared to as received sheet in ISF is tested by forming varying wall angle (45°–80°) conical components. To study the mechanical behaviour of the joint after ISF, pyramid geometries are formed so that the test samples can be cut on the flat regions. Tensile tests are conducted on the samples extracted across the joint as well as in the regions where there is no joint. Microhardness mapping is done across the FSW joint before and after incremental forming. Microstructure evolution during FSW and ISF is studies at different stages and at different locations using optical microscope.

Keywords: Friction Stir Welding, Incremental Sheet Forming, Hybrid Manufacturing, Mechanical Behaviour, Microhardness, Microstructure

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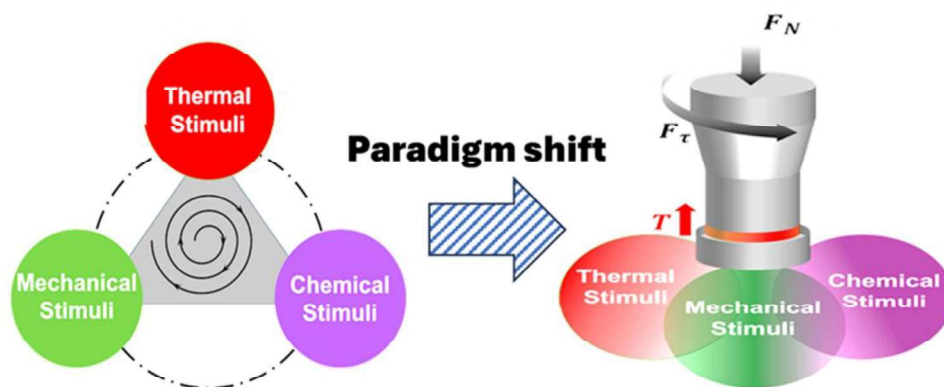
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Multi-Stimuli Integration in Alloy Design: A Shear-Assisted Processing Approach for High-Performance Nano-Composite Materials

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Abstract

In traditional alloy design, thermodynamic modeling is used to predict equilibrium states, followed by thermomechanical treatments to disrupt this equilibrium. Final annealing is then applied to stabilize the material for practical use. However, this conventional approach often treats thermal activation, stress, and chemical stress as separate factors, which can lead to suboptimal use of valuable metallic resources. Our research seeks to integrate multiple stimuli—such as mechanical stress, chemical potentials, and thermal activation—to develop multifunctional composite alloys. By using a multi-stimuli approach, we can achieve more energy-efficient material processing, explore metastable but highly advantageous microstructural templates, and make better use of materials for engineering applications. In this presentation, I will showcase examples of how this integrated approach is being applied in our current work. For instance, we use friction-assisted processing to modify Al alloys with Fe_3O_4 particles, creating nano-composites that include Al, Al-Fe intermetallics, core-shell particles of Fe+MgO, and Al_2O_3 . These composites exhibit impressive mechanical strength, ductility, and ferromagnetic properties. Our approach is also being extended to develop ultra-high conductors, high-strength thermally stable Fe, Al, and high-entropy alloys, tough magnetic composites, and can potentially influence a wide range of material design and application fields.



Keywords: Mechanical properties; Dynamic transformation; Microstructure; Tensile behavior; Precipitates, solid state chemistry, composites

Understanding $\alpha \rightleftharpoons \beta$ reversible transformation in Titanium alloys by in-situ characterization techniques

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Abstract

Titanium alloys are used as structural components in aviation and marine industry for their excellent specific property combinations. Their microstructure, bulk and micro-texture evolution primarily depends on β (bcc, Im3m) $\rightarrow$ α (hcp, P63/mmc) reversible transformation over an extended, complex and multi-stage thermo-mechanical processing (TMP) schedule that dictates most of the ensuing mechanical properties. Several indirect approaches e.g. parent β phase reconstruction from room temperature α phase are adopted in the past to comprehend various aspects of this phase transformation e.g. variant selection, microstructure-bulk texture linkage etc. which suffers from extrapolation of data and other technical constraints [1]. A real time in-situ characterization using advanced techniques are scarce but provides immense possibility of understanding the complete process of micro-texture and bulk texture evolution with temporal resolution which is the prima facie of the present work [2]. It first investigates the bulk texture evolution in near- α (Ti-6Al-2Mo-4Sn-2Zr) and ($\alpha+\beta$) (SP-700) Titanium alloys by conducting X-ray texture measurement at room temperature (RT), in ($\alpha+\beta$) regime by heating and post-cooling back to RT. The alloys were selected in as-cast or ($\alpha+\beta$) deformed conditions to examine the effect of thermal alone and thermo-mechanical factors, respectively on the variant selection within the purview of $\beta \rightleftharpoons \alpha$ transformation. RT β -texture is characterized by predominant basal fiber in Ti-6Al-2Mo-4Sn-2Zr which transforms to prism fiber upon heating. On cooling back to RT, the β -texture dissociates into secondary prism fiber along with primary basal fiber. The high temperature β -texture underwent a complete transformation from ζ and γ -fibers to γ -fibers. Likewise, SP700 alloy shows similar texture fiber transition on heating and subsequent cooling upon $\alpha \rightleftharpoons \beta$ transformation. In another effort, in-situ high temperature electron back-scatter diffraction (EBSD) characterization was carried out for a near ($\alpha+\beta$) Ti-6Al-4V alloy in as-cast condition and after hot deformation. Interestingly, the incremental β -phase in as-cast condition follows Burgers orientation relationship throughout the heating/cooling cycle whereas, the deformed alloy depicts strong heterogeneity in α and β orientation evolution due to their varying spheroidization response. Overall, the present work helps in understanding the sequence and underlying mechanisms of micro-texture and bulk texture evolution through $\alpha \rightleftharpoons \beta$ transformation during TMP of Titanium alloys. The insights should be helpful in designing the TMP schedule for Titanium alloys at the component scale.

Keywords: Titanium alloys; in-situ; X-ray; Electron back-scatter diffraction; Dynamic transformation; Spheroidization; Transformation texture; Microstructure; Micro-texture.

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Finite Element Modelling of Plunging Stage in Additive Friction Stir Deposition (AFSD) Process

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Abstract

Finite Element Modeling (FEM) of Additive Friction Stir Deposition (AFSD) is gaining attention in aerospace, automotive, and defense manufacturing. This solid-state technique reduces thermal gradients and prevents harmful phase transitions, making it ideal for high-integrity components. This study focuses on analyzing the thermo-mechanical interaction between the feed rod and the substrate during the plunging phase of the AFSD process using a finite element (FE) simulation. A Coupled Eulerian-Lagrangian (CEL) model is developed to accurately simulate this interaction, capturing key aspects of material flow, heat generation, and mechanical forces. The investigation examines critical parameters such as the temperature distribution on the substrate surface, the formation of flash on the feed rod, and the corresponding axial load exerted during the plunging phase. By generating high-fidelity data and advancing computational models, this work lays the foundation for the development of more complete simulations capable of replicating the entire AFSD process. This includes both the initial plunging phase and the subsequent feed rod deposition, enabling layer-by-layer modeling of the additive manufacturing process. The findings of this study offer valuable contributions to the AFSD research community, supporting the advancement of predictive modeling techniques and facilitating the broader adoption of AFSD in industrial applications.

Keywords: Additive Manufacturing; Friction; AFSD; FEM; CEL; Temperatur.

Additive Friction Deposition of Metal Matrix Composites

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Abstract

Additive Friction Deposition (AFD), a solid-state technique, has emerged as a versatile and scalable approach for fabricating high-performance metal matrix composites (MMCs) with superior mechanical and tribological properties. This talk presents recent advances in AFD-based deposition of aluminum matrix composites reinforced with a range of metal and ceramic particulates, including nanocrystalline CoCrFeNi high-entropy alloy (HEA), titanium (Ti), and silicon carbide (SiC). Multi-layer friction-deposited AA5083/HEA composites exhibited significantly improved tensile and compressive strengths without the formation of brittle intermetallic phases, owing to the inert nature and high hardness of the HEA reinforcements. In contrast, AA5083/Ti composites showed uniformly distributed Ti particles and fine-grained microstructures, although thin intermetallic bands at layer interfaces slightly compromised ductility in the build direction. Additionally, AA2014/SiC composites demonstrated uniformly dispersed SiC particles within a dynamically recrystallized matrix, achieving ~85% higher microhardness and ~36% lower wear loss compared to monolithic alloy. Microstructural characterization confirmed strong metallurgical bonding between the layers and particle/matrix and absence of deleterious interfacial reactions across all systems. These studies collectively demonstrate the potential of AFD as a fusion-free, solid-state additive manufacturing route for developing next-generation MMCs with improved mechanical performance.

Keywords: Additive Friction Deposition; Metal Matrix Composites; High Entropy Alloys; Mechanical properties; Microstructures; Wear

Sample Length Scale Effects on Power Law Creep: Implications for Creep Rate Measurements

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Abstract

Professor Terence G. Langdon's pioneering contributions over several decades have significantly advanced the understanding of material creep behavior. Besides the intrinsic material properties, the creep response of a material is affected by a few extrinsic parameters, such as sample size, loading configuration, etc. The importance of the near-surface region, which has a relatively lower dislocation density and larger sub-grain size, becomes significant in miniaturized samples, resulting in the measurement of higher steady-state creep rates and a lower stress exponent. Notably, the surface-proximity effects on creep response can be minimized by introducing strain gradients and associated hardening in the sample. The interplay between surface-proximity and strain gradient effects, especially evident in thin cantilever samples, allows the extraction of standard creep response by testing miniaturized samples. Such insights are useful in the estimation of the residual life of in-service components through creep testing of small-volume cantilever samples.

Keywords: Creep; Sample size effect; Strain gradient effects; Surface proximity effect; High throughput mechanical testing; DIC-augmented-bending creep.

Enhancement of joint strength and microstructure of Cu-Al welds obtained using a new friction processing method using SiC interlayer

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Abstract

Al-Cu sheets in lap configuration are welded using a new friction processing method. A flat shouldered tool, without a pin, is rotated and plunged against a sacrificial top sheet to generate pressure and heat needed to generate the weld. A thin coating of SiC particles applied on Al sheet refines the weld microstructure, reduces weld temperatures, process time and increases joint strength without significantly altering joint electrical contact resistance. In joints made with SiC interlayer, SiC particles initially plough through the Cu and Al joint surfaces exposing nascent surfaces and promoting inter diffusion. Diffusion of Si from SiC into the eutectic melt results in formation of uniform joints with higher weld zone thickness. SiC particles agglomerate in the middle of the weld zone. There is excellent wetting of SiC particles with the eutectic melt. Consequently, the gaps between the particles are effectively filled with the eutectic melt.

The SiC particles result in nanostructured lamellar microstructures with Al₂Cu and Al layers in adjoining regions. The highest peel strength achieved with the SiC interlayer is around 70 % higher than that for corresponding pure Al-Cu welds. Effect of SiC particles interlayer on joint electrical resistance is minimal. Joint electrical resistance for welds obtained in this work was around 20-25 $\mu\Omega$. Joints created with SiC particles interlayer have a lower percentage increase in electrical resistance with temperature. Negative temperature coefficient of resistance of SiC particles results in lower percentage increase in resistance for joints with SiC particles interlayer as compared to that for pure Al-Cu joints [1].

Keywords: Friction processing, Al-Cu welds, SiC interlayer, joint electrical contact resistance, joining mechanism

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Recent Advancements in Friction Stir Based Processes

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Abstract

Friction Stir Welding (FSW), a solid-state joining technique developed by The Welding Institute (TWI) in 1991, harnesses frictional heat and intense plastic deformation to achieve ultra-fine grain structures. This leads to significant improvements in mechanical strength, wear resistance, and electrochemical properties of the materials involved. Over the years, various process variants have emerged to expand the scope of FSW, including Friction Stir Processing (FSP), Friction Stir Channelling (FSC), Friction Stir Deposition (FSD), and Friction Stir Additive Manufacturing (FSAM).

This review presents recent advancements across these friction stir-based technologies. FSW has been effectively applied to both similar and dissimilar aluminium alloys, as well as polymer-polymer and polymer-metal joints, with demonstrated improvements in mechanical and electrochemical performance. Validated thermal and material flow models have enhanced the understanding of FSW across aluminium and copper systems. Tool degradation in high melting point materials remains a critical area of study, addressed through both experimental and computational approaches.

FSP has shown promise in enhancing surface properties, such as wear and corrosion resistance, and in imparting antibacterial functionality to titanium alloys. Furthermore, aluminium matrix surface composites have been developed using reinforcements ranging from metals and ceramics to polymers. Notably, soft reinforcements have been found to significantly improve mechanical and corrosion resistance characteristics.

Friction Stir Channelling (FSC) offers a novel route for the creation of integrated micro- and mini-channels in aluminium and copper plates. Research has explored the influence of tool geometry and process parameters on channel formation, under both ambient and submerged cooling conditions. FSC has emerged as a viable technique for manufacturing components like liquid cold plates used in electronics and battery thermal management systems. Friction Stir Deposition (FSD) has also been employed for coating applications, including aluminium alloy deposition on steel substrates. Thermal models developed for FSD processes have shown strong agreement with experimental data.

Collectively, these advancements highlight the versatility and growing industrial relevance of friction stir-based processes across joining, surface modification, and additive manufacturing applications.

Keywords: Friction Stir Welding, Solid-State Processing, Surface Composites, Mechanical Properties, Corrosion, Surface Modification.

Similar and Dissimilar Friction Stir Weld Joints in Copper Alloys

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Abstract

Copper and its alloys are used extensively in different engineering applications because of their good thermal and electrical conductivities. Many applications demand a dissimilar weld joint between Copper alloys and other engineering materials like stainless steel or Ti-alloys. Welding of Copper alloys by conventional fusion welding process is difficult because of its high thermal conductivity. This difficulty is further amplified in case of the dissimilar weld joints because of the formation of intermetallic compounds. Friction stir welding substantially overcomes these difficulties.

Friction stir welding of CuCrZr, an important precipitation hardened alloy was performed to produce sound weld joints at different combinations of tool rotation and traverse speed. Detailed microstructural characterization of the material across the weld joint was carried out at different length scales. Stir zone microstructure showed a fine recrystallized structure, with varying degree of recrystallization and growth. Extent of recrystallization and growth showed a direct correlation with the tool rotation speed and an inverse correlation with the tool travel speed. The joint however, showed lower strength as compared to the parent alloy in aged condition without any loss in the ductility.

Friction stir welding was performed to produce sound weld joints between copper and SS304. This was achieved by using tool-offset towards copper alloy. Microstructural characterization showed mixing of Copper and SS304. Cross-weld tensile tests were performed, in which the joints failed in ductile manner in the copper side. Dissimilar joint between copper and Ti was produced by Friction Stir Processing of copper coating deposited on a titanium plate. This led to substantial annihilation of the micro cracks and enhanced microchemical and microstructural homogeneity in the coating.

These interesting results from these joints of engineering importance are presented and discussed in this paper.

Keywords: CuCrZr alloy, Mechanical properties, FSW, Dissimilar welds, FSP, Coating.

Copper-diamond composite fabricated via Friction stir processing

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Abstract

This study demonstrates, for the first time, the successful fabrication of a copper–diamond (Cu–diamond) composite using the friction stir processing (FSP) technique. The intense shear and compressive forces during FSP resulted in the fragmentation of initial diamond particles, which were effectively embedded into the copper alloy matrix. Significant refinement of both the diamond and chromium (Cr) particles was observed due to severe plastic deformation and attrition during processing. The refined Cr particles appear to promote further grain refinement in the Cu matrix. Microstructural analysis indicates good interfacial bonding between the dispersed diamond particles and the copper matrix, with minor delamination visible only at the chipped edges of some particles. Notably, Cr particles were found to accumulate at the Cu–diamond interfaces, suggesting a strong affinity between Cr and the diamond surface. This interfacial decoration was more pronounced on smaller, fragmented diamond particles, indicating enhanced bonding at finer scales. Thermal conductivity measurements show that the Cu–diamond composite exhibits lower conductivity compared to as-received and FSP-processed copper, mainly due to grain refinement and increased interface density, which impede thermal flow. However, the composite simultaneously displays improved hardness, attributed to the refined microstructure and reinforcing diamond particles. The combination of enhanced mechanical strength with reasonably high thermal conductivity makes this composite a promising candidate for applications such as thermal management systems, wear-resistant components, and electronic packaging. This work demonstrates the potential of FSP as a viable method for fabricating robust metal–ceramic composites.

Keywords: Thermal properties, composite, copper, diamond, TEM, EDS.

An investigation on additive friction stir deposition of peak-aged aluminum alloy

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Abstract

Additive friction stir deposition (AFSD) is a novel solid-state additive manufacturing process in which a consumable feedstock rod is forced through a hollow, non-consumable shoulder and deposited onto the substrate layer by layer without melting the feedstock. The complex interplay among the shoulder rotation speed (N), shoulder traversing speed (v), feed rate (FR) of the feedstock rod, layer thickness (Th), and total build height (BH)/number of layers on the in-process responses such as temperature, reheating cycles, duration of thermal exposure and build hardness. The coupled experimental and numerical scheme proposed as part of the current work helps in understanding the quantitative influence of each individual process condition on the process response. The work further paves the way for the inverse mapping of process conditions to achieve the targeted build properties.

Keywords: Additive manufacturing, Additive friction stir deposition, Aluminum alloy, Hardness, Processing maps.

Characterization of Deformation Process of a typical Nickel base alloy used for Turbine Blades of Aero-Engine

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Abstract

Wrought nickel base super alloys are used for turbine blades of aero-engine for its strength at elevated temperature. Unlike HP (high pressure) turbine blade is mainly designed for creep & thermal fatigue, fatigue is the major degradation for LP (low pressure) blade. The material considered for experimental investigation on deformation processing is a nickel base super ally having major alloying are Co,Cr,W, Mo, Ti & Al etc. The primary route for manufacturing the blade is forging. Carbides at grain boundary provide resistance against creep deformation, however, the texture and distribution of carbide do influence the deformation processing and eventually the structural integrity of the blade particularly carbide stringers affect the fatigue life of a turbine blade.

This paper discusses the tensile properties of the alloy at RT, 400° C and 700° C and flow-curve behavior by estimation of strength factor & strain hardening exponents using Ludwikson relationship. The alloy exhibits two strain hardening exponents over RT, 400° C & 700° C and DSA (dynamic strain ageing) phenomena at 400° C. For further investigation in flow stress behavior of the alloy, compression tests have been carried out at RT & 700° C with a compression of 3% and 15% respectively. Characterization of slip lines with the help of SEM (Scanning Electron Microscope) reveals fine slip lines, fine slip trace and change in orientation of slip at RT with 15% compression while grain boundary triple point, change in orientation of slip along with slip step formation have been observed at 700° C with a compression of 15% respectively.

Keywords: Nickel base alloy, Deformation, Tensile, Flow curve, Ludwikson, DSA, Slip lines.

Oral Presentations

Acoustic Analysis of Brake Noise due to Friction in Electric Bike

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Abstract

Brake pad wear is one of the most common and significant issues affecting the performance of disc brakes, particularly in E-bikes. Addressing pad wear not only enhances rider safety but also prevents premature damage to other braking system components, such as rotor disc. Brake noise can be analysed to assess the wear level of brake pads. The noise from the most common brake type, i.e. the disc brake, occurs in the audible frequency range defined within the range of 1–5 kHz.

Customers or service centres of E-bikes still follow preventive maintenance strategy to replace brake pads as exact time to replace them is not known. Reasons for not being able to predict exact point of time to replace brake pads is due to factors like driving style, braking frequency, traffic conditions, which vary from person to person and city to city. In recent past, attempts are made by researchers to assess health of brakes but there is still gap in understanding effect of brake pad thickness on braking effectiveness using acoustic signals. This research focuses on study of acoustic signals generated during braking. The air-borne acoustic noise signals were recorded using a MEMS microphone embedded within a smartphone, in conjunction with the Decibel-X mobile application. Experiments were conducted on an E-bike using brake pads at three wear levels—new, moderately worn, and heavily worn. Three levels of brake pressure were applied to decelerate the rear wheel to a complete stop from three different initial speeds: 60 km/h, 40 km/h, and 20 km/h. A novel algorithm for processing the recorded acoustic noise signal was developed that could determine time taken by rotor disc to stop from a set initial speed. Experimental trials were conducted to identify best combination of initial wheel speed and brake pressure to determine stopping time of rotor disc using recorded acoustic that can classify brake pads.

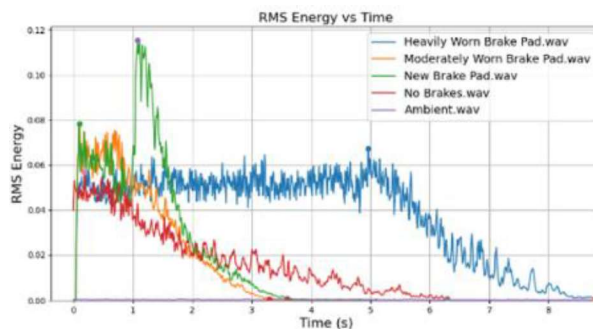


Figure 1: RMS Energy v/s Time for Light Brake Pressure from 60 Km/h

Keywords: Brake pads, Acoustic noise signal, E-bikes, Wear level, Stopping time, RMS energy

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Impact of Process Parameters of Additive Friction Stir Deposited Ti-6Al-4V Blocks on Microstructure and Tensile Properties

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Abstract

This study investigates the impact of process parameters in the Additive Friction Stir Deposition (AFSD) of Ti-6Al-4V. AFSD is a solid-state manufacturing technique combining frictional heating with shear-assisted extrusion. The research aims at assessing the impact of key process parameters (tool temperature, feed rate, transverse velocity and layer thickness) on microstructure and tensile properties. Multiple deposition blocks were analyzed using characterization techniques such as scanning electron microscopy, X-ray diffraction, Electron Backscatter Diffraction (EBSD) and hardness measurements.

Results reveal a uniform Widmanstätten microstructure across samples, with variations in α - lath morphology and prior β grain size dependent on parameter configurations. Hardness values remained consistently within 320-350 HV, indicating process stability. Tensile testing revealed yield strengths between 860 and 910 MPa and ultimate tensile strengths between 960 and 990 MPa, demonstrating the mechanical robustness of AFSD-deposited Ti-6Al-4V. Variations in elongation across different deposition conditions highlight the influence of processing parameters on mechanical performance.

This comprehensive approach to correlating AFSD parameters with microstructural and mechanical outcomes highlights the process's potential for producing high-performance titanium alloy components for industry, especially aerospace applications. The study significantly contributes to understanding process-microstructure-property relationships in the additive manufacturing of Ti-6Al-4V, paving the way for further advancements in solid-state additive manufacturing techniques.

Keywords: Additive Friction Stir Deposition, Ti-6Al-4V, Microstructure, Mechanical Properties.

Study of Friction Stir Welding Parameters and Their Effects

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Abstract

Friction Stir Welding (FSW) is an advanced solid-state joining process originally developed by The Welding Institute (TWI) to address the challenges of welding high-strength and lightweight alloys. Unlike conventional fusion welding, which often results in defects such as porosity, cracks, and phase segregation, FSW operates below the melting temperature of the base materials, ensuring superior weld integrity with minimal distortion. Since its inception, FSW has been widely applied in industries such as aerospace, shipbuilding, automotive, and railway transportation.

This study investigates the key process parameters in FSW and their impact on the weld quality of aluminum plates. The research encompasses the conversion of a conventional milling machine into an FSW workstation, the development of specialized tool designs, and the evaluation of material behavior under various operating conditions. The primary objective is to optimize welding parameters such as tool rotation speed, traverse speed, tool tilt, plunge depth, and probe geometry to achieve high-strength welds with minimal defects.

The experimental setup involved welding aluminum and mild steel plates of 3 mm and 5 mm thickness using cylindrical and conical probes made of mild steel and aluminum. The welds were evaluated through mechanical testing, including bending strength tests and Rockwell hardness measurements. The study revealed that lower rotational speeds favor weld strength for cylindrical probes, whereas conical probes demonstrate superior performance at higher speeds. Additionally, increasing tool rotation speed exhibited varying effects on weld integrity, depending on material type and tool geometry.

Results indicate that probe shape significantly influences material flow and mixing within the weld zone. A well-designed probe ensures effective material stirring, reducing defects such as voids and wormholes. The study also highlights the importance of process monitoring and parameter optimization in achieving consistent weld quality. The findings contribute to the ongoing development of FSW for industrial applications, where precision, efficiency, and mechanical integrity are crucial.

Future work will focus on developing mathematical models for heat generation, finite element (FE) analysis of thermal and mechanical stresses, and further refinement of tool designs to enhance the welding capabilities of FSW. The study underscores the potential of FSW as a viable alternative to conventional welding techniques, promoting sustainable and high-performance manufacturing in various engineering sectors.

Keywords: Friction Stir Welding, Solid-State Joining, Welding Parameters, Aluminum Welding, Mild Steel, Tool Design, Mechanical Properties.

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Influence of herringbone grooves on the performance of hydrogen-lubricated gas journal bearings

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Abstract

Hydrogen offers a green energy solution, being clean, non-toxic, and environmentally friendly. This work investigates the performance characteristics of hydrogen gas-lubricated hybrid journal bearings. Recently, surface modification has emerged as an alternative to improve the performance of tribological systems. Therefore, the effects of herringbone grooves with different groove angles on the bearing performance characteristics have also been investigated. The modified Reynolds equation was solved using the finite element method. The static and dynamic performance parameters of hydrogen-lubricated journal bearings have been evaluated. Numerical simulation results indicate that the application of herringbone grooves substantially affects the bearing performance. The hydrogen gas-lubricated bearing with herringbone grooves provides a lower value of frictional losses than the non-grooved bearing. It has also been noticed that the lower value of groove angles provides a larger reduction in the value of frictional torque. This work is expected to be valuable for bearing designers and academia.

Keywords: Gas bearings; Herringbone grooves; FEM; Hydrogen gas.

Influence of process parameters on mechanical properties and microstructure of friction stir lap welded dissimilar 2024-T3/7075-T6 aluminum alloy joints

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Abstract

2024-T3 and 7075-T6 grade aluminum alloys are extensively used in fabrication of aircraft structural panels, especially for fuselage applications [1]. Riveting is widely employed to join these alloys as they are not weldable by conventional joining methods such as TIG/MIG welding. However, riveting process is expensive, time-consuming, labor-intensive and weight-additive. Therefore, friction stir welding (FSW), being a solid state welding process, has become a choice for various aircraft applications [2-3]. In the present work, systematic studies were conducted on 1.6 mm thick dissimilar 2024-T3/7075-T6 joints produced by friction stir lap welding (FSLW). A hardened and tempered H13 tool with stepped design was employed for welding. Bead on plate experiments were conducted using rotational and traverse speeds varied between 300 to 1400 RPM and 80 to 300 mm/min respectively to identify optimum weld parameters. The initial process envelope parameters were selected based on weld bead's surface appearance, radiography examination and macro/microstructural defects. Hardness and static lap shear tests were conducted on defect-free samples to identify the optimized process parameters that produce highest mechanical properties. Optimization studies were conducted employing two different joint configurations i.e., advancing side near end (ANE) and retreating side near end (RNE) in both as-welded and artificially aged (120°C for 24 hours) conditions. The correlation between FSW microstructure, nature of defects and mechanical properties are discussed in this paper.

Keywords: friction stir lap welding; dissimilar alloys; 2024-T3/7075-T6; tensile properties, microstructure; structure-property correlations

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Influence of Pyrolysis on Microstructure and Mechanical Response of Polymer Derived Ceramic Reinforced Aluminium Nanocomposite

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Abstract

Aluminium nanocomposites synthesized by ex-situ methods are plagued by low toughness, limiting their applicability. The loss in toughness and ductility is due to particle agglomeration and formation of brittle intermetallics, during composite synthesis. Polymer Derived Aluminium nanocomposites synthesized by Friction Stir Processing (FSP) can address these issues. In this study, preceramic polymer, Polymethyl Hydrogen Siloxane (PMHS) was crosslinked and dispersed in commercially pure aluminium using FSP. The polymer particles were fractured to nanoscale during dispersion. The aluminium-polymer composite was pyrolyzed to convert polymer particles to ceramic particles. The pyrolysis temperature and duration were varied from 300-600°C and one to ten hours, respectively. The Differential Scanning Colorimetric (DSC) analysis showed that pyrolysis temperature and duration need to be above 500°C and 10 hours for complete conversion of PMHS to ceramic. The microstructure of the composite was analysed by Scanning and Transmission Electron Microscopy. It was seen that the gases released by polymer degradation causes considerable microporosity in aluminium matrix. Hence, the pyrolyzed composite was FSPed to remove porosity and redistribute ceramic particles. Further, the tensile behaviour of the composite correlated with pyrolysis temperature and duration. It was also seen that strain hardenability improved with pyrolysis duration. At optimal pyrolysis condition, the tensile strength, and toughness of the composite improved by 240% and 50%, respectively. Mechanisms contributing to mechanical behaviour was evaluated and Orowan mechanism was found to be dominant. In conclusion, polymeric route can be a viable method to synthesize tough aluminium nanocomposites.

Keywords: Polymer Derived Ceramics; Aluminium nanocomposite; Friction Stir Processing; Mechanical Behaviour, Strengthening Mechanisms

Investigation on distinct tribocorrosive nature across the weld zone of friction stir welded AA5052

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Abstract

Welded structures possess microstructural variability across the zone. Due to this variability in the structure, their properties vary and hence its performance. When they serve in marine condition, selective degradation happens at different portions of the weld zones and hence this affects its service life. The present study investigates the tribocorrosion occurring at the different zones of a friction stir welded 5052 alloy in marine condition. The study involves, base metal, nugget zone, and heat affected zones at the advancing and retreating sides as samples. The samples were undergone tribocorrosion test in linear reciprocating type tribometer at a minimal frequency adjoined with electrochemical analyzer in a 3.5% NaCl solution. The microstructure of the samples were analysed mainly using optical images, EBSD and XRD. Microstructure of the samples were found mutually distinct, in which NZ was refined-equiaxed (8.8 μm), base metal was coarse-pancake shaped (39.6 μm), AS-HAZ was coarse and serrated (40.1 μm) and RS HAZ was also coarse and serrated (39.2 μm). Fraction of LAGBs was found high only in the base metal. Hardness results of the samples showed that AS (72 HV) had the highest hardness, followed by RS (69 HV), NZ (65 HV) and BM (62 HV). Tribocorrosion results showed that the base metal showed better corrosion resistance than NZ followed by AS-HAZ and RS-HAZ, but the frictional characteristics of the base metal (CoF-1.72) was poorer than all other samples. NZ (CoF-1.19) showed increased stable passive layer formation which protected the sample from further corrosion the minimal IMC presence prevented localized pitting. This improved the NZ frictional characteristics. AS-HAZ and RS-HAZ possessed coarser elongated IMC phases like Al_3Fe and Mg_2Si and these phases promoted intergalvanic corrosion at the particular zone. Base metal showed lower passivation and lower corrosion rate, as the sample possessed coarser grains and lower IMC content. In base metal the material removal was high and the mechanism of removal was purely wear dominant. Rest of samples were observed with synergistic mechanism of material removal and the volume of removal was found minimal.

Keywords: AA5052, Friction stir welding, Tribology, Corrosion, Marine, IMCs, Potentiodynamic-polarization.

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Enhancing Tribological Performance of Cu (II)O/MWCNT Hybrid Nanolubricants for Axle Drive Applications

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Abstract

Axle drive systems require high-performance lubricants with enhanced thermal conductivity and reduced friction to ensure durability and efficiency under extreme operating conditions. In this study, the tribological performance of Cu (II)O (80%)/MWCNT (20%) hybrid nanoparticles in BS-VI mobil oil was investigated to enhance its applicability. A two-step process was employed to formulate the nanolubricants, incorporating hybrid nanoparticles at volume fractions of 0.05%, 0.1%, and 0.15% (v/v). The tribological properties of these nanolubricants were evaluated using both a four-ball tester and a universal tribometer to gain comprehensive insights into their lubrication performance. The results demonstrated that the prepared nanolubricants significantly enhanced thermal conductivity, with a maximum improvement of 2.7% compared to the base oil. Additionally, the coefficient of friction (COF) was reduced by 34.12%, indicating superior friction-reducing capabilities. Surface morphology analysis of the wear track scars revealed that the ball-bearing and polishing effects of the hybrid nanoparticles are the dominant nanolubricant mechanisms. These findings highlight the potential of Cu (II)O/MWCNT hybrid nanolubricants in enhancing the efficacy of lubricants used in axle drive applications, paving the way for their practical implementation in the automotive and industrial sectors.

Keywords: Hybrid nanoparticles; thermo-physical properties; rheology; reciprocating wear; ball bearing effect; polishing effect

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Study of braking load cases on typical tri-cycle Landing Gear arrangement Aircraft

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Abstract

Braking from a high speed landing, taxiing and ground handling such as reversed braking are some of the critical design cases for sizing of landing gear and its attachment structures on Aircraft. In this work, the bookcase requirement from the guideline documents are elaborated for the high performance Aircraft which were compared with the rational loads, arrived from detailed dynamic models of landing gear and its braking system. Detailed dynamic modelling elaborates the numerical representation of landing gear components such as shock strut, jack, drag brace rod, toggles, axle, wheel, tire and its brake with varying degrees of complexity and its impact on braking force. The aspects such as friction modelling of brakes, runway pavement characteristics, landing gear flexibility and their overall influence on airframe internal loads were examined too. The observation are drawn on braking load cases from the rational dynamic model against the bookcase approach towards sizing of landing gear and relevance to the Aircraft project development phase were discussed in detail.

Keywords: Certification requirements, braking & friction modelling, rational braked roll, reversed braking, Airframe internal loads.

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Development and characterization of Cu/ TiN surface composites through friction stir processing

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Abstract

In this study, an attempt was made to incorporate the TiN coating into the Cu surface through Friction Stir Processing (FSP). Initially, on copper substrate TiN coating coated using the Physical Vapor Deposition (PVD) process. Further, Cu-TiN coated surface was carried out single pass friction stirring by fixing the tool rotational speed as 600 rpm and by varying the tool traverse speed from 50 to 200 mm/min in steps of 50 mm/min. after processing the samples were extracted from the stir-zone regime to characterize their microstructure, hardness, wear-resistance and electrical conductivity. It is observed that with an increase in tool traverse speed, the grain size of the stir zone decreases from 60 μm to 5 μm . At the same time, the Vicker's hardness of the friction stir processed samples improved from initial 72 VHN to 112 VHN. A significant reduction in the coefficient of friction (CoF) noted after processing, and it continuously decreased from 0.5 to 0.12 as traverse speed increased. Consequently, the wear rate of the processed samples gradually decreased as traverse speed increased. The electrical conductivity was decreased only about 1.7 %IACS after processing. This research indicates that FSP has potential to enhance the surface tribological properties of copper without significantly compromising its electrical conductivity.

Keywords: Friction stir processing, TiN Coating, Wear, electrical conductivity.

Effect of heat treatment on the microstructure and wear behavior of as-cast Al-15Si-4Ni-2Cu alloy

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Abstract

In the present work the influence of aging time on the microstructure and wear behavior of the artificially age-hardened Al-15Si-4Ni-2Cu alloy in the as-cast condition was investigated. The alloy was subjected to a T6 age-hardening treatment consisting of a 2-hour solution heat treatment at 510°C, followed by water quenching (25°C) and age-hardening at 220°C for different aging times. The microstructure of the age-hardened alloy showed the spheroidization of Si particles, the Ni-rich and a strong precipitation of Al₂Cu phases. In contrast, the as-cast alloy showed a platelet-like morphology of the Si phase coexisting with pointed acicular Al₃Ni and Al-Si-Ni-Cu phases, as well as Chinese script form of the Al₂Cu phase. The wear behavior of the age-hardened alloy showed maximum wear resistance and minimum friction coefficient over the entire range of applied load and sliding speed. The high wear resistance in the age-hardenable alloys is due to the spheroidization of the intermetallic phases and the increase in bonding between the intermetallic phases.

Keywords: Al-Si alloy; Age hardening; Microstructure; Hardness; Wear resistance; Heat treatment.

Effect of Load And Copper Chill on LM13/Zr/C HMMC's: Sand Abrasive Wear Experimentation and Machine Learning Analysis

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Abstract

In this research article, preheated (200° C) Zircon is added to Aluminum alloy (LM13) in terms of 3wt. % and Carbon (3Wt. %) is maintained constantly. Specimens are prepared using the stir casting process and to place the copper chills and non copper chill end of the mold to obtain unidirectional solidification. Matrix and reinforcement of LM13 and 0Wt.%, 3Wt.%, 6Wt.%, 9Wt.%, 12Wt.% of Zircon with 3Wt.% of Carbon specimens are obtained at copper chill end and non copper chill end of the mold. Specimens are tested using a sand abrasion test. Wear rate are extracted and obtained results are compared with specimens obtained at the copper chill end and non copper chill end. It is observed from the sand abrasion test that the wear of the specimens depends on a) Applied load, b) sliding speed and c) Weight % of reinforcements. Results show the minimal wear rate for 9Wt. % of Zircon, at lower loads. Worn specimens are observed under an optical microscope to evaluate the surface morphology of the exposed surface of the specimens. It is observed that deeper groove formation occurs at the specimens at mild wear is observed at the chill end specimens. The results are trained and tested using Auto machine learning approach, Actual prediction plot v/s Validation plot, Training, validation, and test performances of a machine learning model and shows negligible errors.

Keywords: Chill casting, Unidirectional chilling, sand abrasion test, abrasive wear, Machine learning

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Assessing the wear characteristics of the arc wire directed energy deposited AISI 316 material

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Abstract

Arc wire directed energy deposition (AW-DED) is an additive manufacturing process that uses an electric arc to melt and deposit metals layer-by-layer to produce a component. AW-DED is an interesting technique that attracted most of the manufacturing industries owed to its unique capability of building large sized components. Critical components like gears are manufactured using AW-DED which is exclusively used by industries like automotive, aerospace, defense and marine industries. The existing literature had focused on the characterization of various DED materials. However, the literature lacks to address the tribological characteristics of AW-DED components where the wear is a dominant factor in critical components like gears. In this work, the tribological study of the AW-DED AISI 316 steel is explored. Among the various AW-DED process parameters, current is chosen as the input parameter maintaining all other parameters such as wire feed rate, gas flow rate and weld speed constant. Figure 1 shows a typical component fabricated using the developed AW-DED setup. The tribological properties of the fabricated samples are assessed on a pin-on disc Tribometer. The wear characteristics such as specific wear rate and co-efficient of friction are taken as outcome measures.



Figure 1. Typical AW-DED component used for tribological study

Keywords: Arc wire-DED, Tribological Properties, AISI 316, Wear rate.

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Effect of Deep Cryogenic Treatment on Tool Microstructure, Wear, and Surface Integrity in Milling of Inconel X750

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Abstract

Milling of Ni-based superalloys such as Inconel X750 presents significant machining challenges due to high strength, low thermal conductivity, and rapid tool degradation. Enhancing tool life and maintaining surface integrity in such conditions is critical for achieving stable and efficient machining performance. Deep cryogenic treatment (DCT) of tungsten carbide cutting tools offers a promising route to improve wear resistance and edge stability by inducing microstructural changes such as grain refinement, increased high-angle grain boundaries, and fine carbide precipitation. These alterations significantly influence tool behaviour and machining outcomes during milling of difficult-to-cut materials like Ni-based superalloys. In this study, tungsten carbide inserts with two cutting edge radii (0.4 mm and 0.8 mm) were subjected to DCT and analysed using Electron Backscatter Diffraction (EBSD), Energy Dispersive Spectroscopy (EDS), and Scanning Electron Microscopy (SEM) to evaluate elemental reorganization, grain size distribution, and crystallographic texture. EBSD revealed a shift in peak misorientation angles from $\sim 82.7^\circ$ in untreated inserts to $\sim 87.6^\circ$ in cryo-treated tools, indicating an increase in high-angle grain boundaries and improved grain boundary strengthening. Grain size was refined, with peak area fractions shifting from 1.34 μm in T1 and 1.074 μm in T2 to 0.91 μm in Cryo-T1 and 1.12 μm in Cryo-T2. EDS analysis showed increased Ti content (from 0.14% to 0.59% in Cryo-T1) and redistribution of W and Al, supporting the formation of fine precipitates. Milling experiments on Inconel X750 were designed using Central Composite Rotatable Design (CCRD) under Response Surface Methodology (RSM), and surface integrity was assessed through surface roughness, residual stress, and EBSD-based sub-surface evaluation. The results demonstrate that cryo-treated tools exhibited significantly reduced tool wear, with maximum flank wear (V_b) values decreasing from 340 μm in T2 to 245 μm in Cryo-T2. EDS of worn edges indicated reduced diffusion of Ni and Cr from the workpiece. Surface integrity was enhanced with surface roughness (R_a) reduced from 0.63 μm (T2) to 0.36 μm (Cryo-T2), and residual stresses shifting toward favourable compressive values. Chip morphology was improved, with cryo-treated tools producing more uniform and less serrated chips, indicative of stable cutting conditions. This study establishes a direct correlation between cryogenic-induced microstructural refinement and improved machining responses, supported by statistical modelling through RSM.

Keywords: Deep Cryogenic Treatment; Surface Integrity; Tool wear mechanism; Chip morphology; Milling.

Microstructural evolution and Material flow behavior study in Friction stir additive manufacturing of Al 6061-T6 Alloy

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Abstract

Friction Stir Additive Manufacturing (FSAM) is a solid-state, sheet-based additive manufacturing process that builds components layer by layer using the principle of friction stir welding. Understanding the microstructural evolution and material flow behavior is important for optimizing FSAM-manufactured components. This study investigates these aspects in FSAM of 1 mm thin Al 6061-T6 sheets using a cylindrical tool pin, focusing on interlayer bonding, grain refinement, and material mixing. Cross-sectional analysis revealed defect-free interlayer bonding with a well-defined stir zone, where dynamic recrystallization resulted in significant grain refinement. Material flow analysis showed uniform horizontal and vertical mixing, with the advancing and retreating sides exhibiting symmetrical grain structures. However, high compressive forces during processing led to localized bending at the sheet edges. Microstructural examination showed a coarser grain structure in the bottom layers due to reheating effects, whereas the overall grain distribution remained consistent across the build. Hardness measurements closely correlated with the microstructure, with higher hardness observed in finer-grained regions, particularly near the top layers, and lower hardness in relatively coarser-grained regions near the bottom. These findings provide key insights into the microstructure-property relationships and material flow behavior in FSAM, paving the way for its application in lightweight structures and heat-sensitive assemblies requiring refined microstructures and enhanced mechanical properties.

Keywords: *Friction Stir Additive Manufacturing, Al 6061-T6 Thin Sheets, Structure-Property Relations, Grain Refinement, Lightweight Structure.*

A study on the experimental and numerical analysis of Friction Stir Welded AA5083 joints

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Abstract

Friction Stir Welding (FSW) is a solid-state welding technique that is widely used in industries to join similar and dissimilar materials. In this paper, FSW is applied to join the AA5083 aluminum alloy, which is known for its high strength-to-weight ratio and corrosion-resistant properties. Numerical simulations and experimentation were carried out to study the mechanical and thermal properties of the welded joints. The study used ABAQUS software to develop a finite element model. The model was utilized to simulate the thermal behavior during the FSW process. FSW was performed on the AA5083, and temperature-time distribution was recorded with K-type thermocouples at varying rotational speeds of 1000 and 1400 rpm and traverse speeds of 20, 50, and 80 mm/min. The FSW samples were studied for tensile strength, and it was found that there was a direct correlation between the heat generation and the tensile property of the samples. An error of 1.5% to 7.5% was found between the experimental and simulation results, validating the developed numerical approach. The study helped to optimize the FSW process parameters for enhanced tensile strength in AA5083 welded joints.

Keywords: Friction Stir Welding; AA5083; Numerical Analysis; Experimental Analysis; Tensile Strength.

Design Modification and Implementation of Cartridge Signal Flare for Pre-coded Signaling in Transport Application

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Abstract

Cartridge Signal Flare (CSF) is a critical component and used to convey the pre-coded signal to the Air Traffic control (ATC) in case of failure of electronic transmission. This research investigates design modification and implementation in CSF, analyzing failure modes, failure investigation, root causes, and potential mitigation strategies. Failure investigation, when applied to CSF, helps to identify failures that compromise the safety or malfunctions in complex systems. Initial design has flaw of paper case giving bulging due to moisture, case separation from brass holder, blinds during proof trials and misfire of A1 mixture cap during production of various lots. The paper case made from crimson paper has the ability to absorb the moisture during storage giving the bulging while loading the cartridge inside the dispenser. Aluminum (Al) metal case was used in place of paper case eliminating case separation, bulging and gives longer life as compared to paper case. A1 mixture cap was used as mechanical initiator comprising of separate anvil and has cumbersome and time-consuming manufacturing process leading to failures for the ignition. In place of A1 mixture, mechanical primer was introduced that eliminates the problem of failures. Mechanical primer has inbuilt anvil inside the primer body. This eliminates the problem of failures for the initiator. Blinds were eliminated by applying turn over upto 45 degrees of Al case over the rubber washer using suitable designed turn over tool. All these modifications were implemented to improve the quality of the product. These prevent the defects and enhance the operational efficiency of CSF. This research paper described about design modification and its investigation of CSF that fails during lot proof trials. The detail study was undertaken to understand the probable causes of failures. The novelty in this research is that, it is attempted to carry out the design improvement of CSF that is supported by carrying out qualification trials. This research paper focuses on design modification of CSF for giving pre-coded signal, methodologies for identifying root causes, and solutions to preventive and corrective actions to avoid re-occurrence of such failures in future. By applying design modification in systematic way, it is possible to identify the underlying causes of CSF failures and improve safety measures, reducing the risk of catastrophic failures.

Keywords: Signal cartridge, CSF, design modification, failure modes

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Fig 1, 2, and 3 shows the old design, new design using Al case and various components of CSF. Figure 4 depicts experimental set up for CSF and pyro-cartridge testing after modification. All tests have been completed satisfactorily, and CSF were supplied to users after successful design modification implementations. This has resulted large fleet of transport aircraft in operational reediness and achieved self-reliance in this critical technology.

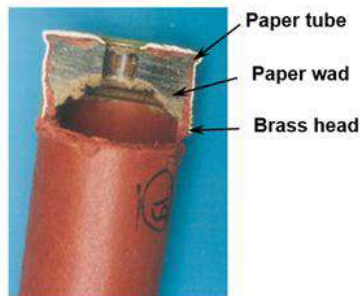


Fig 1 Old design



Fig 2. New design using Al case

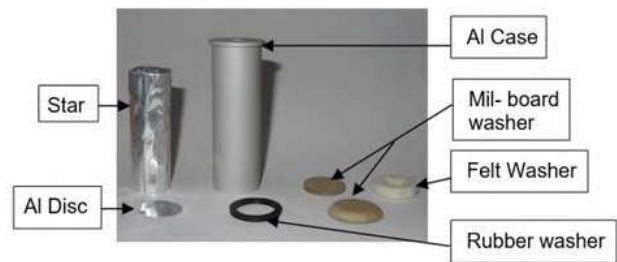
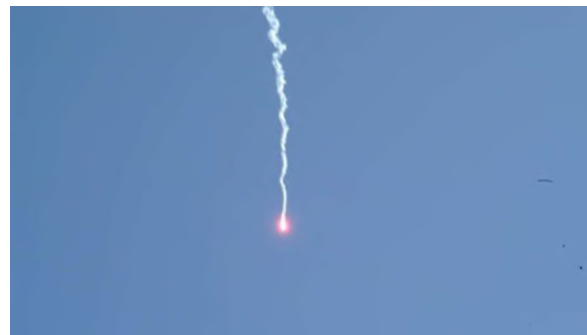


Fig 3 Components of CSF



a) Pyro-cartridge with signal cartridge



b) Signal cartridge showing the colour

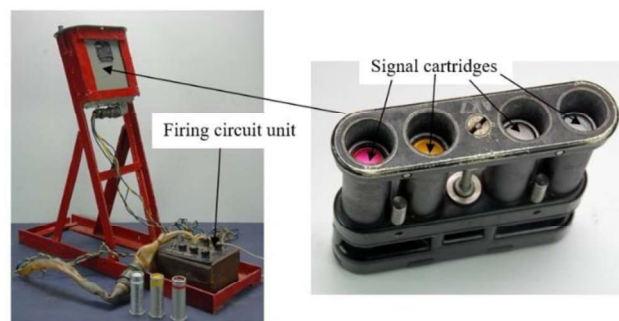


Fig. 4. An experimental set up for CSF and pyro-cartridge testing

Friction stir welding of Additively Manufactured Haynes 282 Ni superalloy

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Abstract

Haynes 282 is a γ' -strengthened nickel-based superalloy commonly used in turbine components for jet engines and thermal power plants. However, fusion-based welding techniques often lead to defects such as heat-affected zone (HAZ) liquation cracking and solidification cracking in H282 alloy. To address this, the present study employs friction stir welding (FSW) on three different states of Haynes 282 (H282) Ni superalloy: as-built additively manufactured (AM), solution-annealed additively manufactured (SAAM), and wrought (W-H282). FSW was carried out using a novel hemispherical tool tilted towards the retreating side. Successful joining of the H282 alloy was achieved with 100% joint efficiency and minimal tool wear. In the as-welded condition, the stir zone (SZ) was found to be free of γ' precipitates, with strengthening attributed to the fine grain size. However, a notably large HAZ was observed. As a result, the joints were subjected to a two-stage post-weld heat treatment (PWHT) to further enhance mechanical properties by promoting grain refinement and γ' precipitation in the stir zone, as illustrated in Figure 1.

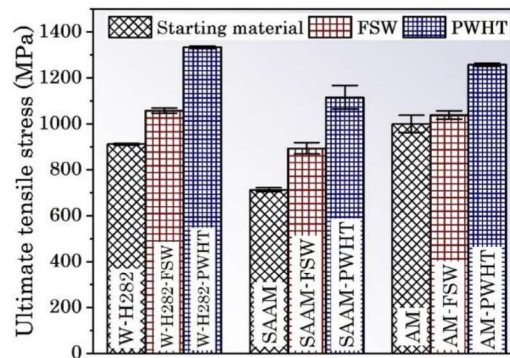


Figure 1. Mechanical properties of starting material, after FSW and after PWHT of H282 alloy.

Keywords: Friction stir welding (FSW), Ni superalloy, Precipitates, Mechanical properties, Microstructure.

Effect of heat input on the microstructure and mechanical properties of friction welded EN24 - alloy steel

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Abstract

Friction welding is an environmentally friendly and cost-effective process for joining of similar and dissimilar materials. In the current research work round shape solid bars of medium carbon steel (EN24) were joined by using continuous drive rotary friction welding (FW) method. The considered parameters were friction pressure, upset pressure and rotational speed. The weld interface (WI) microstructures were investigated using optical microscopy (OM), scanning electron microscopy (SEM) and electron back scattered diffraction (EBSD) technique. The microstructure in the WI region were observed significant refinement of grain size, phase transformation and modification in the grain orientation. The variations of the microhardness in the WI region were correlated with the frictional heat input and subsequently changes in the microstructural characterization. Moreover, tensile test results revealed that heat input is the dominating factor for achieving sound weld-joint strength.

Keywords: Rotary friction welding, Heat input, Microstructure, EBSD, Mechanical properties.

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Enhancing Ductility of LPBF Ti6Al4V through Localized Friction Stir Processing Role of Tool Geometry and Microstructural Transformation

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Abstract

Components manufactured using laser powder bed fusion (LPBF) often exhibit residual stresses and low ductility, which limit their performance in demanding applications. Hence these components are generally heat-treated for ductility improvement and relieving stresses. However, friction stir processing (FSP) has emerged as an alternative localized post-processing method that can improve material properties in targeted regions while potentially reducing post-processing costs compared to full annealing treatments. However, effective use of FSP requires precise control over tool geometry, especially when using tungsten-carbide-cobalt tools for processing Ti64 alloys to achieve the desired material properties. This study investigates the impact of tool geometry and the structure-property relationship in FSP of LPBF-manufactured Ti64 alloy with the primary goal of enhancing the ductility of LPBF components in localized regions. The conical pin tool generated a smoother, defect-free surface, while the threaded pin tool led to tearing and excessive flash formation due to the aggressive dragging of the plasticized material. The FSP transformed a microstructure, changing the α' acicular martensite structure within columnar β -grains into a refined structure composed of fine α -plates and dynamically recrystallized α -phases within equiaxed prior β -grains. This transformation led to a significant improvement in ductility by increasing grain boundaries and relieving internal stresses. Additionally, the reduction in porosity achieved through FSP further enhanced ductility by minimizing the risk of premature failure. This study establishes FSP as a promising localized post-processing method for improving the material properties of LPBF Ti64 components and offers valuable insights into tool geometries to guide future research and industrial applications in additive manufacturing.

Keywords: Laser Powder Bed Fusion, Friction Stir Processing, Tool Geometry, Microstructure, Ductility.

Analyzing the Influence of Pin and Shoulder-Pin Eccentricities on the Macro and Microstructural Evolution of Friction Stir Welds

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Abstract

Beyond artificially introducing tool offset in the holding setup, previous studies have also simulated tool runout by offsetting the pin relative to the shoulder. However, investigations on the combined effects of pin and shoulder eccentricities are missing and needs better understanding. The findings of the present study reveal significant effects of these eccentricities on weld quality. An increase in pin eccentricity led to the formation of wormhole defects, which became more pronounced and eventually resulted in an externally visible groove at higher eccentricities. Interestingly, for the same magnitude of eccentricity, when both the pin and shoulder were offset by equal amounts, the defect was completely eliminated, resulting in a sound-processed region. Further, Microstructural Evolution was studied through Zener Holloman parameter as a function of tool eccentricity.

Surface Modification of Ti-6Al-4V with Titanium Carbo Nitride Sacrificial Tool used Reverse Polarity Electric Discharge Coating

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Abstract

Electric Discharge Coating is an emerging technology in modern era for the surface modification of difficult to process materials such as Titanium, Inconel, Tungsten Carbide etc. with low cost [1]. This work made an attempt on surface modification of the most widely used Titanium alloy Ti-6Al-4V, which possess low wear resistance and high wettability with the aid of Ti₂CN powder metallurgy processed tool used Electric Discharge Coating in reverse polarity. An average recast layer thickness/coating of about 35µm in 30 minutes processing time is attained for the parametric conditions 8A and 0.9 duty factor. Maximum material addition of 0.03mm³/min is obtained within 15 minutes processing time by the quick disintegration of PML tool and cataphoretic deposition. Surface with minimum surface roughness of 1.54µm and maximum contact angle of 119° (hydrophobic surface) is formed with the presence of TiO₂, TiC, TiN, TiC 0.3 N 0.7 and TiC 0.7 N 0.3. Reduction in wettability is observed with the formation of texture like surface by the erosion and material distribution during the material addition. Presence of oxide causes the reduction in surface energy and thus the wettability. Reduction in residual stress is experienced at the processed surface compared to the substrate. Increase in wear resistance is observed with specific wear rate in the order of 10-5mm³/Nm and with half reduction in the wear rate observed from the bare Ti-6Al-4V owing to the presence of carbides, protective oxides and heat affected zone.

Keywords: Electric Discharge Coating, Powder Metallurgy Processed Tool, Titanium Carbo Nitride, Surface Roughness, Wettability, Wear Resistance, Residual Stress.

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Microstructural Insights and Mechanical Evaluation of Dissimilar Rotary Friction Welded CP70 Titanium–SS304L Tubes

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Abstract

This work presents the development and optimization of friction welded joints between commercially pure CP70 Titanium and SS304L Stainless Steel using Design of Experiments (DOE) approach. Rotary Friction Welding (RFW) is employed for its ability to produce high-quality welds without melting the base materials, making it ideal for joining dissimilar metals. The study systematically explores and optimizes key process parameters such as rotational speed, friction pressure, and friction time, forging pressure, and forging time to achieve robust and reliable joints with superior mechanical properties. Non-destructive testing methods, including ultrasonic testing and dye penetrant testing, are used to evaluate the integrity of the welded joints. The macrostructural and microstructural analysis of the welded joints shows distinct interface shapes and material flow characteristics influenced by the applied welding parameters. The detailed microstructural analysis using Optical Microscopy (OM), X-ray Diffraction (XRD), Electron Back Scattered Diffraction (EBSD), Electron Microscopy (SEM) reveals the formation of dynamic recrystallization (DRX) grains, deformed grains, and intermetallic phases at the interface, contributing to the joint strength. Additionally, tests were conducted on welded tubes to evaluate their durability and integrity under various stress conditions. These tests include initial helium leak testing, thermal cycling (LN2 dipping and heating), and hydro pressure testing. The comprehensive evaluation confirms the tube's suitability for applications involving thermal and pressure stresses. This research provides a practical framework for optimizing welding conditions to ensure consistent joint quality in industrial applications.

Keywords: *Rotary Friction Welding (RFW), Microstructural Evolution, Intermetallic Phases, Design of Experiments (DOE)*

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Effect of tool rotational speed, travel speed, and build layer number on force and temperature characteristics in friction stir additive manufacturing of AA5083-O

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Abstract

Friction stir welding (FSW) is the fundamental process of the solid-state additive manufacturing technique known as friction stir additive manufacturing (FSAM), which joins material layers either in the form of sheets or plates. As FSAM is a thermo-mechanical process, the information on temperature and forces during the joining of the build layers plays an important role in process monitoring and control. The majority of FSAM works are on understanding several process parameters and their effect on the final mechanical properties, such as strength and hardness, in the build. Despite significant advancements in understanding the effects of process parameters on the final build quality, an integration with the process's thermal and mechanical behaviour during FSAM process remains crucial for understanding the physics of the process. These understandings can lead to further improvement of mechanical properties and enhanced overall efficiency in FSAM. Among the few studies that focus on the temperature and force measurements during friction stir-based additive manufacturing, there is a lack of combined understanding of force and temperature variations, particularly across multiple build layers or interfaces. Additionally, the temperature and force characteristics with respect to the process tool rotational speed, travel speed, and build height are all corresponding to good quality and consolidated welds. In fact, the measurement and analysis of force and temperature can also be a good indicator of the quality of the additive build.

In this context, the present work is focussed on measuring and analysing the force and temperature under the effect of the critical process parameters viz. tool rotational speed, travel speed, and build interface count (representative of the build layer number). FSAM of aluminium alloy 5083-O, having a thickness of 3 mm, is performed to join and make a five-layer additive build. The characteristics of force and temperature are recorded using a strain dynamometer and a K-type thermocouple. It has been found that the general trend of force and temperature variations with respect to tool rotational speed and travel speed, which is valid for a consolidated weld, is not observed at some of the parameters studied here. These observations are discussed in detail with the observed material mixing defect of grooves. The variation of vertical force and temperature with increasing layer numbers is also explained in this context of consolidated and groove-formed builds.

Keywords: Friction stir additive manufacturing; Aluminium alloy 5083; Force; Temperature; Build layer number.

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Joining of pure tungsten and EN8 material using rotary friction welding

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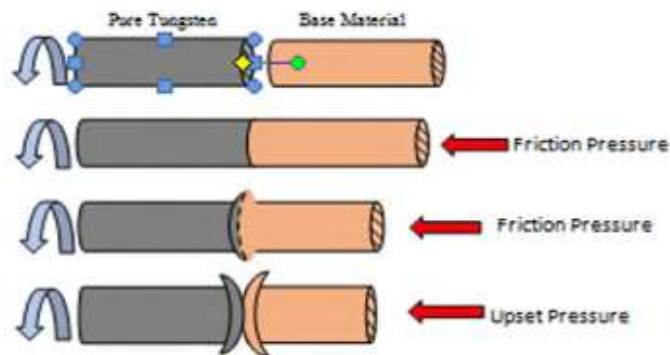
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Abstract

Rotary friction welding (RFW) is a solid-state joining process widely used for bonding dissimilar materials, offering high-quality joints without melting the base metals. This technique is especially advantageous for materials that are difficult to weld using conventional fusion methods. This study investigates the friction welding of pure tungsten with EN8 tool steel, focusing on optimizing welding parameters and using copper interlayer to enhance joint quality. Initial trials revealed that direct welding of pure tungsten to EN8 without an interlayer resulted in poor joint strength due to tungsten's inherent properties such as high hardness and melting temperature. To address this challenge, copper was introduced as an interlayer material with varying thicknesses to reinforce the bond. The welded joints were subjected to manual bend tests to evaluate their integrity, followed by tensile and torsion test. Tensile strength testing using a Universal Testing Machine (UTM). The optimized configuration, including the copper interlayer, resulted in a significant improvement in joint strength, with a measured tensile strength of 226 MPa. This work demonstrates the feasibility of using a copper interlayer to effectively bond dissimilar materials such as pure tungsten and EN8 tool steel through friction welding.



Keywords: Rotary friction welding, Pure tungsten, EN8 tool steel, Mechanical properties, copper interlayer, Microstructure.

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A Conceptual Study on Smart Manufacturing Perspectives for Affordable and High-Performance Artificial Limb Design Using AI and Digital Twin Tools

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Abstract

The convergence of Artificial Intelligence (AI) and Digital Twin technologies within smart manufacturing ecosystems is reshaping the landscape of prosthetic limb design by enabling greater customization, process adaptability, and cost-efficiency. This study proposes a conceptual framework that integrates AI-powered generative design, biomechanics simulation, and cyber-physical synchronization through digital twins to enhance the functional and structural optimization of artificial limbs. Grounded in the principles of Industry 4.0 and smart manufacturing systems, the approach leverages data-driven decision-making and virtual validation environments to reduce material usage, accelerate design iterations, and improve product lifecycle management. Drawing from recent advances in cyber-physical production systems (CPPS), integrated product-process digital twins, and AI-enhanced predictive analytics, the framework aims to deliver affordable, high-performance, and patient-specific prosthetic solutions. Supported by case studies and systematic reviews from the literature, this work highlights the transformative potential of digitalization in assistive technology manufacturing, offering actionable insights for future research and industrial deployment in personalized medical device development.

Keywords: Smart Manufacturing, Artificial Intelligence, Digital Twin, Cyber-Physical Systems (CPS), Prosthetic Design, Product-Process Integration, Generative Design, Biomechanics Simulation, Additive Manufacturing, Personalized Medical Devices, Industry 4.0, Affordable Prosthetics.

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Development of a Framework for Overall Complexity Index in Friction Stir Welding Process

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Abstract

Friction Stir Welding (FSW) is one of the novel process to join similar and dissimilar materials. The use of FSW is growing day by day in various industrial sectors such as aerospace, automobile, defense, marine etc. because of high joint strength and formation of defect-free welds as process is carried out at a sub-melting temperature. However, FSW is considered as a relatively complex process as numerous parameters related to weld condition, weld geometry and weld quality have a significant impact on the overall performance of the joint. Therefore, there is a strong need to develop a systematic approach for evaluating the complexity associated with the FSW process.

The present work is mainly focused on providing specific framework for computing complexity of FSW using different variables associated with the process. It will also help in making appropriate decision to employ FSW process in various industrial sectors. A five layered hierarchical structure comprised of Overall Complexity Index (OCI), factors, elements, attributes and meta-attributes have been developed to compute the complexity involved in FSW process. The top layer of hierarchical structure is OCI that is driven by three factors related to weld condition, weld geometry and weld quality. These factors are categorized into five elements (process parameters, tool parameters, type of joint, destructive testing and non-destructive testing) and further into 18 attributes (welding speed, characteristics of tool, workpiece material, plunge force, dimension of joint, requirement of various testing and joint efficiency). These attributes along with 81 meta-attributes (quantification as well as requirement of these attributes) are employed in the calculation of OCI in the scale from 0 to 100. The higher value of OCI indicates the greater complexity involved in manufacturing industrial component using FSW. The proposed approach of OCI is also tested on different case studies and found very suitable in decision making to adopt FSW for manufacturing industrial component. This work further provides better insight about importance of complexity computation for FSW so that benchmarking for the use of FSW can be achieved and that will contributed in philosophy of Design for Manufacturing and in turn into Design for FSW (DoFSW).

Keywords: Friction Stir Welding; Complexity; Design for FSW; Design for Manufacturing

Atmospheric Deformation Quantification from High-Temperature Gradients A Mathematical Method Based on Radiosonde

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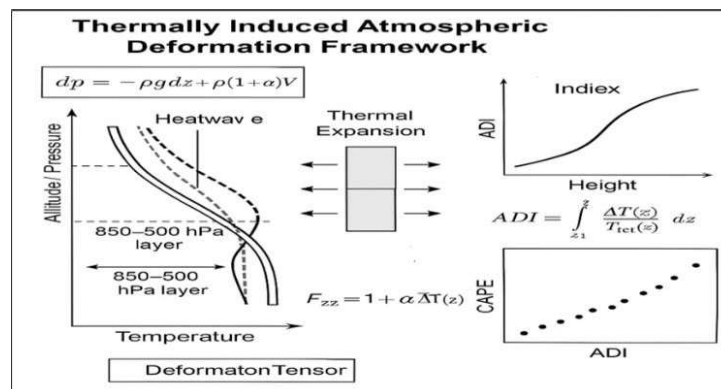
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Abstract

The vertical structure of the atmosphere is significantly impacted by extreme surface and upper-air temperature anomalies, which cause detectable deformation of atmospheric layers. In this work, a new mathematical modeling framework for measuring vertical deformation caused by high temperatures using radiosonde observations is presented. A more realistic depiction of upper-air dynamics during heatwave conditions is achieved by the model's extension of hydrostatic equilibrium formulations to incorporate thermally induced expansion effects by integrating thermal strain theory with classical atmospheric physics. Vertical profiles of temperature, pressure, and geopotential height were obtained by analyzing radiosonde data obtained during several severe temperature events. A recently proposed dimensionless metric called the Atmospheric Deformation Index (ADI), which measures the cumulative thermal strain across tropospheric columns, was computed using these. Vertical displacements caused by thermal expansion were described by a deformation gradient tensor, and its impact on convective instability parameters including lapse rates and the Convective Available Potential Energy (CAPE) was assessed. The findings indicate that the ADI can capture increased vertical deformation during heatwaves, especially in the 850–500 hPa layer, which is associated with deep convective potential and increased instability. Validating the sensitivity and applicability of the suggested model, a comparison with climatological radiosonde profiles shows notable variations in thermal structure during high-temperature occurrences. The proposed method provides a physically consistent way to diagnose atmospheric thermal deformation and can be used for heatwave monitoring, nowcasting convective conditions and enhancing upper-air model initialization in numerical weather prediction systems.



Keywords: Deformation at high temperatures, Observations from radiosonde, Expansion of the atmosphere, Modeling of the thermostat, Index of Atmospheric Deformation (ADI), Instability in the upper air, Forecasting heatwaves, Analysis of vertical profiles

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Influence of Friction Pressure and Friction Time on Mechanical Properties and Microstructural Characteristics of Linear Friction Welded Ti-6Al-4V Alloy Joints

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Abstract

Titanium alloy (Ti-6Al-4V) is frequently used in aero engine components due to its excellent high temperature strength and lightweight. Ti-6Al-4V can be welded by almost all the fusion welding processes but it resulted in the formation of coarse-grained microstructure in the fusion zone. To overcome these problems, solid state welding processes are now adopted in the aerospace industries because it avoids total melting of materials and provides finer grain structures in the nugget region. Linear Friction Welding (LFW) process is a new variant of rotary friction welding (RFW) process and is being used to fabricate aero engine components now days. The joint quality is influenced by LFW process parameters such as friction pressure, friction time, oscillation frequency, forging pressure and forging time.

The Friction Time and Friction Pressure plays the major role in affecting the mechanical properties of the weld joint. In this investigation, an attempt has been made to explore the effect of the LFW process parameters like, Friction Time and Friction Pressure on mechanical and metallurgical properties. The tensile properties of the joints were evaluated as per the standards. Microstructural features of various regions of welded joints were analyzed using optical microscopy (OM) and scanning electron microscopy (SEM).

From this study, it is found that during lower friction pressure and friction time, the relative motion between the mating surfaces is minimum and it results in poor joint strength. Higher friction pressure and friction time enhances the friction between the surfaces and facilitates the plastic deformation. And, for the friction pressure of 20 MPa and friction time 20s, a maximum joint efficiency of 95% achieved.

Keywords: *Ti-6Al-4V alloy, Linear Friction Welding, Tensile Properties, Microstructure.*

Improving corrosion resistance of friction stir welded dissimilar joints of Aluminium – Magnesium alloys by Micro Arc Oxidation (MAO) coatings

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Abstract

The joining of aluminium and magnesium alloys using FSW process results in intercalated and lamellar microstructure in the nugget region (stir zone). The corrosion behaviour of stir zone is entirely different from the parent metal because of the mechanical mixing of Al and Mg alloys. Compared with similar FSW joints, dissimilar joints corrode severely. So, it is important to identify the conditions that will lead to minimum corrosion rate in weld nugget region of Al/Mg dissimilar joints. Hence, in this investigation, an attempt has been made to identify the minimum corrosion rate conditions for friction stir welded dissimilar joints of AA6061 Al and AZ31B Mg alloys under NaCl environment by response surface methodology (RSM). Further, an attempt has been made to develop a micro-arc-oxidation coating on the dissimilar welds to improve the corrosion resistance.

Rollled plates of AA6061-T6 aluminium alloy and AZ31B magnesium alloy plates with thickness of 6 mm were used in the present investigation. The plates were cut to the required size (150 mm × 75 mm) by power hacksaw. A square butt joint was fabricated by FSW process. The initial joint configuration was obtained by securing the plates in position using mechanical clamps. The direction of welding was normal to the rolling direction of the plates. Single pass welding procedure was used to fabricate the joints. AA6061 aluminium alloy was placed in the advancing side and AZ31B magnesium alloy in retreating side. Taper threaded cylindrical tool made of super high speed steel was used to fabricate the joints. A computer numerical controlled FSW machine (22 kW, 4,000 rpm, 60 kN) was used to fabricate the joints. From the previous work carried out in our centre, the optimised FSW parameters were taken and used in this investigation.

From the fabricated joints, the specimens were extracted from weld nugget region for conducting immersion corrosion test with the dimensions of 15 mm × 15 mm × 6 mm. Then the specimens were grounded with 600#, 800#, 1,200# and 1,500# grit SiC paper. Finally, it was cleaned with acetone and washed in distilled water and then dried by warm flowing air before immersing in the prepared NaCl solution. NaCl solutions with concentrations of 0.2, 0.36, 0.6, 0.84 and 1 mol were prepared. The pH value was measured using a digital pH metre and varied from 3 to 11 as prescribed by design matrix. The corrosion rate of the weld nugget region was calculated by weight loss method.

Specially designed electrical controller MAO coating unit of 30 kVA was used in the present study. An alkali solution with a mixture of potassium hydroxide and sodium meta silicate was employed as electrolyte in

this present work. Substrate (specimen) was connected to an AC power source (high voltage) with a constant current density all over the coating process. The substrate immersed fully in the electrolyte bath in a non-conductive container. The morphology (top surface and cross-section) of the coatings were analysed using secondary electron microscopy (JEOL-JSM-5610LV) and then the percentage of porosity was measured with an image analysis software. X-Ray diffraction (XRD) analysis was carried out to find out the phases present in the MAO coatings.

An empirical relationship was developed to predict the corrosion rate of weld nugget region of friction stir welded dissimilar joints of AA6061 Al – AZ31B Mg alloys with 95% of confidence level. The relationship was developed incorporating the chloride ion concentration, pH value of environment and immersion time using statistical tools, such as design of experiments and regression analysis. MAO parameters were optimized using response surface methodology to achieve coatings with minimum porosity and maximum hardness. The optimized values (1.76 vol% of porosity and 1360 HV of hardness) are closely matched with the experimentally determined values. Among the three MAO parameters investigated, current density is found to be the predominant factor, followed by oxidation time and inter-electrode distance and this is confirmed by Analysis of Variance test (F-ratio)

Joining of Aluminium (Al) and Magnesium (Mg) alloys is essential in industrial applications. Though, it is hard to achieve superior dissimilar joints between these two kinds of alloys through conventional fusion welding techniques due to development of large inter-metallic compounds at the weld region, which have a strong negative effect on the mechanical properties of the joint. Friction stir welding (FSW), a solid state welding process, is having potential to join these dissimilar metals due to the lower processing temperature over conventional fusion welding techniques. However, the corrosion behaviour of stir zone is entirely different from the parent metal because of the mechanical mixing of Al and Mg alloys. Hence, in this investigation, an attempt has been made to improve the corrosion resistance of friction stir welded dissimilar joints of AA6061 Al and AZ31B Mg alloys under NaCl environment by providing a thin micro-arc-oxidation coatings.

Keywords: Friction Stir Welding, Dissimilar joints, Aluminium alloy, Magnesium alloy, Corrosion, Micro arc oxidation coating.

Prior β -grain Refinement in Wire Arc Additive Manufactured Ti6Al4V

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Abstract

Wire arc additive manufactured (WAAM) Ti6Al4V is highly valued in aerospace applications due to its high deposition rate (~ 10 kg/hr) and cost-effective production of large, near-net complex-shaped components. Its as-built microstructure is typically characterized by large, columnar prior β -grains extending over centimeter length scale, with a strong solidification $\langle 001 \rangle$ β fiber texture aligned with the build direction. As a result, according to the Burgers Orientation Relationship (BOR), an $\alpha + \beta$ microstructure at room temperature exhibits anisotropic and unpredictable mechanical properties. Thus, the strategies of prior β -grain refinement in WAAM Ti6Al4V are important. These include the addition of grain growth restrictors (such as B, TiN, ZrN and Y), changing of wire feed speed, and the application of interpass deformation techniques (including rolling, hammer peening and ultrasonic peening). These approaches lead to the development of refined, equiaxed grains with random texture, thereby significantly achieve the unscattered and isotropic mechanical properties. The detail underlying micro-mechanisms of β -grain refinement supported by stop-action samples and advanced characterization tools like large area optical microscopy, large area EBSD mapping, simulations and X-ray tomography are explored.

Keywords: Wire arc additive manufacturing; Ti6Al4V, Prior β -grain refinement; Texture; Mechanical properties.

Vision-based DQA and geometrical digital twin reconstruction for incremental forming

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Abstract

Single Point Incremental Forming (SPIF) has evolved as an advanced forming process for the low-volume production of complex and customized parts without requiring customized dies. However, SPIF has some limitations, such as poor dimensional accuracy with reference to the original design models. Inaccuracies in SPIF-formed products result from the release of residual stress. Precise measurement of the SPIF-formed part is crucial to address this limitation, wherein we require Dimensional Quality Assessment (DQA) of the as-built product at various stages of forming. The capital cost of state-of-the-art methods, such as coordinate measuring machine (CMM) or laser-based scanning (LBS) systems, is significantly high, and access is limited to a handful of researchers and high-value production industries. To overcome these limitations, the author proposed a cost-effective vision-based solution wherein we record images of the ROI (Region of Interest) from different viewpoints and orientations using a consumer-grade camera. In the present work, we generate the geometrical Digital Twin (gDT) of ROI using photogrammetry, wherein we transform 2D images into a 3D point cloud (PC). The dimensions of the as-built ROI are estimated from the gDT and compared with the virtually designed model. The proposed study provides a detailed framework for generating the gDT of the SPIF-formed part for DQA.

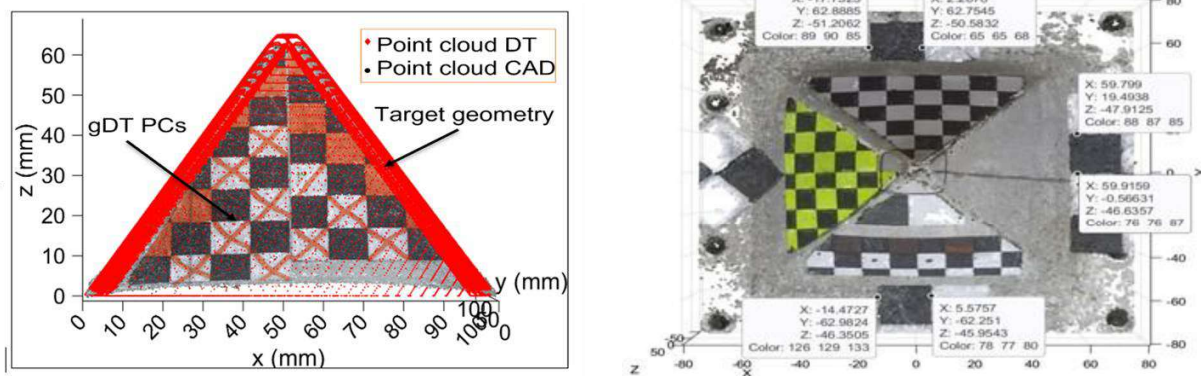


Figure: (a) Reconstruction of geometrical digital twin of formed product using Photogrammetry. (b) DQA of as-built structures

Keywords: Single point incremental forming; spring-back; geometrical digital twin; smart manufacturing; DQA.

Abrasive Water Jet Machining of a High Strength Titanium Alloy: Characteristics And Response

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Abstract

This study investigates the abrasive water jet machining (AWJM) characteristics of a high-strength titanium alloy (Ti-6Al-4V) using an L18 orthogonal array, considering three input parameters: impingement angle (2 levels: 45° and 90°), water pressure (175, 225, and 275 MPa), and traverse speed (20, 40, and 60 mm/min). The influence of these parameters on material removal rate (MRR), surface roughness, kerf width, and material integrity was systematically analysed. The maximum MRR of 49.173 g/min was achieved at a 90° impingement angle, 275 MPa water pressure, and 60 mm/min traverse speed for a 10-mm thick sample, with an associated surface roughness of 3.178 µm. The minimum surface roughness of 2.153 µm occurred at a 45° impingement angle due to the glancing impact of abrasive particles, resulting in smoother cuts. The maximum kerf width was observed for the 45° impingement angle, medium water pressure (225 MPa), and low traverse speed (20 mm/min), attributed to the longer exposure time and wider abrasive spread at shallow angles. Microstructural examination revealed no significant changes, and Vickers hardness remained largely unaffected due to minimal heat generation. Microscopic strain induced by AWJM was also found to be low (0.00002677), compared to the pre-machining value (0.000004311), affirming AWJM as an efficient, cold cutting process for titanium alloys with minimal thermal and mechanical damage.

Keywords: Abrasive water jet, material removal rate, Surface roughness, Micro strain, Kerf width, micro strain.

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Micro Drilling and Some Investigations on Effects Drilling Parameters on Hole Quality of ALCARL – a novel Fiber Metal Laminates (FMLs)

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Abstract

ALCARL, a novel fiber-metal laminate (FML) comprising aluminum and carbon-fiber composite layers, has been developed for aerospace skin and structural panels due to its enhanced stiffness and high strength-to-weight ratio. For fastening in aircraft assemblies, precision micro-drilling of ALCARL is crucial and challenging because simultaneous cutting of metal and composite layers exposes the tool to contrasting mechanical and thermal conditions. This can lead to change in diameter and delamination damage. In this study, micro-drilling tests were conducted on ALCARL under mist cooling using carbide micro-drills of 300 μm and 500 μm diameter. Spindle speeds (10,000–35,000 rpm) and feed rates (2–2.5 mm/min) were varied in a Taguchi L8 orthogonal array. Hole quality metrics included entry and exit hole diameters, delamination factor, taper, and radial overcut and undercut. Linear regression, analysis of variance (ANOVA), and signal-to-noise ratio analysis were applied to quantify the effect of each parameter on these responses.

Results showed that drill diameter was the most significant factor affecting all hole quality metrics and deformation-induced defects. Spindle speed had a moderate effect on delamination severity and entrance-hole diameter accuracy, whereas feed rate was the least significant factor. Notably, the 300 μm drills tended to oversize the entry hole (overcutting) and produce more severe exit delamination, whereas the 500 μm drills often produced slightly undersized holes and reduced dimensional fidelity (greater taper and roundness error) due to thermal expansion of the composite matrix. Regression models for delamination and entry-hole diameter showed R^2 values up to 0.96, indicating strong predictive capability. These detailed findings demonstrate how advanced micro-machining characterization of ALCARL can guide drill tool design and machining strategies to control deformation in FMLs. By identifying dominant parameters and developing predictive models, manufacturers can optimize drilling conditions and implement predictive maintenance of cutting tools. Such optimized strategies will mitigate drilling-induced damage and improve the geometric accuracy and structural reliability of fastened joints in aerospace components.

Keywords: *Micro Drilling; Hole accuracy; Delamination; Carbon Composites, Fibre Metal Laminates; Aerospace materials, Hole accuracy*

Rotary Friction Welding of Electron Beam Melted Ti-6Al-4V

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Abstract

Among the various additive manufacturing (AM) processes, powder-bed fusion techniques like electron beam melting (EBM) have been extensively employed to fabricate geometrically complex metallic components for critical applications. However, limitations in build size and the need for assembling multiple parts necessitate reliable joining of AM-processed materials. In the present work an attempt has been made to rotary friction weld (FRW) of EBM-fabricated α - β titanium alloy Ti-6Al-4V. FRW experiments were conducted on as-built cylindrical bars (12 mm diameter) using varying process parameters (rotation speed, friction pressure, upset pressure and burn off length). Comprehensive microstructural characterization, microhardness, and tensile tests were carried on optimized FRW joints. The as-built EBM Ti-6Al-4V base material showed columnar β phase microstructure while the weld zone showed Widmanstatten microstructure in the friction weld zone. Room temperature tensile strength of FRW joints showed higher strength than as built samples. Tensile fracture occurred at base material. The weld zone also exhibited higher microhardness than the as-built EBM Ti-6Al-4V base material, could be due to fine Widmanstatten microstructure in the weld zone.

Keywords: Additive manufacturing, Electron beam melting, Ti-6Al-4V, Rotary friction welding, Microstructure analysis, Mechanical properties.

Numerical Modelling of Dissimilar μ -Friction Stir Lap Welding of Aluminium and Copper using CEL approach

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Abstract

Friction Stir Welding (FSW) is a solid-state joining process that extends to a wide range of applications in the fields of aerospace, automotive, and marine environments. The ability of this process to join dissimilar materials is particularly advantageous in today's industrial landscape, as there are only a limited number of alternative techniques available, such as diffusion bonding, brazing, and soldering. The material combinations that can be welded include aluminium to copper, aluminium to steel, aluminium to magnesium, magnesium to steel, etc. Numerical modelling of these processes is challenging, as the underlying physics involves complex thermomechanical phenomena. The present study focuses on numerical modelling of the micro friction stir lap welding of Al and Cu to study the peak temperature and temperature distribution during the process. The modelling approach followed is a Coupled Eulerian-Lagrangian (CEL) method, which is normally used in high deformation processes. Here the workpiece is modelled as a Eulerian body and the tool as a rigid Lagrangian body. Johnson-Cook constitutive law has been used to model the viscoplastic behaviour of the workpiece materials. The results show that the peak temperatures are well within the melting temperatures of both materials and in the range of recrystallization temperatures. These results will be validated with experimental data to develop a robust empirical model.

Keywords: Dissimilar materials, Lap welding, Micro FSW, CEL modelling, Peak temperature, Temperature distribution.

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Development of A Support Vector Regression Model for Estimating the Friction Coefficient of Brake Blocks Used in Trains

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Abstract

Estimation of coefficient of friction between the wheel and brake block is essential for the development of Longitudinal Train Dynamics (LTD) model of a train which helps to determine the heat generation during braking as well as prediction of braking distance. Several mathematical models for the coefficient of friction were reported in the literature which considers the coefficient of friction as a function of instantaneous speed, sliding distance, initial velocity, brake load and type of brake block. In the current paper, a Support Vector Regression (SVR) model is proposed by considering the coefficient of friction as a function of initial speed, brake load and instantaneous speed. The model is developed from the experimental details of cast-iron brake blocks used in Indian railways. The results of locomotive braking distance prediction were compared against actual field data of locomotive braking distance. It is found that the LTD model utilizing SVR model predicted the braking distance with an error of 4.2%.

Keywords: coefficient of friction; cast-iron brake blocks; braking distance; Support Vector Regression; Longitudinal Train Dynamics.

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Characterization of Solid-State Layer Deposition using AA2219 alloy by Friction based Advanced Manufacturing Technique

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Abstract

The demand for defect-free, high-performance aluminum components in aerospace applications has propelled the development of Solid-State Additive Manufacturing (SSAM) technique. SSAM of AA2219 alloy using a friction-based advanced manufacturing technique, specifically Additive Friction Stir Deposition (AFSD). AA2219, a precipitation hardenable, Al–Cu alloy, is widely used in aerospace due to its high strength-to-weight ratio, excellent weldability, and superior performance at cryogenic temperatures. Unlike conventional fusion-based processes, this method utilizes localized frictional heat and severe plastic deformation to achieve interlayer bonding, minimizing thermal degradation and residual stress accumulation. A systematic parametric study was conducted to optimize key process variables, including tool rotational speed, axial force, travel speed, and tool tilt angle. Two deposition modes, displacement-controlled and force-controlled were explored to evaluate process stability and layer integrity under different operational conditions. Post-deposition, specimens were extracted along three orthogonal planes (X, Y, and Z) to assess anisotropy in microstructure and mechanical behavior resulting from material flow and thermal gradients.

The deposited samples were subjected to a two-step heat treatment comprising solution treatment at 535 °C followed by artificial ageing at 191 °C, aimed at enhancing mechanical properties through precipitation hardening. This process also facilitated the assessment of material stability and microstructural evolution under elevated temperature conditions, supported by in-situ characterization. Comprehensive microstructural analysis was conducted using optical microscopy, scanning electron microscopy (SEM), and electron backscatter diffraction (EBSD) to investigate grain refinement, phase distribution, and texture evolution. Mechanical performance was evaluated through Vickers microhardness testing and uniaxial tensile tests performed along all three principal directions. Results indicate that process parameter optimization 1200rpm, 240mm/min significantly influences layer quality, while heat treatment improves mechanical performance without compromising structural integrity. The study demonstrates the viability of friction-based solid-state deposition for fabricating dense, anisotropy-aware components and provides a foundation for its adaptation in critical applications across aerospace, automotive, and defense sectors.

Keywords: Additive Friction Stir Deposition, AA2219, SEM, EBSD, Phase distribution, Texture, Microhardness, Tensile tests.

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Impact of Laser Shock Peening on microstructure and cryo tensile behaviour of AA2219 Friction Stir Weld

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Abstract

The impact of Laser Shock Peening (LSP) on the microstructure and cryo tensile behaviour of AA2219 T87 friction stir weld joints is investigated in this work. The effect of LSP on the microstructure was captured using EBSD, TEM, and XRD. Irrespective of the number of layers of LSP, the grain size and area fraction are comparable, and LSP does not introduce any preferential orientation in the operated region and exhibits a random texture. TEM results indicated that dislocation pile-up and dislocation walls occurred due to a single layer of LSP. Three layers of LSP led to the movement of the dislocation walls towards each other and produced dislocation cells. Owing to the increase in the severity of plastic deformation in the six layers of LSP, the dislocation location walls come closer and form dislocation tangles. The XRD results indicate that the LSP process has increased dislocation density, and a shift in the peak also indicates an increase in the compressive stress. The LSP process led to an increase in yield strength of 7%, 10%, and 14% with single, three, and six layers, respectively, at ambient temperature. Similar increase is observed at cryogenic temperatures (77 K and 20 K), that is, 5 – 6%, 7 – 8%, and 10 – 12%, with single, three, and six layers of peening. At all investigated temperatures, LSP resulted in an increase in the yield strength. Repeated layers of LSP led to a proportional increase in the yield strength at all studied temperatures. The LSP did not significantly affect the ultimate tensile strength and elongation at any of the investigated temperatures. The results of this study are useful for increasing the structural margins and reducing the inert mass of aerospace pressure vessels.

Keywords: AA2219, Friction Stir Weld (FSW), Laser Shock Peening (LSP), Transmission Electron Microscope, X-Ray Diffraction, Tensile properties.

Solid-state Manufacturing Strategies for Aluminum Alloys: Welding to in-space applications

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Abstract

Solid-state processing and manufacturing methods are increasingly important for aluminum alloys for application in aerospace, automotive, marine, and space sectors. Recent investigations in AMP laboratory highlight potential use of friction stir processing to enhance bulk properties, dissimilar friction stir welding to achieve good aluminum–steel joining, multitrack processing to improve potential additive manufactured structures, and hybrid repair techniques to restore performance in damaged components. In addition, laser-assisted friction stir welding has also been explored to reduce the load-bearing capacity of tool and thereby making it suitable for in-space robotic applications. These approaches avoid many common limitations of fusion-based methods by promoting formation of refined microstructures, minimizing defects, and enabling improved structural and mechanical properties. Therefore, it demonstrates how solid-state manufacturing is highly sustainable for critical and emerging industries.

A Snapshot of Dr. Jayant Kumar's views on ICFP from Japan and Asia Pacific Industry Perspective

In Japan and across Asia-Pacific, friction-based manufacturing is growing fast as industries push for lighter, stronger, and more sustainable products. Japan leads in precision applications for aerospace, automotive, and e-mobility, using friction stir and linear friction welding to join advanced materials for EVs and aircraft. Emerging markets like China, India, and ASEAN are investing in friction-based additive manufacturing to produce high-performance parts locally. Strong partnerships between industry, research labs, and universities are driving eco-friendly solutions and enabling the joining of materials that are hard to weld with traditional methods. With automation and AI improving quality and efficiency, the region is set for steady growth — and Japan is at the centre, sharing technology and expertise across borders.

Poster Presentations + Flash Talks
(ORAL)

Electrochemical Corrosion Analysis of Aluminum 6061 deposited on Steel Substrate using Friction Surfacing

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Abstract

Friction Surfacing (FS) is an advanced technique of surface modification by depositing similar or dissimilar material. FS is a thermo-mechanical solid-state deposition technique where a high-speed rotating tool generates frictional heat and deposits the material in plasticizing state. The improved mechanical and wear performance is achieved by grain refinement caused by dynamic recrystallization. A lower heat generation, lower distortion and residual stress, and a higher rate of deposition makes the process superior over the conventional deposition process like laser cladding, plasma arc deposition, and electro-deposition. Deposition of aluminum alloys on steel can be utilized to improve the thermal heat distribution and improve wear and corrosion resistance of the automobile components. In this study, Al6061 is deposited on cold rolled low carbon steel (steel) using FS method. The aim of this study is to improve the corrosion resistance of steel by depositing Al6061 on the surface. The corrosion behavior of deposited Al6061 is evaluated in contrast to substrate and consumable rod using Electrochemical Impedance Spectroscopy (EIS), Potentiodynamic Polarization (PDP), and Cyclic Polarization (CP) techniques. The microstructural studies are performed using Optical Microscopy (OM), Scanning Electron Microscopy (SEM), and Electron Backscatter Diffraction (EBSD) techniques to correlate the effect of grain refinement on the corrosion resistance. The post-corrosion SEM analysis is also conducted to observe the pitting morphology after PDP. The study shows that the deposition using FS significantly improves the corrosion resistance of steel.

keywords: Friction surfacing, surface modification, aluminum alloys, corrosion, pitting behavior, EBSD, EIS.

Development of the Heat Transfer and Material Flow Model for the Friction Stir Deposition of Dissimilar Alloys

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Abstract

Friction Stir Deposition (FSD), also known as friction surfacing, employs a consumable rotating tool to deposit material by generating heat through friction and plastic deformation. FSD has potential applications in surface coatings to improve its surface properties such as corrosion and wear resistance, strength and high temperature stability. Numerical modeling plays a crucial role in optimizing process parameters and understanding the physics of the process, reducing the reliance on extensive experimental trials. The present study focusses on the development of a finite-volume-based heat transfer and material flow model for depositing a dissimilar alloy of aluminium on steel substrate. This quasi-steady state moving heat source model incorporates temperature-dependent thermo-mechanical properties of the material, tool, and substrate. The model is capable of predicting the heat generation, temperature distribution, thermal cycle and material flow during the process. The thermal cycle and peak temperature is validated with the experimental study. It is observed that the predicted thermal cycle and peak temperatures shows good agreement with the experiments. The effect of process parameters on the model and experimental results are also analysed in this study.

Keywords: Friction stir deposition, Finite Volume Method, Heat Transfer and Material Flow Model, Aluminium Alloy, Steel, Additive Manufacturing, Surface Coatings.

Influence of Tool Pin Profile and Reinforcement Particles on the Corrosion Characteristics of Friction Stir Welded AA5052

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Abstract

In this study, friction stir welding (FSW) of AA5052 was carried out both with and without Boron Carbide (B4C) reinforcement particles. Three different tool pin profiles—Threaded, Tapered, and Hexagonal—were used in the welding process. The influence of reinforcement particles on the corrosion properties of the welded samples was analyzed. Vickers hardness tests were performed to assess the microhardness. Immersion testing, potentiodynamic polarization, and electrochemical impedance spectroscopy (EIS) were conducted to evaluate the corrosion properties. The different tool geometries influenced the stirring and mixing actions during welding, affecting the material properties. Additionally, the reinforcement particles modified the microstructure and properties of the welded zones. Fine grains were observed in the welded zone compared to the base metal, which exhibited coarse, elongated grains due to plastic deformation and dynamic recrystallization. The hardness in the stirred zone was significantly higher in samples with reinforcement particles, showing an increase of up to 53.65% in the highest hardness values. This was due to grain refinement and particle strengthening at the nugget zone resulting from the addition of reinforcement particles. The weight-loss method was employed for immersion testing, and the corrosion current density and voltage were measured through electrochemical corrosion analysis. The threaded pin samples welded using reinforcement particles had a corrosion current value of 7.45×10^{-8} A, while the base metal had a current value of 6.02×10^{-7} A. The lower corrosion rate of the welded samples with reinforcement particles was due to the formation of a protective oxide layer that enhanced the passivation and protected the sample from corrosion.

Keywords: Friction Stir Welding, AA5052, Reinforcement particles, Microstructure, Microhardness, Corrosion Analysis.

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Influence of FSW Tool Pin Profiles on Fatigue Life: A Computational and Experimental Approach Considering Residual Stress

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Abstract

The pin geometry in Friction Stir Welding (FSW) significantly influences weld joint integrity by affecting residual stress distribution and fatigue performance. This study presents a comparative analysis of different pin profiles to minimize residual stresses and enhance the fatigue life of welded joints. The workpiece material is marine-grade AA5052 aluminum alloy, while the welding tool is fabricated from H13 tool steel. Three distinct pin geometries such as tapered, threaded, and hexagonal are selected for evaluation, with welding simulations conducted under constant process parameters: an axial force of 4 kN, a tool rotational speed of 800 rpm, and a traverse speed of 1 mm/s. A coupled thermo-mechanical finite element model (FEM) is employed to predict the residual stress distribution for each pin profile, with numerical results validated through experimental X-ray diffraction (XRD) measurements. The analysis reveals that the threaded pin profile promotes a more uniform residual stress distribution along the weld zone, contributing to improved joint integrity. Furthermore, fatigue life assessment indicates superior performance of the threaded pin compared to the tapered and hexagonal profiles, attributed to the reduction of localized tensile stresses in the weld zone. These findings demonstrate that the threaded pin geometry is more effective in minimizing residual stress concentrations and enhancing fatigue resistance in the FSW of AA5052 aluminum alloy. Future research can extend this approach to optimize additional welding parameters for further improvement in joint performance and durability.

Keywords: Friction Stir Welding, AA5052, Residual Stress, Fatigue, Finite Element Modeling, XRD

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A Review of Developments in Portable Friction Stir Welding (FSW) Equipment for Onsite Applications

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Abstract

This paper provides a comprehensive review of advancements in portable Friction Stir Welding (FSW) equipment, emphasizing key developments and challenges in designing compact, field-deployable systems. FSW, a solid-state joining process, has gained significant attention as an alternative to fusion welding, particularly for aluminum alloys used in automotive, marine, and aerospace applications. While conventional FSW machines offer excellent weld quality, their bulky and stationary nature limits their applicability in onsite and remote environments. Developing portable FSW systems presents several engineering challenges, including reducing machine size and weight while ensuring precise control over process parameters such as axial force, rotational speed, and traverse speed. One of the primary constraints in miniaturizing FSW equipment is the high axial force required for tool penetration and material flow. To address this, strategies such as increasing spindle rotational speed and preheating the workpiece have been explored. A higher spindle speed enhances frictional heating, softening the material and reducing resistance to plastic deformation, thereby lowering axial force requirements. Similarly, preheating reduces the workpiece's yield strength, facilitating smoother material flow and decreasing traverse force. Additionally, fixing portable FSW machines in various onsite surfaces remains a challenge, and currently most of the existing systems rely on technologies such as heavy-duty vacuum pads for their onsite fixation. Further research is needed to develop adaptive, lightweight attachment mechanisms that enhance mobility and usability. This review systematically explores the advancements made in portable FSW machines, highlighting key technological developments, design optimizations, and challenges that have shaped their evolution for onsite applications.

Keywords: FSW, Portable FSW Machine, Onsite FSW, Aluminium Alloys, Process Parameters

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Experimental Investigation and Analysis of Friction Stir Welding of Al 65032 Plates Using a Butt Joint Configuration

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Abstract

Friction stir welding (FSW) is an advanced solid-state welding technique widely used for joining aluminum alloys due to its superior mechanical properties and minimal defects. This study investigates the friction stir welding of Al 65032 plates using a butt joint configuration. The objective is to analyze the effect of process parameters on weld quality, microstructural characteristics, and mechanical properties. Experiments were conducted by varying tool rotational speed and welding speed to assess their influence on tensile strength and hardness. The results indicate that optimized parameters lead to improved weld strength and microstructural refinement. This study provides valuable insights into enhancing the efficiency and reliability of FSW for industrial applications.

Keywords: Friction stir welding, Al 65032, butt joint, process parameters, mechanical properties, and microstructure

Evaluation of spray deposited water based friction modifiers for altering friction and wear at rail-wheel interface

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Abstract

Friction at the rail-wheel interface, particularly on turns, affects rail-wheel wear, derailment ratio, contact noise, rolling contact fatigue, etc. Friction modifiers help manage friction at the rail-wheel interface. Therefore, a laboratory-based analysis of the friction modifier behavior is important. In this work, the effects of water-based friction modifiers are studied using a ball-on-disk setup and optical microscopy. The results show that talc and zinc peroxide increase the friction coefficient, while solid lubricants decrease friction at the interface. The binding agent bentonite maintains a moderate and stable friction coefficient of approximately 0.38. Zinc peroxide has nanoscale features and enhances friction by entering the contact zone. Talc provides slightly lower friction compared to zinc peroxide because of its stickiness. The lamellar structure of graphite and the stickiness of molybdenum disulfide (molyka) result in low, stable friction coefficients.

Keywords: Friction modifier, ball-on-disk experiment, wear test, wear, surface engineering, optical microscopy

The effect of reheating during layer-wise addition in friction stir additive manufacturing (FSAM) of AA2024 on microstructure and mechanical properties

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Abstract

Friction stir additive manufacturing (FSAM) is an efficient solid-state approach to manufacturing high-strength aluminium builds without solidification defects. During the FSAM process, the phenomenon of reheating needs further attention as it might affect the microstructure and the resulting mechanical performance of the build. In this study, the effect of reheating during layer-wise addition in FSAM of AA2024 was studied. Four layers were added in this study and after the addition of each layer, a sample was cut from the build for microstructural analysis to investigate the reheating effects on the build. Fine grain microstructures were observed in the build with average grain size decreasing from the bottom (4.4 μm) to the top (3.8 μm). The EBSD analysis revealed that with each reheating cycle, the fraction of high-angle grain boundaries (HAGBs) and recrystallized grains were reduced, implying the possibility of annealing/static recrystallization in the lower layers. Precipitate dissolution of coarsening was noticed in SEM images at the lower layers. The hardness value was around 130-160 Hv in a freshly processed layer, and with each reheating cycle, the hardness decreased by 20-40 Hv in that layer. The tensile sample taken in the weld direction achieved an ultimate tensile strength of 370 MPa (77% build efficiency) with a 50% improvement in elongation. The sliced tensile sample from the top of the build had higher tensile strength (400 MPa), whereas the sliced tensile sample from the bottom had better elongation with reduced strength (350 Mpa).

Keywords: Friction stir additive manufacturing, reheating effects, Microstructure, Precipitate, Mechanical properties, aluminium alloy, AA2024

Characterization of the wire produced from aluminium scrap through friction stir extrusion process

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Abstract

The ever increasing demand for customized and light in weight products had urged the manufacturing industries to produce tailor made components through numerous manufacturing routes. Among the various manufacturing methods, subtractive machining technique are employed to make tailor made components. In subtractive machining, the net shape of a component is achieved by the removal of extra materials from raw stock in the form of machining chips (MC). Under the family of light in weight materials, aluminium alloys are exclusively used in combat vehicles owed to their reduced weight for improved vehicle mobility, high strength to weight ratio, superior corrosion resistance and meeting the ballistic requirements. The recycling of aluminium MCs is a pressing issue as it directly reduces the carbon foot print and greenhouse gas emission. Solid state recycling can be adopted as an alternate to conventional recycling methods. A hybrid forming technique namely friction stir extrusion which combines friction stir compaction and direct extrusion can be employed to recycle the MC. Friction Stir Extrusion is a solid-state manufacturing process that combines frictional heating and plastic deformation to extrude materials. A rotating tool generates heat through friction, softening the material without melting it. The softened material is forced through a die, resulting in the formation of a continuous extruded product. A novel die setup is developed using P20 steel. A schematic representation of the tool-die setup is presented in

Figure 1. The tool rotational speed is identified as input variable. The impact of the input variable on the quality of the extruded wire is assessed using scanning electron microscope images, energy dispersive spectroscopic profiles and X-ray diffraction analysis.

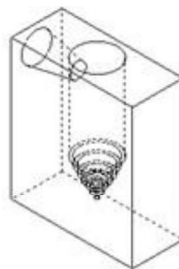


Figure 1. Schematic representation of tool-die developed for FSE process

Keywords: Friction stir extrusion, Solid-state processing, aluminium scrap and recycling.

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A Review on the Effect of Multi-Pass Friction Stir Welding (Fsw)

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Abstract

Friction Stir Welding (FSW) is a solid-state joining process particularly effective for high-strength aluminum alloys. It produces defect-free welds with superior mechanical properties. Multi-pass FSW enhances weld quality, mechanical performance, and microstructure refinement. For example, it has been shown to improve tensile strength and fatigue resistance by promoting uniform grain structure and reducing weld defects. Applying multiple passes reduces defects, refines grains, and increases joint strength. However, it also introduces complexities such as residual stress buildup, heat accumulation, and hardness variations, affecting weld integrity.

This review examines the effects of multi-pass FSW on microstructural evolution, mechanical properties, and defect formation. Key process parameters such as pass sequence, overlap ratio, and heat input are analyzed for their impact on final weld characteristics. Recent advancements in multi-pass FSW, particularly in aerospace, automotive, and marine industries, are highlighted. The challenges and benefits of multi-pass techniques are explored with a focus on optimizing process parameters. Strategies for mitigating residual stresses, heat accumulation, and hardness variation are also discussed, including optimized pass sequencing, to enhance weld integrity and longevity.

By consolidating recent research, this review provides insights into optimizing multi-pass FSW and explores future research directions. These efforts contribute to the broader adoption and industrial application of this advanced welding approach.

Experimental and Statistical Analysis of Friction Stir Processing Parameters for Improved Microstructure and Mechanical Properties of Aluminum alloy

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Abstract

Friction Stir Processing (FSP) is a solid-state technique used to refine the microstructure and enhance the mechanical properties of materials, especially aluminum alloys. By employing a non-consumable tool to generate frictional heat, FSP facilitates plastic deformation and dynamic recrystallization of the material, resulting in improved grain refinement and mechanical performance. This study aims to optimize FSP parameters to enhance the microstructure and mechanical properties of in-house prepared aluminum plates through an experimental approach. The research investigates the effects of key processing parameters, including rotational speed, traverse speed, and dwell time, on the microstructural characteristics and mechanical behavior of aluminum plates. An extensive experimental analysis was conducted to determine the optimal parameter combinations that maximize grain refinement, hardness, and tensile strength. The results demonstrate a significant correlation between optimized FSP parameters and the improved performance of the aluminum plates. Microstructural evaluations, performed using optical and scanning electron microscopy, revealed a uniform distribution of fine grains, which substantially contribute to enhanced mechanical properties. This study highlights the effectiveness of an experimental approach in optimizing FSP parameters, providing a solid foundation for achieving superior material performance. The findings have important implications for various industries, such as aerospace, automotive, and marine, where aluminum alloys are essential. Current studies contribute to the development of lightweight, high-strength materials for challenging modern engineering by advancing Friction Stir Processing (FSP) capabilities.

Keywords: Friction Stir Processing, aluminum alloys, microstructure, mechanical properties, optimization, experimental approach.

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Hybrid Physics-based Machine Learning Framework for Friction Stir Welding: Predicting UTS in AISI 321–Al 65032 Welds

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Abstract

Friction Stir Welding (FSW) is a solid-state joining method that produces high-strength welds with few defects. Nevertheless, accurately predicting the ultimate tensile strength (UTS) is still a challenge, particularly with dissimilar joints such as stainless steel (AISI 321) and aluminum alloys (Al 65032). Traditional physics-based models often fail in predicting physical phenomena of increased thermo-mechanical complexity, while fully data-driven approaches struggle with the scarcity of experimental data. This research work proposes a hybrid framework that combines physics-based modeling and machine learning (ML) corrections, allowing for enhanced predictions of UTS in FSW to cater the above gap. In order to develop a physics-based reference, linear regression model based on critical process parameters—peak temperature (T_{max}), tool rotation speed (TRS), welding speed (WS), and offset has been utilised. The residual errors between measured and predicted UTS are modeled with multiple machine learning (ML) algorithms including: AdaBoost, Random Forest, and Extra Trees, and values were evaluated with Leave-One-Out Cross-Validation. The best performing of each algorithm were Random Forest for similar welds and Extra Trees for dissimilar welds. The final hybrid model, which utilized physics and ML residuals was retrained on the full database, produced a mean absolute error of 3.19 MPa at an R² of 90%. Furthermore, SHAP (SHapley Additive exPlanations) analysis revealed that T_{max} and TRS have the greatest impact on UTS. These findings were supported by microstructural characterization using scanning electron microscope (SEM) revealed refined microstructures and minimal defects and X-ray diffraction (XRD) confirmed phase stability in the weld zone.

Keywords: Friction Stir Welding, Dissimilar welding, Hybrid Modeling, Physics-Based Modeling, Machine Learning, Microstructural Characterization.

Complementary Role of Solid Lubricants in Sintered Copper-Based Brake Composite Friction Material

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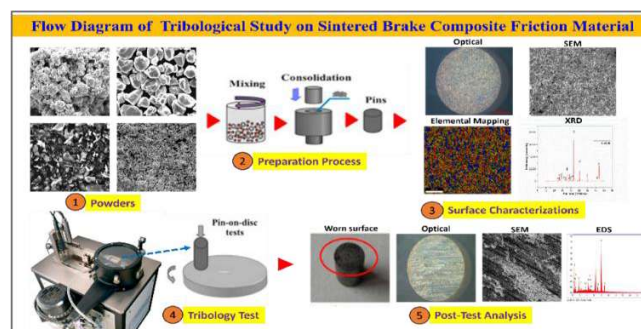
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Abstract

The brake pad friction materials contain binders, reinforcing fibres, fillers, solid lubricants, abrasives, etc. Despite many components in brake pad materials, solid lubricants play an essential role in enhancing their tribological properties, particularly frictional behavior and wear in automotive brake systems [1]. Among several metallic binders and ceramic particles, the copper (Cu) and silicon carbide combination offers strong wear resistance, high toughness, high thermal conductivity, and low thermal expansion. Additionally, combining SiC with Cu material in the composite is more compatible. This study aims to investigate the complementary role of solid lubricants, namely graphite (Gr), molybdenum disulphide (MoS₂), and antimony trisulphide (Sb₂S₃) in Cu/SiC hybrid brake composite friction materials. For this study, an experimental investigation is carried out to examine the tribological behavior of sintered copper-based brake composite friction materials containing different volume ratios of various types of solid lubricants. The composite test samples are prepared using conventional powder metallurgy techniques and undergo microstructure analysis and material characterization. The experiments use a fully instrumented pin-on-disc (PoD) test rig with linear variable differential transducer (LVDT) for wear and strain gauge for friction measurement under dry conditions for medium-duty automotive applications. In post-test analysis, the morphology of worn-out surfaces, wear mechanisms, and compositions of brake friction materials are examined using a field emission scanning electron microscope (FESEM) with energy dispersive x-ray spectroscopy (EDS).

Keywords: Automotive; Brake; Composite; Copper; Friction; Sintering; Solid lubricants; Wear



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Development of High Pressure Compressive Reverse Shearing, a new severe plastic deformation process

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Abstract

Materials are processed for their application primarily by deformation. The choice of using a particular processing technology is driven by the mechanical properties of the processed material. Imparting large strains into metal is known to improve the mechanical properties, especially the strength of the material. The strength of metal, in general, is governed by grain size. In this work, a new Severe Plastic Deformation (SPD) process has been developed to impart a large shear and a small compressive strain into the material, in a single-step operation. Commercially Pure (CP) aluminum cuboidal shape billets were subjected to 84% reduction in thickness. The processing was carried out by varying the operating parameters for the same thickness reduction, for several samples, to tailor the mechanical properties of the materials. From the obtained results, the effect of the variation in processing parameters on the properties of the material can be easily examined. The mechanics of the process is established and the von Mises equivalent strain has been calculated which is in the SPD range. Microstructural investigations show enormous stretching of the grains and the formation of sub-grains. The frequent change of strain path with the deformation leads to the fragmentation of the grains heavily to reach the steady state regime of grain size, 1 micron. A threefold increase in the strength of the material has been observed with a strong shear texture.

Keywords: Severe Plastic Deformation (SPD) process; Crystallographic Texture; von Mises equivalent strain; Processing-Controlled Properties (PCP); Commercially Pure Aluminum.

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Enhancement of mechanical properties of AZ31 magnesium alloy through friction stir processing

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Abstract

Melting based manufacturing process such as additive manufacturing process generally develop porosity and cracks in the processed part, resulting in part failure due to crack initiation and propagation upon load application. To overcome the issue, a solid state manufacturing process, known as friction stir processing (FSP), can be employed as it processes the material below its melting temperature. Magnesium (Mg) is the lightest metal, 36% lighter than aluminum and 352% lighter than steel. Integrating Mg with FSP enhances Mg alloys by refining grains, improving homogenization, and thereby increasing strength, making them suitable for applications like automotive, aerospace, and biomedical implants. In the current study, FSP of AZ31 Mg alloy with process optimization is presented. The friction stir processed (FSPed) material is further investigated for microstructure and tensile properties. Key findings of the study are refinement in the microstructure and improvement in the mechanical properties. The FSP boosted the tensile strength of the wrought Mg alloy from 195 MPa to 230 MPa. A significant improvement of 17.95% in the tensile strength of the Mg alloy is observed due to grain refinement.

Keywords: Friction stir processing; Mg alloys; Microstructure; Mechanical properties; Dynamic transformation; Grain refinement.

Exploring Sustainable Aluminum Sheet Scrap Recycling via Friction Stir Welding A Feasibility Study Toward a Circular Economy

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Abstract

Climate change has intensified the need for industries to reduce their environmental impact, encouraging the aluminium sector to adopt more sustainable practices focused on waste reduction and resource efficiency [1]. Although recycling aluminium is far more energy-efficient than primary production, conventional methods such as melting and rolling are still energy-intensive, labour-demanding, and generate considerable greenhouse gas emissions, which limit their environmental advantages. This study explores a novel, low-impact recycling approach aimed at minimizing the environmental drawbacks associated with traditional methods. Specifically, it proposes the use of Friction Stir Welding (FSW) to join aluminium alloy scrap sheets as a sustainable alternative that eliminates the need for high-temperature melting. The viability of this technique was assessed by evaluating the mechanical and formability characteristics of the refabricated sheets using Single-Point Incremental Forming (SPIF), a process that allows flexible shaping of metal sheets with minimal tooling [2]. The experimental results indicate that the FSW-joined scrap sheets exhibited favourable mechanical properties, achieving a weld strength of approximately 250 MPa. Furthermore, the formability tests revealed that the FSW-refabricated sheets attained forming heights comparable to those of sheets produced through conventional rolling, thereby validating the structural integrity and applicability of the proposed method. Overall, the findings demonstrate the potential of the FSW-based approach as an environmentally friendly and energy-efficient alternative for recycling aluminium sheet scrap. This method offers a viable pathway toward the production of lightweight components with zero emissions, contributing to a more sustainable and circular aluminium manufacturing ecosystem.

Keywords: Sustainable Manufacturing, Recycling, FSW, ISF, Material Characterization.

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Wear and surface characteristics of additively manufactured and naturally aged blocks of SS-316

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Abstract

Additive manufacturing (AM) is revolutionizing material fabrication, offering complex geometries and tailored properties. However, its tribological performance compared to Conventionally Manufactured (CM) materials remains an area of active research. This study investigates the wear and friction behaviour of additively manufactured SS316 steel samples under varying normal loads using a reciprocating ball-on-flat method. The results were compared with the CM materials. Reciprocating tribological tests were conducted at a frequency of 5.0 Hz, with applied under variable loads. The coefficient of friction (COF), wear depth, and wear volume loss were measured at each load condition. Surface characterization of both AM and CM samples was performed using 2D and 3D wear topography analyses to assess wear mechanisms. Additionally, scanning electron microscopy (SEM) was employed to examine the wear surfaces, including backscattered electron (BSE) imaging, energy-dispersive spectroscopy (EDS), and color mapping to analyze material transfer and subsurface deformation. Wear debris morphology was also studied under varying loads to elucidate dominant wear mechanisms. The results indicate distinct differences in wear resistance and frictional response between AM and CM samples, influenced by their microstructural characteristics and surface properties. AM samples show a notable reduction in wear volume loss compared to CM, which can be due to improved resistance to abrasion and delamination. The AM sample had molten pools, pores and fine grains in the microstructure, unlike the CM samples. These pores and fine grains affect the friction and wear differently; consequently, both factors are considered together in this study. The findings provide insights into optimizing AM materials for tribological applications, particularly in high-load environments. This study contributes to the growing understanding of the potential of AM in wear-critical applications and offers a basis for further research into process optimization for improved durability.

Keywords: Additive manufacturing; Stainless steel 316; Tribological properties; Coefficient of friction; Wear depth; Wear volume loss

Microstructure, tensile, and wear properties evaluation of friction stir processed CNT-reinforced SLM fabricated AlSi10Mg

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Abstract

Additive manufacturing has opened new avenues for fabricating complex and lightweight metallic components, with AlSi10Mg emerging as a promising aluminum alloy due to its excellent strength-to-weight ratio and corrosion resistance. However, the as-built microstructure of Selective Laser Melting (SLM)-processed AlSi10Mg often suffers from residual porosity and suboptimal mechanical properties. This study investigates the combined effects of Friction Stir Processing (FSP) and carbon nanotube (CNT) reinforcement on the microstructure, tensile behavior, and wears resistance of SLM-fabricated AlSi10Mg. CNTs, renowned for their exceptional mechanical and thermal properties, were incorporated into the alloy matrix via a controlled groove-filling and FSP approach, ensuring uniform dispersion and enhanced interfacial bonding. Microstructural analyses using optical microscopy, scanning electron microscopy (SEM), and electron backscatter diffraction (EBSD) revealed significant grain refinement, improved homogeneity, and effective CNT distribution within the stir zone. The FSP-treated region exhibited complete porosity elimination and dissolution of the eutectic Si network, contributing to enhanced matrix integrity. Tensile testing demonstrated substantial improvements in yield strength, ultimate tensile strength, and ductility, primarily attributed to grain boundary strengthening, load transfer from the CNTs, and Orowan strengthening mechanisms. Additionally, dry sliding wear tests showed a significant reduction in wear rate and friction coefficient, underscoring the positive influence of CNTs on surface durability and resistance to material loss.

Keywords: Additive manufacturing, AlSi10Mg, Selective Laser Melting (SLM), Friction Stir Processing (FSP), Carbon Nanotube (CNT), Grain refinement, microstructure, tensile strength and wear.

Fatigue crack growth rate behaviour of friction stir welded AA6061-T651 aluminium alloys and base metal: A comparison

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Abstract

This work presents a comparative study of fatigue crack growth rate (FCGR) behaviour of AA 6061-T651 friction stir welds and base material. Compact tension (CT) specimens of base material and the friction stir welded (FSW) joints were employed to evaluate fatigue crack growth rate (FCGR) at stress ratios $R = 0.1$ and a frequency of 11 Hz. A series of tests was conducted, which included microstructural examination (optical and transmission electron microscope), tensile testing, hardness measurement, and fatigue crack growth rate testing, along with fractography analysis. The findings of this study indicated that the fatigue crack growth rate (da/dN) for base metal was comparatively lower than that of friction stir AA 6061-T651 welds. The better fatigue crack growth performance of base metal was associated with a lower fatigue crack growth exponent, demonstrating increased resistance to the developing fatigue cracks. Nevertheless, the fatigue characteristics of friction-stir AA 6061-T651 welds were inferior to those of the base metal. This may be linked to metallurgical alterations and the development of residual stress in the welds during the welding process.

Keywords: FSW, Fatigue crack growth behaviour. Tensile properties, Microhardness, Fractography.

Performance of Steel-Aluminum Hybrid Structures Fabricated via Friction Stir Surfacing (FSS)

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Abstract

Friction stir surfacing (FSS) is an emerging technology in solid-state additive manufacturing technique, with the ability of layer-by-layer deposition, eliminating solidification challenges to fabricate potential structural components. This paper presents the study of the mechanical and metallurgical behaviour of mild steel-aluminum alloy (AA6082-T651) hybrid system fabricated via FSS. Mechanical evaluations involve anisotropic tensile testing and hardness measurements along the perpendicular direction of the deposition to assess interfacial integrity and strength heterogeneity. A microstructural study was carried out to confirm the efficient diffusion bonding between steel and aluminum. This defect free hybrid structure of steel and aluminum was successful in improving the tensile property by 25% compared to aluminum alloy and 33% reduction in weight relative to equivalent steel structures. This lightweight, high strength hybrid structure holds significant potential for defense, aerospace, and automotive applications, where energy efficiency and structural performance are critical.

Keywords: Friction stir surfacing (FSS), Defect-free deposition, Anisotropic property, Mechanical properties, Microstructure.

Yield Locus Characterization of FSW AA2219-T87 Using Modified Cruciform Specimens: Comparison with TIG Welds and Base Material

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Abstract

Aluminum alloys, particularly AA2219-T87, are widely used in aerospace structures due to their high strength-to-weight ratio, excellent weldability, and superior cryogenic performance. As welding plays a critical role in the fabrication of such components, it is essential to understand how different welding processes influence the alloy's mechanical behaviour under complex loading conditions. Traditional uniaxial testing provides limited insight into real-world applications where components are often subjected to multiaxial stresses. In this context, planar biaxial testing offers a more comprehensive evaluation of welded joint performance.

This study investigates the yield behaviour of AA2219-T87 alloy under uniaxial and planar biaxial loading conditions for friction stir welded (FSW), tungsten inert gas (TIG) welded, and base material samples. A modified cruciform specimen design was employed to ensure complete inclusion of the weld zone within the gauge area. Biaxial tensile tests were conducted at seven distinct load ratios covering the tensile quadrant of the stress space. The yield loci constructed from these tests reveal a significant reduction in the safe deformation zone for welded samples, particularly under plane strain loading. The FSW samples demonstrated superior performance compared to TIG-welded specimens, with yield loci lying intermediate between the base material and TIG welds.

The degradation in mechanical response is attributed to microstructural alterations caused by welding, such as grain refinement, residual stresses, and orientation changes. Ongoing fractography and SEM analyses aim to elucidate the underlying damage mechanisms, while EBSD investigations provide insights into intragranular misorientation and its contribution to deformation behaviour. These findings highlight the advantage of FSW over TIG welding in preserving mechanical integrity under multiaxial stress states.

Keywords: AA2219, FSW, TIG Welding, Cruciform Sample, Yield locus development, Planar Biaxial Testing, Microstructure evolution

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Machine Learning-Based Prediction and Optimization of Friction Stir Processing in casted Aluminum Plates

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Abstract

The advancement of material processing techniques has increasingly relied on intelligent tools to enhance efficiency and performance. This study presents a machine learning (ML)-driven framework for predicting and optimizing the key process parameters in Friction Stir Processing (FSP) of aluminum plates. FSP is a solid-state technique known to improve mechanical and microstructural properties of metallic materials. However, determining optimal process conditions such as tool rotational speed, traverse speed, and dwell time through traditional experimental methods can be time-consuming and costly, particularly when accounting for the complex interdependencies among variables. To overcome these limitations, a supervised learning approach was employed using Random Forest Regression and Artificial Neural Networks. These models were trained on experimental datasets to accurately forecast essential material responses, including tensile strength, grain refinement, and surface hardness. Furthermore, optimization was achieved through Genetic Algorithms and Bayesian Optimization, which enabled the identification of parameter sets yielding superior performance. The AI-predicted parameters were experimentally validated, showing substantial improvements in microstructure uniformity and mechanical strength when compared to baseline conditions. The integration of ML not only expedited the decision-making process but also demonstrated its capacity to generalize across varying process conditions. This hybrid modelling-optimization framework presents a powerful, scalable tool for advanced manufacturing applications, reducing dependency on trial-and-error methods. The findings underscore the potential of data-driven methodologies to significantly enhance process control in solid-state material processing.

Keywords: Friction Stir Processing, Machine Learning, Optimization, Aluminum Alloys, Artificial Intelligence

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Microstructure tailoring through shot peening for improved surface performance of WAAM-deposited mild steel

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Abstract

The grain size and morphology of the wire arc additively manufactured (WAAM) components are strongly influenced by complex thermal cycles, which also govern their mechanical and surface properties. Several studies have investigated the effect of shot peening on the mechanical properties of WAAM components, but the quantitative relationship of shot peening with the microstructure and its subsequent effect on the surface properties, such as tribological and fatigue performance, remains unexplored. The present study focused on the quantification of microstructural evolution as a function of peening intensities and its effect on surface integrity and frictional performance. WAAM-deposited mild steel was peened at various Almen intensities, and the microstructures were observed using scanning electron microscopy (SEM), electron backscatter diffraction (EBSD), and transmission electron microscopy (TEM). Additionally, models were developed to optimize intensity for the desired microstructure, and mechanical characterization, including pin-on-disc wear and low-cycle fatigue tests, was conducted on the optimized specimens. The EBSD results showed a transition from columnar to equiaxed grains at the peened surfaces, while TEM revealed increased dislocation density and refined grain size, which enhanced the wear resistance, reduced the coefficient of friction, and improved the fatigue performance of the specimens peened at the optimized intensity. This study demonstrates a novel correlation of the microstructure of WAAM components with the peening intensity and establishes a foundation for pre-emptive control over microstructure evolution through optimizing the peening intensity.

Keywords: Wire arc additive manufacturing; Shot peening; Microstructural analysis; Tribological performance; Low cycle fatigue.

Effect of Surface Roughness on Corrosion Behavior

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Abstract

Modern electric vehicles (EVs) use pulse width modulation (PWM) inverters to achieve variable speed control, which results in shaft voltage and bearing current. Among all the components of an electric motor, bearings are more susceptible to electrical failure, resulting in premature bearing failure and restricting the lifespan of the electric motor. The electric-related failure modes in bearings are classified as lubricant degradation and morphological damage. The shaft voltage leads to charge accumulation at the bearing-lubricant-ball interface, which acts as a standard capacitor system. If the voltage surpasses the dielectric strength of the lubricant, electric discharge occurs, causing lubricant degradation, including loss of viscosity, production of chemical sediments, and pitting. This results in increased vibrations and noise, accelerated wear, and decreased load-bearing capacity. As pitting progresses, it substantially influences surface morphology. When these bearing surfaces are subsequently exposed to a corrosive environment, it further exacerbates the morphological damage, resulting in decreased bearing performance. The current research focuses on developing and testing a novel design accommodating a three-electrode system to perform corrosion studies. The corrosion characteristics of AISI52100 bearing steel in fresh and degraded NLGI 3 (mineral base oil with lithium thickener) grease are investigated. The surface roughness, morphology, chemical composition, and hardness changes before and after hydrogen charging are analyzed using a profilometer, SEM-EDS, and nanoindentation.

Keywords: Electric vehicle; Surface roughness; Lubricant degradation; Morphological damage; NLGI 3; Corrosion; Pitting.

Mechanism and Control of a Strength-Boosting Wearable Device

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Abstract

This paper focuses on creating a pneumatically powered wearable system to enhance human physical strength. The exoskeleton uses lightweight pneumatic actuators, enabling high force output while maintaining user comfort and efficiency. Designed for ergonomic functionality, it aims to reduce physical strain in labor-intensive tasks such as heavy lifting in industries and mobility support in rehabilitation. The system is intended for industrial, healthcare, and defense applications, where augmenting human strength is vital. By leveraging pneumatic technology, the exoskeleton ensures cost-effectiveness, reliability, and adaptability across various environments. Special attention is given to energy efficiency and lightweight materials to optimize performance and usability. This paper represents a significant step towards practical solutions for strength augmentation in demanding settings.

Keywords: Pneumatically powered, exoskeleton, cost-effectiveness, reliability, adaptability, strength augmentation.

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Dynamic Mechanical Analysis of Acacia Nilotica Filler Blended PLA Based Bio Composite Using Bio/Medical Application

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Abstract

This study examines the effects of untreated and NaOH-treated Acacia Nilotica filler at volume percentages of 10, 20, and 30% on the dynamic mechanical behavior of PLA composites. After being pulverized in a ball mill, the filler was mixed with PLA using an ultra-sonification technique. The findings demonstrate that adding up to 20% Acacia Nilotica filler to PLA enhances the dynamic mechanical properties of the composite material. The dynamic mechanical properties decline as the filler content is increased over 30% v/v. The visco-elastic characteristics of the composite were tested using a dynamic mechanical analyzer. It was found that the damping (tan δ) factor decreased and the storage modulus increased when up to 20% Acacia Nilotica was added to the mixture.

Keywords: Dynamic Mechanical analysis, Acacia Nilotica, Storage modules, Biomedical applications.

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Optimization of friction stir welding process parameters to enhance the flexural strength in stir casted of metal matrix composites

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Abstract

The present experimental investigation is to improve the flexural strength of aluminium matrix composites (AMCs) made with AA7075 reinforced with different weight percentages (3%, 5%, 7%, and 9%) of silicon carbide (SiC) particles by optimising Friction Stir Welding (FSW) parameters. Both hexagonal and threaded hexagonal tool profiles were used to weld the composites after they were manufactured using the stir casting. The FSW process parameters were varied based on a Taguchi L16 orthogonal array i.e. tool rotational speed, traverse speed, axial force, and reinforcing percentage. The microstructural characteristics and elemental composition were examined using Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) and mechanical performance was assessed utilising flexural testing. Tool traverse speed and rotational speed had a substantial impact on flexural strength for both tool types, according to Analysis of Variance (ANOVA). At 5% SiC, 1500 rpm, 50 mm/min, and 850 N, the threaded hexagonal tool outperformed the hexagonal tool, with maximum flexural strength of 384.90 MPa. The excellent correlation between the predicted and experimental findings was confirmed by regression models developed for both tool geometries, which demonstrated great predictive accuracy with R² values is 99.6%. Under ideal welding conditions, SEM and EDS analysis showed enhanced particle dispersion and bonding, but an excessive SiC content caused voids and particle clustering. These results confirm that AA7075/SiC composites can be used for high-performance structural applications by increasing their structural integrity through process parameter optimisation.

Keywords: Aluminium alloys, Metal Matrix Composite, Friction stir welding (FSW), Optimization.

Tribo-Microstructural Evaluation of Titanium Grade 2 sheet under Polymeric and Carbon Based Nano-Solid Lubricants and its Influence on SPIF-Induced Surface Roughness for Biomedical Applications

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Abstract

Single Point Incremental Forming (SPIF) is a flexible manufacturing technique suitable for producing complex, customized components such as biomedical implants. However, forming hard to form alloys particularly, titanium alloys, presents challenges due to their poor tribological properties, leading to surface imperfections that can affect implant performance. This study evaluates the effectiveness of two solid nano-lubricants i.e., polytetrafluoroethylene (PTFE) and graphene, both with particle sizes ≤ 100 nm, in improving the tribological performance during SPIF of commercially pure Titanium Grade 2. Using a pin-on-disc apparatus, friction and wear behaviours were analysed, with tungsten carbide as the counter face material. Surface morphology and chemical composition were examined through Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS). The results indicate that PTFE achieved a lower average coefficient of friction (0.148) compared to graphene (0.155). Correspondingly, the wear rate for titanium lubricated with PTFE was significantly reduced (2.3×10^{-4} mm³/N·m) relative to graphene lubrication (3.4×10^{-4} mm³/N·m). Microscopic analyses revealed a more stable and continuous wear track in the PTFE-lubricated samples, indicating better surface protection compared to the more pronounced wear and surface damage observed with graphene.

Further evaluation of the SPIF-formed Ti Grade 2 sheet parts using Alicona optical 3D surface measurement showed that PTFE-lubricated specimens demonstrated marked improvements in surface topography, reducing average, RMS, and maximum roughness by 13.39%, 20.5%, and 24.81%, respectively. These findings highlight the superior tribological performance of PTFE as a solid nano-lubricant, enhancing the SPIF process of titanium alloys in biomedical applications.

Keywords: Nano-Lubricants, Tribological, Surface morphology, Coefficient of friction, Wear Rate, Surface Topography, Roughness.

Surface Finishing of Biodegradable Magnesium Alloy (ZE41A) using Viscoelastic Polymer Abrasive Tool: Effect of Interfacial Friction and Abrasion

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Abstract

Biodegradable magnesium (Mg) alloys such as ZE41A have garnered significant interest in biomedical implants due to their lightweight nature and biocompatibility. However, their clinical deployment is limited by the difficulty in achieving functionally smooth surface finishes that mitigate localized corrosion and promote tissue integration. This study explores the interfacial friction and abrasion-driven finishing process using a flexible abrasive tool composed of a viscoelastic polymer matrix with silicon carbide abrasives. The surface finishing occurs through controlled frictional interactions and abrasion action of the viscoelastic tool during finishing of ZE41A substrates. Key process parameters including tool penetration depth and shaft diameter were varied to optimize the surface response. Surface morphology was examined using scanning electron microscopy, and surface topography was quantified using a non-contact 3D white light interferometer. The finishing process achieved a reduction in average surface roughness from 1.97 μm to 0.48 μm . The results highlight the potential of polymer-based frictional abrasive tools for precision finishing of biodegradable Mg alloys, contributing to improved surface quality and functional performance in biomedical applications.

Keywords: *Friction-based finishing, ZE41A magnesium alloy, viscoelastic abrasive tool, surface integrity, biodegradable implants.*

Abnormal grain growth in Inconel 718 alloy fabricated by friction surfacing deposition additive manufacturing

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Abstract

The microstructure evolution of multilayer deposited Inconel 718 alloy, produced by friction surfacing deposition additive manufacturing (FSDAM) process provided important insights into abnormal grain growth (AGG) under high axial load conditions. A semi-automatic friction surfacing machine was used for continuous deposition of Inconel 718, with process parameters optimized based on preliminary single-layer deposition trials. Electron backscatter diffraction (EBSD) analysis confirmed the occurrence of discontinuous dynamic recrystallization (DDRX), which contributed to grain refinement across the layers. However, under higher axial loads, AGG was observed, characterized by the presence of coarser grains within a predominantly refined matrix. The recrystallized grains exhibited a higher average misorientation angle than the deformed grains, although the fraction of $\Sigma 3$ boundaries remained relatively constant. Additionally, microtexture analysis consistently identified the evolution of the C texture component $\{001\} \langle 110 \rangle$ across all layers. Selective grain growth mechanisms further contributed to a sharp recrystallization texture, especially at higher axial loads where AGG was more prominent. Future investigations will aim to explore elemental segregation and secondary phase evolution to identify driving forces contributing to AGG.

Keywords: Inconel 718 alloy; Friction stir deposition; Microstructure evolution; Dynamic recrystallization (DRX); Additive manufacturing; Electron back scattered diffraction (EBSD); Abnormal grain growth.

Comparative study on Hot Air Jet Erosion Behavior of HVOF-Sprayed WC-Base Coatings on Boiler Tube Steel

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Abstract

This study investigates the evaluation of hot air jet erosion behavior of three different High-Velocity Oxy-Fuel (HVOF) sprayed coatings: WC-12Co, WC-17Co, and WC-10Co-4Cr applied to boiler tube steel. Erosion tests were conducted at 550°C using alumina particles as erodent at impingement angles of 15°, 30°, and 45°. The coated specimens were characterized by coating thickness, microhardness, and bond strength. The erosion rate was determined based on mass loss, and the worn surfaces were examined using Scanning Electron Microscopy (SEM) and X-ray diffraction (XRD) analysis. Results revealed a significant variation in erosion resistance among the coatings. WC-12Co and WC-17Co exhibited increasing erosion rates with rising impingement angles, with the highest erosion observed at 45°. SEM analysis of the eroded surfaces indicated less WC particle pull-out, reduced plastic deformation, and lower surface damage in WC-10Co-4Cr compared to the other coatings. XRD analysis confirmed reduced particle pull-out and minimal phase degradation in WC-10Co-4Cr coatings. The study concludes that WC-10Co-4Cr is a more effective protective coating for boiler steel in high-temperature erosive environments due to its superior erosion resistance, phase stability, and oxidation behavior, making it a promising candidate for boiler tube protection.

Keywords: *Coatings; HVOF; mechanical properties; high temperature erosion; SEM*

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Spheroidization trend of secondary thermo-mechanically processed Ti-6Al-2Mo-4Sn-2Zr (Ti-6242) alloy

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Abstract

Titanium-based alloys are extensively used in the aerospace, defence and many structural industries due to their command in fatigue and creep resistance, high fly-to-buy ratio, superior corrosion resistance, and mechanical stability at elevated temperatures. It transforms allotropically into two crystal structures i.e. the one stable at room temperature (RT) is known as α -phase (hcp; P63/mmc) and the second one is the β (bcc; Im3m) phase, which forms upon crossing the transus temperature (T_β). They are associated with the Burgers' orientation relation (BOR) such that $\{0001\} \alpha \parallel \{110\} \beta$ and $\langle 11-20 \rangle \alpha \parallel \langle 111 \rangle \beta$. The key importance is that the microstructure of Titanium alloys provides optimal strength, corrosion and oxidation resistance and ductility as prime structural components in various parts of aircrafts such as disks, impellers of the gas turbines and sheet metal components used in the air frames. The microstructure of Titanium and its alloys evolves through a multi-stage thermo-mechanical processing (TMP) schedule that determines majority of subsequent mechanical properties. Spheroidization is a key mechanism for microstructure and micro-texture determination. It invariably brings significant heterogeneity within the bimodal microstructure and seek more investigation especially its impact on the ensuing mechanical properties. In the present study, the spheroidization behaviour of the hot compressed Ti-6242 alloy was investigated and correlated through different characterization techniques to attain some insights crucial for component making in the structural and aviation industry for high temperature application.

Keywords: Titanium alloys, hot deformation, Spheroidization, Ti-6242 alloy, Heterogeneity, Microstructure.

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Microstructural evolution and mechanical property enhancement of selective laser melted Inconel 718 via friction stir processing and subsequent aging treatment

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Abstract

This study investigates the effects of applying a double aging heat treatment after friction stir processing (FSP) on the microstructural and mechanical properties of Inconel 718 alloy produced by selective laser melting (SLM). FSP was carried out at 300 rpm with a tool downward force of 11.8 kN, followed by a two-stage aging treatment at 720 °C for 8 hours and then 620 °C for 6 hours, with air cooling. Due to dynamic recrystallization during FSP, the average grain size was significantly refined from about 23 μm in the as-built condition to roughly 2 μm , resulting in marked improvements in mechanical performance compared to the as-built SLM component. Furthermore, subsequent double aging accelerated the precipitation of γ' and γ'' phases, leading to additional performance gains. As a result, the yield strength (YS) increased from ~ 700 MPa to ~ 945 MPa, and the ultimate tensile strength (UTS) rose from ~ 1010 MPa to ~ 1180 MPa, although ductility decreased, evidenced by a drop in elongation from 30% to 22%. Meanwhile, microhardness showed a 30% increase relative to the as-built condition. After both FSP and double aging, the YS reached ~ 1150 MPa, the UTS went up to ~ 1445 MPa, and hardness increased by 28%, though ductility was further reduced to 18%. These results underscore the efficacy of combining FSP with double aging to enhance the microstructure and mechanical characteristics of SLM-fabricated Inconel 718.

Keywords: Selective laser melting; Inconel 718; Friction stir welding; Microstructure evolution; Mechanical properties.

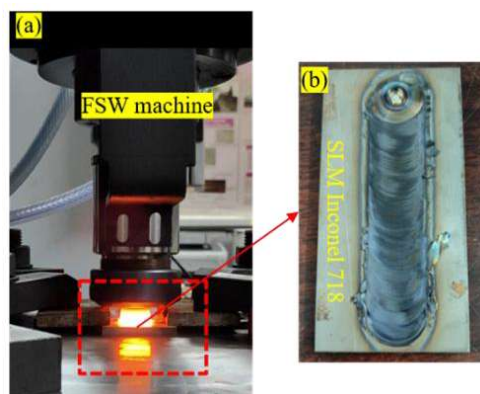


Fig: (a) FSW Machine on which FSP is carried out; (b) FSPed + SLM final product

Study of gradient microstructure and its mechanical characteristics by friction stir processing in Al-Mg-Sc alloy (AA5024) after thermal annealing

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Abstract

The present study aims at investigating effect of gradient microstructure on its deformation behavior after thermal annealing to improve mechanical characteristics by friction stir processing in Al-Mg-Sc alloy. Microhardness measurement was performed on as received and annealed alloy samples. Friction stir processing was carried on the as-received alloy sheet at tool traverse speed of 100 mm/min, rotation speed 1000 rpm, pin length 0.5 mm, plunge 0.2 mm and tilt angle 2°. The detail microstructural study of friction stir processing samples conducted through EBSD reveled that formation of subgrain structure and followed by fine recrystallized grains with nearly random orientation. The analysis also suggests that continuous dynamic recrystallization involving progressive subgrain rotation is the possible mechanism for microstructural changes. Upon annealing, the alloy showed continuous recrystallization with transformation of the elongated grains structure possessing strong rolling texture to coarse equiaxed microstructure with random orientation. The annealed alloy exhibited reduce hardness due to coarsening of precipitates. The profound examination through scanning electron microscopy analysis validated distribution of Al₃Sc precipitates. The significant improvement in the grain refinement and precipitates within the stir zone led to a substantial variation in microhardness, ultimate tensile strength and ductility. A study of fracture morphology ensures the ductile fracture behavior due to dimple formation.

Keywords: Friction stir processing, Gradient microstructure, Grain refinement, Thermal annealing, Precipitates, Continuous dynamic recrystallization, Mechanical characteristics, Dimple formation etc.

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Effect of Rolled and Selective Laser Melting Microstructures on the Tensile, Corrosion, and Wear Properties of Friction Stir-Processed Ti-6Al-4V Alloy

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Abstract

This study investigates the influence of initial microstructures: (i) rolled and Selective Laser Melting (SLM) on the mechanical, corrosion, and wear behaviour of Ti-6Al-4V alloy subjected to Friction Stir Processing (FSP). The FSP technique was employed to refine and homogenize the distinct as-fabricated microstructures, aiming to enhance the overall performance of the alloy. Microstructural analysis revealed significant grain refinement and the dissolution of porosity in both material conditions, with the SLMed sample showing a more pronounced transformation due to its initially heterogeneous and porous nature. Tensile testing demonstrated improved strength and ductility in the FSPed samples, with the SLMed-FSPed variant exhibiting superior mechanical properties attributed to enhanced dynamic recrystallization and texture evolution. Corrosion resistance assessments in simulated physiological environments indicated a marked improvement post-FSP, especially for the SLMed material, due to the elimination of keyhole-induced porosity and a more uniform passive oxide layer formation. Wear testing further confirmed that FSP effectively mitigates wear loss, with the SLMed-FSPed sample outperforming its rolled counterpart due to the combined effects of microstructural refinement and hardness enhancement. Overall, the findings highlight the critical role of initial processing history on the effectiveness of FSP in tailoring the performance of Ti-6Al-4V alloy for demanding structural and biomedical applications.

Keywords: Ti-6Al-4V alloy, Friction Stir Processing (FSP), Selective Laser Melting (SLM), Microstructure refinement, Mechanical properties, Corrosion resistance and Wear behavior.

The Current State of Materials Used in Friction-Based Additive Manufacturing for Dental Crowns: Limitations, Opportunities, and Future Trends

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Abstract

The advancement of additive manufacturing (AM) has revolutionized restorative dentistry, particularly in the production of dental crowns. Friction-based additive manufacturing (FBAM) offers numerous benefits such as solid-state processing and improved mechanical properties, but its implementation in dental applications is obstructed by difficulties in material selection. This review examines the current state of materials used in the fabrication of dental crowns via FBAM, focusing on biocompatibility, wear resistance, esthetics, and structural integrity. It discusses materials like zirconia, alumina, metal-ceramic composites, and emerging biopolymers. The paper discusses limitations associated with dental-grade ceramics, including poor thermal control, high-resolution features, and challenges in compatibility. Still, it suggests opportunities for innovation through hybrid materials, functionally graded materials, and improved post-processing methods. Future research inclinations and material development possibilities could encourage broader use of FBAM in dental restoration.

Keywords: Friction-based additive manufacturing; Biocompatible materials; Dental crowns; Friction stir additive manufacturing; Materials science; Frictional heat.

Table 1. Materials used in Friction-Based Additive Manufacturing (FBAM) for Dental Crowns

S.N	Materials Used	FBAM Technology	Properties	Advantages	Disadvantages
1	Zirconia (ZrO ₂) reinforced composite	Friction Stir Additive Manufacturing	High strength, wear resistance, biocompatible	Excellent durability and biocompatibility, esthetically pleasing	Difficult to process, risk of cracks during post-processing
2	Alumina (Al ₂ O ₃) composite	Friction Stir Deposition	High hardness, good wear resistance	Cost-effective, chemically stable, suitable for crowns	Brittle nature, less translucent
3	Metal-Ceramic (Ni-Cr with ceramic overlay)	Friction Stir Hybrid Additive Manufacturing	Good toughness from metal base, aesthetic overlay	Strong base support with aesthetic finish	Biocompatibility concerns with Ni-Cr alloys
4	Polymer-Ceramic Nanocomposites	Friction Stir Processing Additive Manufacturing	Tunable mechanical and aesthetic properties	Lightweight, customizable, potential for cost reduction	Lower wear resistance and strength compared to full ceramics

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Effect of Heat Treatment on Microstructure and Wear behaviour of Al_xCoCrFeNi High Entropy Alloy

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Abstract

Al_xCoCrFeNi high-entropy alloys (HEAs) are among the most extensively studied HEAs for their structural and mechanical properties. While the influence of Al concentration and aging temperature on microstructure and phase evolution is well documented, their effect on the alloy's tribological behavior remains relatively underexplored. In this study, Al_xCoCrFeNi alloys with $x = 0.3, 0.5$, and 0.7 were synthesized via arc melting, followed by solution treatment, quenching, and subsequent aging at 500°C and 900°C . X-ray diffraction (XRD), scanning electron microscopy (SEM), electron backscatter diffraction (EBSD), and transmission electron microscopy (TEM) were employed to characterize the phases and microstructural changes. The results revealed the presence of face-centered cubic (FCC) and ordered body-centered cubic (BCC/B2) phases in the Al_{0.3} alloy, with the BCC phase fraction increasing with Al content. Notably, the Al_{0.7} alloy exhibited a significant phase reversal, from 24% FCC and 76% BCC at 500°C to 56.6% FCC and 43.4% BCC at 900°C . Microhardness measurements correlated with phase fractions, showing a hardness increase from 216 HV (Al_{0.3}) to 491 HV (Al_{0.7}). Tribological performance was assessed through room temperature pin-on-disc dry sliding wear tests against an EN31 steel disc. Detailed analysis of worn surfaces and debris using SEM and X-ray photoelectron spectroscopy (XPS) revealed a transition in wear mechanisms: from abrasive and oxidative in Al_{0.3}, to a combination of adhesive and abrasive in Al_{0.5}, and predominantly abrasive in Al_{0.7}. The Al_{0.3} alloy exhibited the lowest wear rate ($1.2 \times 10^{-4} \text{ mm}^3/\text{Nm}$), attributed to the formation of a compact oxide layer at the contact interface. The Al_{0.5} alloy, with intermediate hardness, showed the highest wear rate ($3.06 \times 10^{-4} \text{ mm}^3/\text{Nm}$), due to combined adhesive and abrasive mechanisms induced by the coexistence of a soft FCC matrix and hard needle-like B2 precipitates. In contrast, the Al_{0.7} alloy demonstrated a reduced wear rate ($2.2 \times 10^{-4} \text{ mm}^3/\text{Nm}$), owing to its high hardness and dominant abrasive wear characterized by micro-cutting and mild ploughing. This comprehensive study establishes clear correlations among phase evolution, microstructure, mechanical response, and wear mechanisms, offering valuable insights for wear-resistant alloy design in Al-modified CoCrFeNi HEAs.



Keywords: High entropy alloys, Al_xCoCrFeNi, Microstructure, Wear, Wear Mechanism, Microhardness Sample.

Effect of Heat Treatment on Mechanical and Microstructural Properties of Ceria-Stabilized Zirconia and Polymer-Derived Ceramic Reinforced AA7075 Composites Fabricated Through Friction Stir Powder Additive Manufacturing (FSPAM) Process

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Abstract

Fusion-based composite manufacturing faces challenges such as hot cracking, distortion, metallurgical incompatibility, and brittle intermetallic formation due to liquid-solid phase transformations. In contrast, friction stir powder additive manufacturing (FSPAM) is an emerging solid-state additive manufacturing process that eliminates these issues by avoiding melting. This study investigates ceria-stabilized zirconia and polymer-derived ceramic-reinforced AA7075 composites manufactured through the FSPAM process. The composite exhibited a yield strength of 223 ± 7 MPa, an ultimate tensile strength of 393 ± 3 MPa, and a microhardness of 125 ± 9 HV at room temperature. Fractographic analysis revealed ductile failure with 5.5 ± 0.4 % elongation. The mechanical properties closely matched those of AA7075-T4 alloys due to strong metallurgical bonding. A post-fabrication heat treatment shows significant improvements in mechanical properties. These findings highlight FSPAM as a promising process in solid-state additive manufacturing of aluminum-based composites for high-strength and high-temperature applications.

Keywords: Friction stir powder additive manufacturing, Aluminum matrix composite, Microstructural evolution, Mechanical characterization, Heat treatment.

Poster Presentations

Microwave Hybrid Heating of Nickel-Based Alloys for Steel Cladding: A Review

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Abstract

Steels have more applications in automotive, structural, and construction because of their exceptional strength. The wear, corrosion, and oxidation are the major problems of steels, which shorten their service life in demanding applications. To minimize these issues, different surface modification techniques are employed, and cladding is one of the surface modification techniques. Thermal spray, welding, laser cladding, and microwave hybrid heating (MHH) are the different cladding techniques. Among these cladding techniques, MHH emerged as a promising alternative cladding technique. Reduced porosity, finer microstructure, and improved mechanical properties occur due to uniform heating generated at the molecular level by microwave heating. In this process, substrate polishing, pre-placing the clad powder, using a high-dielectric loss factor susceptor for controlling the temperature gradient, and exposure to microwaves are involved. Less power consumption, selective heating, minimal environmental impact, and improved wear and corrosion resistance are the different advantages of microwave hybrid heating over conventional techniques. Recent studies demonstrated that Ni-based and Co-based alloys showed a better performance in slurry erosion, sliding wear, and abrasive wear resistance of the different steel grades. This review focused on the microwave hybrid heating for nickel-based alloy powder cladding on metallic substrates.

Keywords: Steel; Wear; Corrosion; Surface Modification; Microwave Hybrid Heating; Ni-based alloys.

Impact of varying tool rotational speed on Elastic modulus of Zn-Mn alloys processed by Friction stir processing

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Abstract

The Zn-Mn alloys are known as biodegradable alloys, i.e. materials that degrade safely within the physiological conditions of the body, post healing of tissue. For biomedical applications especially for orthopedic applications elastic modulus of the material decides its suitability for implant materials. Stress shielding effect may occur and loosening of implant happens, if there is any mismatch between elastic modulus of implant material and bone. The elastic modulus that decides the applicability of material in biomedical applications is least explored in this domain i.e factors affecting elastic modulus. The current study explores the effect of tool rotational speed (560, 710, and 900 rpm) on elastic modulus of Zn-xMn (x=0, 0.4, 0.8, 1.2, and 1.6 wt%) alloys processed by friction stir processing (FSP). By friction stir processing of Zn-Mn alloys there is fragmentation of matrix (α -Zn) and secondary phases (MnZn₁₃) and also uniform distribution of secondary phases in the matrix. The elastic modulus is precisely measured using a resonance frequency damping analyzer (RFDA) with the impulse excitation method. By alloying with manganese, the elastic modulus of as-cast Zn (85 GPa) increased by 6%. The elastic modulus of FSPed Zn-Mn alloys needs to be measured. The microstructure and mechanical properties of FSPed Zn-Mn alloys are further correlated with the elastic modulus.

Keywords: Biodegradable alloys, implant materials, Friction stir processing, dynamic recrystallization, grain refinement, mechanical properties.

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Friction Riveting: A Critical Analysis of Process Parameters, Material Compatibility and Performance

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Abstract

Friction riveting is an advanced joining method emerged as promising alternative to conventional methods due to its ability to produce defect free joints with minimum thermal damage to material. The aim of this review is to present influence of process parameters on the properties of friction riveted joints. This review seeks to highlight research findings and the recent developments associated with this notable method. Friction riveting technique have been advanced in several ways. Optimizing process parameters, such as rotational speed, axial force, and feeding rate, improves joint formation and strength. Innovations in rivet design have led to significant improvements in performance, including enhanced tensile and pull-out forces as well as a substantial increase in energy absorption compared to traditional blind riveting. Researchers have demonstrated the transferability of the technique to low-cost equipment, one-sided joining (friction stir blind riveting), and applications involving 3D printed polymers, aerospace, and dissimilar material combinations. Investigations have further highlighted three emerging trends that are tailored process optimization for specific material combinations (e.g., aluminum alloys with polymers or composites). Expanded application contexts across automotive, civil, general manufacturing, and electronic assemblies. Increased use of microstructural analysis and early-stage computational modelling is helping to refine joint performance. Friction-based riveting methods yield higher joint strengths than the traditional self-piercing techniques.

Keywords: Friction Riveting, Process Parameters, Microstructural analysis, applications.

Effect of Calcium Addition on the Microstructural, Mechanical Properties and Wear Resistance of Zn-Al-Cu-Mg alloy via squeeze casting

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Abstract

This study investigates Zinc-Aluminium alloy's microstructural characteristics, mechanical properties, and wear behavior, with Calcium (Ca) additions ranging from 0.5 to 1.5 wt.%. The alloys were fabricated under controlled atmospheric conditions using a hydraulic squeeze casting technique to achieve high density and reduced porosity. Chemical analysis, optical microscopy (OM), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and X-ray diffraction (XRD) were performed to evaluate squeeze-cast Zn-Al alloys with different Ca contents. Wear testing using a linear reciprocating tribometer method demonstrated enhanced resistance to material loss with moderate Ca reinforcement. The microstructure of the Zn-Al alloy with Ca reinforcement comprises the intermetallic phase CaZn₁₃, which exists dispersed within the Zn-Al solid solution. Microstructural analysis using SEM and XRD confirmed the presence of CaZn₁₃ phases, which influenced fracture behavior. The results indicated that Calcium additions up to 1.5 wt.% increased both microhardness and tensile strength, with the 1.0 wt.% Calcium addition yielded the highest hardness value and a tensile strength compared to the base alloy, resulting in a lower wear rate than the specimens without Ca. In addition to quantitative evaluations of wear rate and volume loss, in-depth examinations of debris and wear tracks occurred using a 3D profilometer and scanning electron microscopy (SEM). These findings suggest that adding calcium improves grain refinement in microstructural examination, and mechanical properties and wear resistance occurred at 1.0 wt.% Ca, emphasizing the importance of controlled Ca addition in improving the functional performance of Zn-Al alloys for advanced engineering applications.

Keywords: Zinc-Aluminium Alloy; Mechanical properties; Linear reciprocating tribometer; SEM; 3D Profilometer.

Smart Tooling and Material Engineering in Friction Stir Welding: A Review of Innovations Driving High-Performance Joints

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Abstract

Friction Stir Welding (FSW), a solid-state joining process, has revolutionized the welding landscape for both metals and polymers, offering an eco-friendly and energy-efficient alternative to traditional fusion welding. Unlike fusion welding, which often compromises mechanical integrity due to excessive heat, FSW preserves material properties by generating localized frictional heat using a non-consumable rotating tool. This review highlights recent advancements in FSW with a specific focus on polymer-to-polymer and polymer-to-metal joints, which are increasingly vital in sectors like automotive, aerospace, and electronics due to their demand for lightweight, high-strength, and corrosion-resistant materials. The paper extensively analyzes the impact of tool design—including pin geometry, shoulder features, and tool material—on joint strength and microstructural evolution. Special attention is given to novel shoulder modifications and pin profiles such as triflute, threaded, and A-skew configurations, which optimize material flow and reduce defects. Moreover, the selection of tool materials and surface coatings plays a critical role in enhancing weld quality, minimizing voids, and improving wear resistance. Through this comprehensive synthesis, the review provides insights into how tool–material compatibility and process parameter optimization can significantly influence weld integrity, paving the way for advanced applications and future research in micro- and nanoscale FSW operations.

Solid-state joining of copper and stainless steel by electromagnetic force

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Abstract

The solid-state joining of dissimilar metals, particularly copper and stainless steel, poses significant challenges due to their contrasting physical, chemical, and metallurgical properties. Electromagnetic pulse welding (EMPW), a high-speed, solid-state joining technique, offers a promising solution by utilizing transient electromagnetic forces to create metallurgical bonds without melting the base materials. This study investigates the feasibility and effectiveness of joining copper and stainless steel using EMPW. Key process parameters such as discharge energy, standoff distance, and field-shaper design were optimized to achieve defect-free joints. Microstructural analysis revealed the formation of a wavy interface with localized interfacial bonding zones, indicating strong metallurgical adhesion without the formation of brittle intermetallic compounds. Mechanical testing confirmed enhanced joint strength, while scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) provided insights into the bonding mechanism and elemental diffusion at the interface. The results demonstrate that electromagnetic pulse welding enables high-quality, reliable joints between copper and stainless steel while preserving the distinct properties of both materials. This technique is highly suitable for applications in electric vehicle manufacturing, aerospace, and power electronics, where lightweight, high-conductivity, and corrosion-resistant joints are required. The study reinforces EMPW as a versatile and efficient process for joining dissimilar metals in advanced engineering systems.

Keywords: Solid-state joining, Electromagnetic pulse welding, dissimilar metal, copper, Stainless steel, Microstructure, process parameters.

Microstructural engineering and its role on strain gradient plasticity during V-bending of magnesium sheets

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Abstract

Magnesium (Mg) based sheet metals have potential applications in sheet metal parts of several automotive, electronics, and other industries owing to their excellent lightweight properties. To meet these applications, the bendability of magnesium alloy sheets constitutes a fundamental requirement for improving its manufacturability. However, the presence of strain gradients during bending operation and the resulting migrations of neutral layers critically influences spring back recovery, which is crucial to the accuracy of finished products. The current study aims to design microstructures with varying degrees of yield asymmetry ratios and establish its influence on migrations of neutral layers. A combination of severe plastic deformation (SPD) and post-SPD annealing treatments was used to engineer several grain sizes in a Rare Earth containing Mg alloy. Engineered Mg alloys with varying microstructural grain sizes were subjected to bending operation using a specialized mini-bending setup coupled with digital image correlations. An improved Finite element analysis, which accounts for asymmetrical stress response, was used to decipher the strain gradient effects on asymmetrical stress response during bending. The role of deformation mechanisms such as extension twinning was established through electron microscopy-based characterization of bent Mg alloy sheet metal samples. Based on the results of Digital Image Correlations and Finite Element Analysis, a detailed stage-wise mechanism of neutral layer migration was proposed for various engineered microstructures which correlates well with the microstructural evolution across grain size

Keywords: Magnesium alloys, Mini V Bending, Digital Image Correlations, Finite Element Methods, Severe Plastic Deformation, Micromechanical deformation.

Fatigue Life Prediction of Laminated Bi-layered (Mg/Al) and Tri-layered (Al/Mg/Al) Clad Sheets

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Abstract

The inherent lightweight characteristics of Mg alloys represent potential to be used as a structural material in the aerospace, automotive, and naval industries. In addition, the Mg alloys have high specific strength, high specific stiffness, and outstanding damping characteristics. However, the inferior corrosion and wear resistance have restricted its usage for making parts and components. Furthermore, the poor room temperature formability of the Mg alloys is a roadblock for developing the wrought Mg alloys sheets and for their utilisation as structural materials. Several attempts have been made to improve the formability and expand the usage of Mg alloys, such as rare earth alloying in the Mg alloys and elevated temperature processing of Mg alloys. Among these, the elevated temperature processing has a more industrial potential for developing Mg alloy sheets. However, the corrosion and oxidation resistance of the Mg alloys deteriorates more with an increase in elevated temperature processing conditions. In recent days, Mg-based advanced materials have been developed to improve the formability of Mg alloys. The suitable approach is by employing the cladding of ductile and high corrosion-resistant materials over the substrate Mg material. For doing this, pure Al alloys have been found to be a desirable material for developing the cladding over the Mg material owing to their comparable light weight and specific strength characteristics to the Mg alloys. For developing the clad structures, solid-state joining techniques such as diffusion bonding and explosive bonding have been utilised due to their low joining temperature. The performance of the laminated clad structures is solely dependent on interfacial bonding characteristics. The major issue in the development of clad sheets is the formation of intermetallic compounds, which deteriorate the mechanical performance of sheets. The performance of the clad structures strongly depends on the quality of the bonding and nature of the loading applied to the clad materials. Fatigue loading is one of the most practical and critical loadings which occur in most engineering components during their usage. So, understanding the fatigue life of the laminated clad structure is important for ensuring its life and performance. Therefore, the present study aims to investigate the influence of a clad layer (pure Al) on the fatigue performance of the Mg sheets in the bi-layered and tri-layered laminated clad sheets. The detailed post-mortem, mainly microstructural investigation of fatigue-fractured samples, was carried out using field emission scanning electron microscopy (FESEM) equipped with energy dispersive spectroscopy (EDS) and electron back-scattered diffraction (EBSD) detectors. The detailed fatigue test and microstructural analysis helped in understanding and formulating the fatigue life prediction of the bare Mg sheets and the laminated clad sheet materials.

Keywords: *Laminated clad sheets; Microstructure; Dynamic recrystallization; Fatigue behavior; Characterization.*

Microstructure, texture, and mechanical properties of Al sheets, produced by room temperature consolidation of powder by HPCRS

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Abstract

Powder metallurgy is a bottom-up approach to form ultrafine-grained and nanostructured materials. However, the drawback of the process is the sintering stage, during which grain growth occurs, leading to the loss of nano-level structures. To overcome this limitation, sintering-free consolidation of powders has been explored using severe plastic deformation (SPD) techniques. We have developed a new single step SPD technique that induces high shear strain (>20) called HPCRS (High Pressure Compressive Reciprocating Shear). In this method, the sample is placed in a channel, a compressive load is applied on one side, and an oscillating load is applied in a direction perpendicular to the compressive load. Pre compacted pure Al powder (99.7%) compacts were processed by HPCRS at different conditions of frequency, amplitude, and load rate. The process parameters involved are the frequency (0.01 Hz- 1 Hz), amplitude (3- 5mm) of oscillation, and the normal loading rate (1- 4 kN/s) of compressive load. A large equivalent shear strain (~10) was imposed on the sample. The consolidation is correlated with the von Mises equivalent stress applied for the processing. The consolidated sheets showed grain refinement and shear texture. We report for the first time the powders being consolidated in reverse shear. For comparison, a bulk CP Al block was processed under the same HPCRS parameters. Without sintering, 99.6% theoretical density was achieved in a single-step processing. The density is found to be increasing with von Mises stress. Shear stress imposed on the sample is causing consolidation. The powder-processed sample showed a yield strength of 180 MPa and UTS of 240 MPa, while the bulk Al after processing had a yield strength of 154 MPa and UTS of 190 MPa. This increase in the strength of the powder-processed sample has been attributed to strengthening due to alumina particles.

Keywords: severe plastic deformation, ultrafine-grained materials, mechanical properties, texture evolution, powder metallurgy, aluminum, HPCRS [4] Jack R. Janik et al, Exploring the Boundaries of Electrically Induced Bearing Damage in Grease-Lubricated Rolling Contacts (2024).

The process of microstructural evolution during linear friction welding of Ti6Al4V alloy

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Abstract

The present investigation describes the microstructural evolution process during the linear friction welding (LFW) of Ti6Al4V alloy. Linear friction welding was carried out on a 500 kN custom-built linear friction welding machine. Welding experiments were stopped at various time intervals to understand the joint formation process. Microstructural investigations were carried out by Scanning Electron Microscopy (SEM) equipped with EBSD. During the initial stages, asperity-level deformation and seizure take place. The α and β phases deform and align along the oscillating direction. The fragmentation of β phases and deformation-induced temperature rise leads to vanadium diffusion from the β phase into the α phase. With the increase in welding time, seizure increases to 100 % of the contact. A deformed zone is developed with the weld center above the β transus temperature and a subsurface region below the β transus temperature. With the continued deformation, the high-temperature weld center material is removed as flash. As the flash starts to form, the subsurface region enters the weld center region at a rate equal to the rate of flash formation, and a steady state condition is reached. After the welding is complete, the weld center region consists of either a widmanstatten structure or a martensitic structure, depending on the welding parameters used. Three welding experiments were carried out to establish the microstructure after welding. The normal pressure was varied from 25 MPa to 550 MPa with a frequency of 40 Hz and an amplitude of 1.5 mm. Martensite was observed at the weld center at a 25 MPa normal pressure, while the widmanstatten structure was observed at normal pressures of 300 MPa and 550 MPa. The flash of all the welds showed α/β lamellar microstructure formed after cooling from the high-temperature β phase.

Keywords: linear friction welding, Ti6Al4V, microstructure, β transus temperature, martensite.

Process-Driven Microstructural Evolution and Its Impact on Strength and Electrochemical Corrosion in Dissimilar FSW AA5052–AZ31 Joints

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Abstract

The mechanical strength and electrochemical stability of friction stir-welded (FSW) AA5052/AZ31 joints are vital for their structural applications. This study investigates the influence of three tool rotational speeds on microstructure, intermetallic compound (IMC) formation, and their effects on interfacial bonding and corrosion behavior in AA5052/AZ31 joints. Tensile, microhardness, and 10-day immersion tensile tests in 3.5 wt.% NaCl was conducted, along with nanoindentation to evaluate residual stresses and their combined impact on strength and corrosion performance. Advanced characterization techniques (EBSD, SEM, TEM, and XPS) were employed. The FSW process promoted dynamic recrystallization and severe plastic deformation (SPD), which fragmented the brittle β -Al₃Mg₂ and γ -Al₁₂Mg₁₇ phases. The highest tensile strength (190 MPa) and microhardness (140 HV) were obtained for MRS-900 and HRS-1100, respectively. However, immersion testing revealed strength degradation due to corrosion. Electrochemical corrosion rates followed the order: HRS-1100 > MRS-900 > LRS-700 > AZ31 > AA5052, indicating enhanced corrosion rate at higher heat input. XPS results revealed a relatively stable Al₂O₃/Mg (OH)₂ film in MRS-900, offering partial protection, while LRS-700 showed early oxidation, and HRS-1100 exhibited unstable passive layers due to high heat input. Although MRS-900 exhibited the highest residual tensile and compressive stresses (205 MPa and –226 MPa), the joint performance was governed by the combined effects of heat input, residual stress, and microstructural evolution rather than IMCs alone.

Keywords: Friction stir welding; AA5052/AZ31; Microstructure; Intermetallic compounds; Electrochemical corrosion.

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Effect of Infill Geometry and Density on the Tensile Performance of PLA– Carbon Fiber Composites Processed by Fused Filament Fabrication Technique (FFF)

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Abstract

Poly(lactic acid) (PLA) is widely used in fused deposition modelling (FDM) but suffers from brittleness and low thermal stability, limiting its engineering applications. This work investigates the tensile properties of PLA reinforced with 15 wt.% short carbon fibres (PLA–CF), focusing on the influence of infill pattern and density. ASTM D638 Type I tensile specimens were fabricated using three infill patterns (Grid, Tri-Hexagonal, and Concentric) and three infill densities (30%, 60%, and 90%). Tensile tests evaluated yield strength, ultimate tensile strength (UTS), and elongation at break.

Results show that Tri-Hexagonal infill consistently delivered the highest tensile performance, with the 90% infill variant achieving ~38 MPa yield strength and ~40 MPa UTS, significantly exceeding typical neat PLA values. Grid patterns showed the lowest strengths, while Concentric patterns performed moderately. Elongation at break ranged from 2–4%, lower than neat PLA (6–8%) due to fiber-induced brittleness. These findings demonstrate that optimizing infill geometry and density in PLA–CF composites enables production of lightweight, high-strength 3D-printed parts for functional engineering applications.

Keywords: Fused deposition modelling, PLA–carbon fiber composite, ASTM D638, tensile properties, infill pattern, infill density, additive manufacturing.

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Smart Monitoring and Prediction of Lubricant Degradation

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Abstract

The degradation of lubricants is a prominent issue in industrial machinery, automotive systems, aerospace applications, etc., this is a challenge faced in modern maintenance management. Subsequently, there is a rise in use of advanced monitoring and predictive technologies to prevent catastrophic equipment failures and optimize operational efficiency. In general applications and especially Electric Vehicles (EVs), Heat acts as one of the primary drivers for lubricant degradation. Thermal load accelerates degradation in high load-speed application and hence its effect is needed to be analyzed. This study presents a framework for smart monitoring and prediction of lubricant degradation utilizing machine learning (ML) techniques integrated with sensor technologies. With the use of Convolutional Neural Network (CNN), the complex patterns (with feature extraction techniques) in lubricant degradation data are analysed. The data to the model are pre-processed (Cleaning, normalization and augmentation) for proper performance. The data used to estimate lubricant condition include images of the lubricant (color or clarity changes), i.e. Greases such as NLGI 2 and NLGI 3 are heated (temperature range from 80-150oC) and are continuously obtained. These data are used to develop a predictive CNN provide reliable prediction of lubricant deterioration levels. The model is evaluated using Precision, recall, F1-score and confusion matrix metrics. The model is also used determine viscosity range of the degraded lubricant. The outputs are verified and analysed with the results through proper (ASTM D4440) types of standard(viscosity) tests. Various other types of ML algorithm like (random forest and Support Vector Machine (SVM)) is compared to help determine the accurate model for a given application. The proposed work, with cloud monitoring and IoT technologies integration, could reduce running costs, enhance equipment longevity, and minimize operational downtime. These advancements enable real time monitoring and predictive insights, with studies indicating up to a 40% reduction in production recovery time during lubricant transitions. This research helps to lay foundation for the advancement of intelligent maintenance systems which could significantly improve the overall machine reliability and operational efficiency, with reduce impacts in environment with optimized utilization of lubricant and extended service intervals.

Keywords: Lubricant degradation, Machine Learning, Predictive Maintenance, Real-time Monitoring.

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Experimental Study of Bearing Life Reduction under Combined Electrical and Mechanical Loads

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Abstract

Premature bearing failure is a common problem in modern industrial machinery, especially in applications where Variable Frequency Drives (VFDs) or inverters are used. The increased use of these electronic devices causes undesired electrical currents to travel through bearings, resulting in early-stage electrical damage. Frosting, pitting, and eventually fluting are common manifestations found on bearing races and rolling elements, reducing operational reliability and raising maintenance costs. Traditional experimental setups, such as the pin-on-disc device, have long been used to simulate such failures. However, these arrangements have severe limitations: they fail to adequately imitate the internal geometry of true bearings, with only one contact point rather than several rolling elements and hence are not realistic of real-world settings.

To address this gap, we have developed a specialised test setup capable of evaluating bearings directly under both electrical and mechanical loads. This arrangement facilitates the simultaneous application of controlled mechanical forces and electrical currents to the entire bearing assembly, closely replicating real operational conditions where such failures originate. The rig offers flexibility to adjust test parameters to align with diverse field configurations, thereby providing a highly representative simulation environment. Initial investigations using this setup have already demonstrated damage patterns, such as early frosting, pitting, and incipient fluting, that are consistent with those observed in service, reinforcing the rig's capability. Notably, the experiments indicate that electrical loading induces additional and accelerated damage beyond that caused by mechanical loading alone. Insights gained into the degradation mechanisms are strengthening the foundation for a more robust and representative methodology to assess bearing failures arising from electrical loading, advancing the development of more accurate failure prediction models.

Keywords: *electric vehicles (EVs), electrical arcing, bearings, electrical current, premature failure, electro-damage.*

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Investigation on microstructure and mechanical properties of iron–nickel-based superalloy joints by using rotary friction welding

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Abstract

Incoloy 800H, an iron–nickel–chromium alloy renowned for its exceptional high-temperature strength, corrosion resistance, and creep-rupture properties, is essential in advanced engineering applications, particularly where environmental conditions are extreme, such as in petrochemical processing, power generation, and high-temperature furnace components. This research investigates the rotary friction welding (RFW) of Incoloy 800H to itself, with the aim of producing defect-free, high-strength welds that maintain the material's outstanding mechanical integrity. The study employed a systematic trial-and-error method to optimize welding parameters. Under these conditions, welds exhibited no visible defects and preserved the essential properties of the base material. Microstructural analysis revealed a dynamically recrystallized zone (DRZ) at the weld interface, characterized by ultra-fine equiaxed grains generated through intense plastic deformation and localized heating. Adjacent to this, a heat-affected zone (HAZ) demonstrated grain coarsening, while the base material retained its original grain morphology, confirming that thermal and deformation effects were well contained within the weld region. These findings demonstrate that rotary friction welding enables the formation of metallurgically sound joints in Incoloy 800H with minimal disturbance to the heat-affected areas, ensuring reliability for demanding industrial applications. Future work will investigate key mechanical properties, such as microhardness and tensile strength, and correlate these results with the observed microstructures to deepen understanding and refine welding parameters for even greater performance. By integrating process optimization, microstructural analysis, and mechanical evaluation, this research advances knowledge in solid-state joining of high-temperature alloys, supporting the development of reliable manufacturing strategies for critical industries.

Keywords: *Incoloy 800H, Rotary Friction Welding, Microstructural Characterization, Dynamically Recrystallized Zone, Heat-Affected Zone, High-Temperature Alloys, Mechanical Properties.*

Towards understanding the structure-property evolution mechanisms in wrought-to-printed and printed-to-printed linear friction welded Ti alloy near net blanks for aerospace applications

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Abstract

The near-net manufactured (NNM) blanks from linear friction welding (LFW) can significantly enhance the buy-to-fly ratio of critical Ti-alloy components for critical space and energy applications. The severe limitations of the laser powder bed fusion, which include the limited build volume and lower material deposition rates, can be simultaneously addressed by near-net manufacturing for critical space applications that require large-sized complex parts with finer resolutions. A systematically coupled experimental and numerical investigation is presented here for the first time to reveal the feasibility of LFW for the manufacturing of novel near-net blanks in wrought-to-printed and printed-to-printed combinations. Results show that the microstructure and mechanical property evolution in the weld zone of both joints are nearly identical due to dynamic recrystallisation. However, the thermo-mechanically affected zones (TMAZ) in printed specimens exhibited the lowest hardness due to globularized needles. In contrast, the TMAZ of the wrought specimen hardness increases considerably towards the weld interface due to the deformed and intact bi-modal microstructure. The proposed heat transfer model coupled with the kinetic model is sensitive enough to predict the measured hardness distribution with a maximum error of 5%. Further, attempt to empirically relate the hardness with the corresponding yield and ultimate tensile strengths of the joints deemed appropriate for five different welding processes from five independent literature. Additionally, both joint configurations exhibit an identical peak residual stress of ~ 200 MPa in the weld zone, attributed to their similar thermal cycle. Overall, printed-to-printed and wrought-to-printed joints exhibited excellent synergy between strength and ductility with improved elongation of 14% and 164%, respectively, due to the closure of micropores in the printed specimen.

Keywords: Additive manufacturing, Near-net manufacturing, Linear friction welding, Titanium alloy, Numerical modelling, Hardness model.

Thermal and Microstructural Analysis of Friction Stir Welding on High Strength Aluminum alloys for Aerospace applications

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Abstract

Friction Stir Welding (FSW) has emerged as a transformative solid-state joining technique for high-strength aluminum alloys widely used in aerospace applications. Its ability to produce defect-free, high-integrity joints with minimal distortion addresses many challenges posed by conventional fusion welding methods.

This study focuses on the detailed thermal profiling and microstructural analysis of FSW on aerospace-grade aluminum alloys, such as AA2024 and AA7075.

The investigation reveals distinct thermal cycles influencing grain refinement, recrystallization, and phase distribution within different weld zones, including the nugget, thermo-mechanically affected, and heat-affected zones. Understanding these microstructural evolutions is critical to optimizing mechanical properties and enhancing structural reliability under demanding aerospace service conditions. The results underscore the potential of FSW to improve joint performance, making it a preferred method in aerospace manufacturing.

Keywords:

Friction Stir Welding, High-Strength Aluminum Alloys, Aerospace Applications, Thermal Profile, Microstructural Analysis, Grain Refinement, Recrystallization, Weld Zones, Structural Integrity.

Microstructure, mechanical properties and thermal stability of Al-Fe composite processed by friction stir processing

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Abstract

This paper demonstrates the feasibility of incorporating reactive metallic particles, such as iron, as reinforcement in an aluminium matrix via friction stir processing (FSP). FSP led to significant grain refinement of the aluminium matrix and a uniform distribution of the iron particles. The iron particles remained in their elemental state, neither dissolving into the aluminium nor forming any detrimental intermetallic compounds, which is a state not achievable under typical equilibrium conditions. Twinning and fracture of Fe particles were observed with their frequency being different on the advancing and retreating side indicating existence of a strain gradient across the stir zone. Transmission electron microscopy (TEM) and electron backscattered diffraction (EBSD) studies revealed the occurrence of dynamic recrystallization, which refined the grain size and resulted in an equiaxed grain microstructure. The EBSD analysis showed that more than 60% of the grain boundaries were high-angle boundaries. The processed composite exhibited a greater than three-fold improvement in its 0.2% proof stress while maintaining a ductility substantially higher than that of ceramic particle-reinforced composites. Scanning electron microscopy (SEM) images of the fractured surface confirmed excellent bonding between the iron particles and the aluminium matrix, supporting the use of metallic particles as reinforcement to preserve ductility in metal matrix composites. The thermal stability of the composite was assessed by annealing it at various temperatures for different durations. The results showed that the iron particles reacted with the aluminium matrix to form an intermetallic phase upon annealing at 450°C. In contrast, the aluminium matrix itself underwent abnormal grain growth at a lower temperature of 400°C upon thermal exposure.

Friction stir welding of aluminium using zinc strip as a filler material

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Abstract

Friction stir welding (FSW) of aluminium alloys leads to a drop in the mechanical properties in the weld zone. Through the grain refinement improves strength, the dissolution of strengthening precipitates in the weld zone leads to a drop in strength. Overall, there is a decrease in strength and hardness in the weld zone, compared to the base material. To overcome this issue, we used zinc strip as a filler material during FSW. Zn has very high solid solubility in aluminium (~82 wt.% at 443°C) and low melting point (420°C). We propose that the decrease in strength due to the precipitate dissolution can be compensated by the solid solution strengthening due to dissolution of Zn in aluminium. With pure aluminium as a model system, FSW was carried out using Zn strip as a filler material. FSW resulted in dissolution of Zn in the weld nugget forming solid solution. FSW also resulted significant grain refinement in the weld nugget through dynamic recrystallization. The average grain in the weld nugget after FSW was 2-3 μm compared to ~62 μm of the base aluminium plate. A majority of the grain boundaries exhibited high-angle characters. The combined effect of grain size refinement and solid solution strengthening resulted in improvement in elastic modulus, hardness and strength of the weld nugget. Tensile tests showed improvement in strength with little loss in ductility. The methodology can be extended to aluminium alloys. At the end we highlight the strategies to be used for FSW of real-life components with a filler material.

Influence of WC reinforcement on the Wear Characteristics of AISI 316L WAAM Cladding on Medium Carbon Steel

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Abstract

Introduction

Wire Arc Additive Manufacturing (WAAM) is valued for its cost-effective, high-deposition fabrication of metallic components with low waste. For medium carbon steels, WAAM claddings improve wear and corrosion resistance but often lack hardness for harsh conditions. Adding hard particles like tungsten carbide (WC) or titanium carbide (TiC) enhances hardness, wear resistance, and microstructure by refining grains and improving substrate bonding, though uneven particle distribution and agglomeration pose challenges. This study examined WC-reinforced SS316L WAAM cladding (10WC, 20WC) on EN8 substrate, evaluating wear and hardness under 10 N and 40 N loads at 29 °C and 500°C. Both 10WC and 20WC outperform EN8 in wear resistance, with 20WC showing more wear than 10WC at higher loads (31%) and temperatures (17%). CoF rises to ~0.7 for 20WC at low load but falls to ~0.3 at high load, better than EN8 (~0.4); at 500 °C, CoF is similar across samples and decreases with load. Hardness increases by 3.9 times in 20WC. The 10WC excels in wear under severe conditions, 20WC maximizes hardness, and CoF is driven by load and temperature.

Methodology

The WAAM cladding of 316L stainless steel (SS316L) on medium carbon steel (EN8) substrate (100 mm × 100 mm × 18 mm) using 1.2 mm diameter filler wire, where in two occasions WC particles of 40-50 µm in diameter incorporated with 10 and 20 weight percentage of variations in each layer of deposition to created WC reinforced WAAM claddings. These WAAM cladded samples with 10wt.% WC and 20wt.% WC are referred to as 10WC and 20WC, respectively and the EN8 substrate is referred to as Base in the entire manuscript. A Fronius TPS320i MIG (GMAW) power source and ABB (IRB1520ID) 6-axis articulated robot are used to develop these structures in a bidirectional strategy. The optimised current, voltage, travel speed, and gas flow rate used to perform experiments are 160A, 21V, 10 mm/s, and 18 lit./min, respectively. Cylindrical disk samples (dia. = 20 mm, height = 6 mm) were prepared using a wire electro-discharge machine (GX360L, CHMER, Taiwan) from two cladded parts (50 mm × 50 mm × 10 mm) and polished with SiC papers. The wear test was performed in a rotary tribometer (model: TR-20 HTHV, DUCOM Instruments, India) using a ball-on-disc arrangement (as per ASTM G99) with a counter surface of WC ball at room temperature (29 °C) and 500 °C temperatures. The sliding speed, distance, and two different loads were considered as 0.5 m/s, 1000 m, 10 N and 40 N, respectively. After the wear test, each wear track was analysed using FESEM, ZEISS (Germany), and the surface profile was measured by a profilometer (MarSurf PS 10). The sample hardness (Brinell hardness) was determined using the BSHT-B-3000TS (model) machine and then converted into the HRC scale.

Results and discussion

The wear surface profiles of the samples, as illustrated in Figure 1, demonstrate that the base sample (forged EN8) consistently exhibits a larger wear track compared to the WC-reinforced SS316L WAAM cladding samples (10WC and 20WC), regardless of the applied load (10 N or 40 N) or temperature (29 °C or 500 °C). This suggests that incorporating tungsten carbide (WC) significantly enhances wear resistance. However, the wear surface area of the 20WC sample increases by 31% when the load rises from 10 N to 40 N and by 17% when the temperature increases from 29 °C to 500 °C, compared to the 10WC sample. Despite these increases, the 20WC sample still maintains a smaller wear surface area than the base sample under all tested conditions. The coefficient of friction (CoF) results, shown in Figures 2a and 2b, further highlight differences among the samples. At room temperature (29 °C), the CoF of the WC-reinforced samples rises to approximately 0.7 with higher WC fractions under a lower load of 10 N. In contrast, when the load increases to 40 N, the CoF drops to about 0.3, with the 20WC sample exhibiting a lower CoF than the base sample (~0.4). At an elevated temperature of 500 °C, the variation in CoF among the samples becomes statistically insignificant, falling within a 5% error bar and remaining consistent at a given load. Nonetheless, similar to the room temperature findings, the CoF decreases with increasing load across all samples. In summary, WC reinforcement in SS316L WAAM cladding enhances wear resistance and alters frictional behavior compared to the forged EN8 base sample. The optimal WC fraction depends on operating conditions, with the 10WC sample showing superior wear performance under higher loads and temperatures, while the CoF is influenced primarily by load and temperature across all samples.

The hardness of the WAAM cladded layers increased with the addition of hard particles (Fig. 2c). The highest hardness was achieved in the cladding containing 20% WC, which showed a significant increase (about 3.9 times higher than the base steel) compared to the base. This enhancement is attributed to the hard particles' ability to prevent plastic deformation and improve the overall strength of the cladded layer.

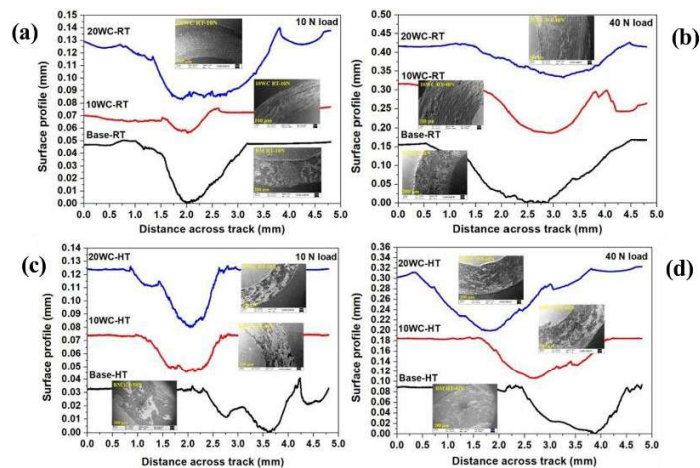


Fig. 1 Wear surface profile of different samples at (a) RT-10N, (b) RT-40N, (c) HT-10N and (d) HT-40N.

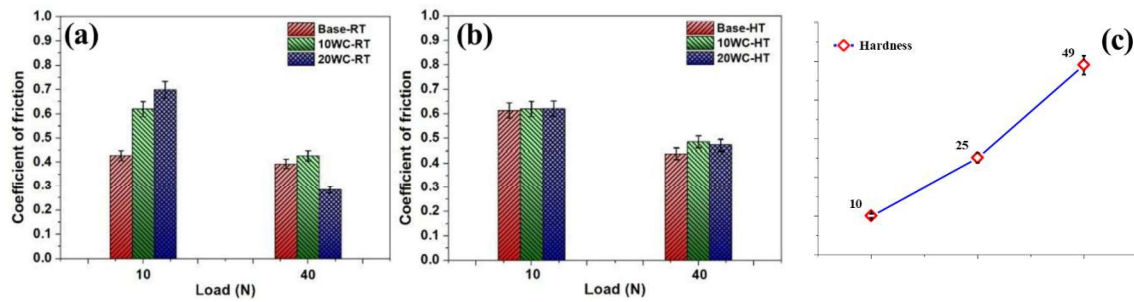


Fig. 2 Coefficient of friction with different loads of different samples at (a) RT and (b) HT along with the (c) hardness of samples.

Conclusions

The following conclusions can be drawn from the study.

- WC-reinforced SS316L WAAM cladding samples (10WC and 20WC) exhibit significantly smaller wear surface areas than the base sample (forged EN8) across all tested conditions (10 N and 40 N loads, 29 °C and 500 °C), demonstrating that tungsten carbide (WC) reinforcement markedly enhances wear resistance.
- The 20WC sample shows a larger wear surface area than the 10WC sample under higher loads (31% increase from 10 N to 40 N) and temperatures (17% increase from 29 °C to 500 °C), but still outperforms the base sample, indicating that 10WC offers better wear resistance under severe conditions.
- At room temperature and low load (10 N), CoF increases with WC fraction (up to ~0.7 for 20WC), but at higher loads (40 N), it decreases to ~0.3, with 20WC showing a lower CoF than the base sample (~0.4). At 500 °C, CoF differences among samples are statistically insignificant, and CoF decreases with increasing load across all conditions.
- The hardness of WAAM cladded layers increases with WC addition, with the 20WC sample achieving 3.9 times higher hardness than the base steel, attributed to WC particles' ability to resist plastic deformation and strengthen the cladding.

Keywords: WAAM; WC-reinforcement; 316L Cladding; Wear; Hardness.



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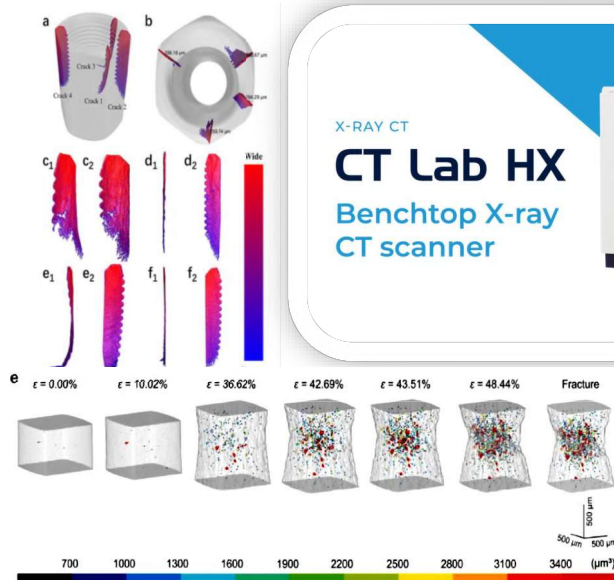
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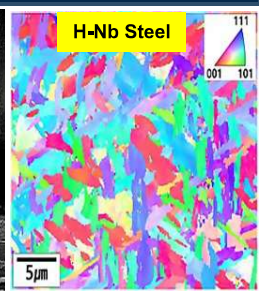
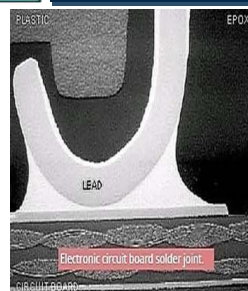
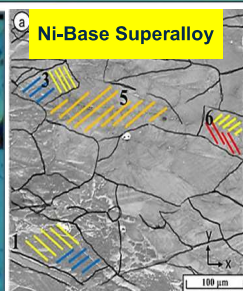
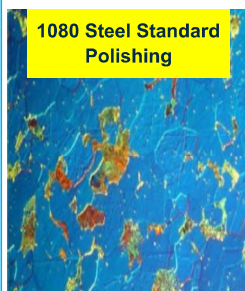


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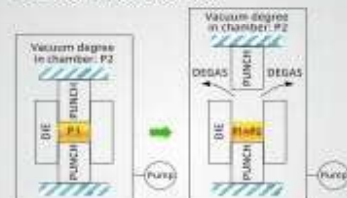
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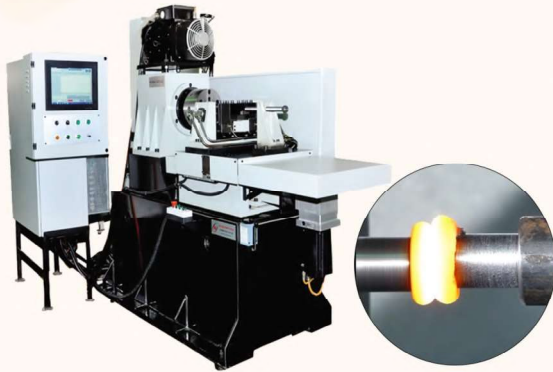
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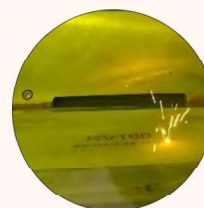
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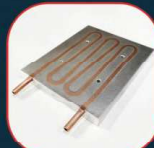
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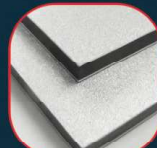
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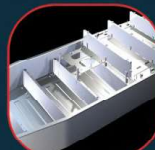
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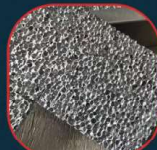
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