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A Review Paper on Friction Stir Processing on Aluminium Alloys

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Abstract

Friction stir processing is a step from friction stir welding, targeted at surface modification through improving the local microstructure via localized plastic deformation. The tool consists of a rotating mechanism incorporating a shoulder and pin that are inserted into the material, traversing the designated area. When the tool's shoulder and the workpiece make contact, friction develops, generating heat that produces plastic deformation. This localized plastic deformation and heat impact result in considerable modifications to the microstructure. Friction stir processing impacts various material properties, encompassing the formation of nanograins, increased surface hardness, improved fatigue strength, wear resistance, and tensile strength. This study predominantly explores the alterations observed in the microstructure and mechanical attributes of aluminium alloys and their composites through friction stir processing, examining the present trends and advancements in process parameters.

Keywords: Friction stir processing, scanning electron microscopy, XRD, FSW, CBP

INTRODUCTION

Friction Stir Processing (FSP) represents a solid-state joining and processing methodology employed to modify the microstructure and properties of materials, notably metals and metal matrix composites. Originating as a derivative of Friction Stir Welding (FSW), FSP entails the utilization of a rotating tool to agitate and blend the material at elevated temperatures, all while avoiding melting. FSP has various advantages over standard processing technologies, including the ability to generate fine-grained structures, minimize porosity, and enhance mechanical characteristics. This introduction highlights the essential principles and benefits of FSP, setting the foundation for further investigation into its applications and breakthroughs in materials processing.

Friction Stir Processing (FSP) is a solid-state processing method that has been derived from the principles of Friction Stir Welding (FSW). It involves the employment of a non-consumable spinning tool to stir and mix the material at elevated temperatures without melting. Unlike traditional processing processes such as casting or forging, which involve significant heat input and deformation, FSP operates at lower temperatures, resulting in reduced distortion and enhanced microstructural control.

The process begins with the spinning of the tool, which generates frictional heat at the interface between the tool and the workpiece. As the tool advances along the material surface, it forms a plasticized zone where the material suffers extreme

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plastic deformation. This plasticized zone is then allowed to cool and solidify, resulting in a refined microstructure with appropriate characteristics.

FSP offers various advantages over standard processing approaches. It can build fine-grained structures with increased mechanical qualities, including higher strength and toughness. Additionally, FSP can be used to homogenize alloys, scatter reinforcing particles, and reduce flaws like as porosity and segregation. Moreover, FSP is environmentally benign, as it does not produce toxic emissions or waste products.

In addition to its application in materials processing, FSP has found applications in surface modification and repair of components. By selectively treating particular portions of a workpiece, FSP can increase surface attributes like as hardness, wear resistance, and corrosion resistance. This makes it particularly appropriate for restoring worn or damaged parts in industries such as transportation and manufacturing.

Research in FSP continues to advance, with continuous efforts focusing on optimizing process parameters, investigating new tool geometries, and broadening the spectrum of materials that can be efficiently processed. Advances in computational modelling and simulation tools have also permitted a clearer knowledge of the underlying mechanisms regulating FSP, resulting to more precise control over the process and enhanced predictability of its effects.

Friction Stir Processing (FSP) holds significant importance in various industries and research fields due to several key reasons:

Enhanced material characteristics: FSP permits the refinement of microstructure and the enhancement of mechanical characteristics in materials, for example enhanced fatigue resistance, hardness, and strength. This results in the creation of lightweight, high-performance components characterized by enhanced durability and reliability.

Joining dissimilar materials: FSP provides a solid-state joining approach for dissimilar materials, including metals, alloys, and composites, without the requirement for conventional fusion welding procedures. This feature opens up potential for designing unique hybrid structures with specialized attributes to fulfil specific application requirements.

Environmental sustainability: As a solid-state process, FSP generates minimal waste, reduces energy usage, and removes the need for consumable materials like filler metals or fluxes required in traditional welding processes. This makes it an environmentally benign and sustainable production approach.

Surface modification and repair: FSP can be used to modify surface qualities and repair worn or damaged components by selectively treating particular areas. This involves enhancing surface hardness, wear resistance, and corrosion resistance, consequently extending the service life of key parts in numerous industries.

Process versatility: Friction stir processing (FSP) demonstrates versatility, offering applicability to an extensive array of materials encompassing metals, alloys, and composites. Moreover, it can accommodate diverse forms and dimensions of workpieces, further enhancing its adaptability and utility. It gives flexibility in processing complex shapes and can be simply integrated into existing manufacturing processes.

Research and development: FSP serves as a valuable research tool for researching fundamental material behaviour, process optimization, and new applications. Ongoing research in FSP contributes to improvements in materials science, engineering, and manufacturing technologies.

REVIEW

Kumar *et al*. investigated how the microstructure and structural characteristics of the AA7075-T6 aluminium alloy that was friction stir-processed were affected by the tool pin profile. Comparing threaded cylindrical tool pin profiles to straight cylindrical pin profiles, they discovered that the former provided finer grain sizes and better mechanical qualities. The research emphasized the role that tool design plays in regulating the mechanical behaviour and microstructural evolution of FSP [1].

The application of FSP to improve the corrosion resistance of aluminium alloys was examined in a recent work by Mishra *et al*. They discovered that enhanced corrosion resistance was the consequence of FSP-induced microstructural refinement and redistribution of alloying elements, which is explained by the development of a protective oxide layer on the surface. According to the study, FSP may be used as a surface modification method to reduce corrosion in aluminium alloys [2].

The effect of FSP on the structural characteristics and microstructure of functionally graded AA7075 was examined by Veeramallu *et al.* in 2022. The hardness variation of the FSPed samples along their thickness direction was examined, and the impact of tool traversal speed on the microstructural evolution was examined. They discovered that the samples' hardness varied along their thickness, with higher traverse speeds resulting in lower hardness because of insufficient stirring time. According to the study, functionally graded materials with customized mechanical properties can be created using FSP [3].

The effects of external cooling on the fatigue behaviour of FSPed AA-6061 were studied by Satyanarayana *et al*. in 2022. They found that recrystallized fine grains and evenly dispersed precipitates from external cooling generated a stir zone with enhanced fatigue life and decreased fatigue crack propagation rate. The study emphasized how cooling-assisted FSP improves aluminium alloy fatigue performance and microstructural stability [4].

Yadav *et al*. presented "Effect of Process Parameters on Microstructure and Mechanical Properties of Friction Stir Processed Al-Cu Alloy". This investigation analysed the impact of process parameters on the mechanical properties and microstructural features of Al-Cu alloy during Friction Stir Processing (FSP), encompassing traverse speed and tool rotation rate. To improve the process variables for improving material qualities, the researchers examined the FSPed samples' hardness, tensile properties, and grain size distribution [5].

EXPERIMENTATION

Singh *et al*. presented “Animal waste powder utilization for Al6061/ SiC composite using friction stir processing with scroll shoulder hexagonal tool”. This study addresses the use of chicken bone powder (CBP) as reinforcement in AA6061/SiC composite to minimize costs while preserving quality. Various CBP percentages (2, 4, and 6%) together with 2% SiC are evaluated using a scroll shoulder hexagonal tool for manufacture. Analysis techniques include microstructural analysis, SEM, EDS, XRD, tensile strength, fractography, hardness testing and tool analysis. Results show reduced grain size of SiC and CBP particles, homogeneous distribution of reinforcement without agglomeration, increased tensile strength, absence of harmful contaminants in XRD, and significant improvements in tensile strength (up to 29.28%) and hardness (up to 18.22%) with higher CBP percentages. Overall, the work illustrates the feasibility and usefulness of employing animal faeces as reinforcement in composite materials (Figure 1) [6].

Aluminium alloy 7075-T6 plates were utilized as the base material, while SiC powder with a particle size ranging from 30 to 40 µm served as reinforcement. These materials were processed using an H13 steel tool. The base material, also referred to as the matrix material, consisted of 7075-T6 aluminium alloy plates measuring 180 mm×70 mm×8 mm. AA7075 contains zinc as a major alloying element, renowned for its notable attributes such as fatigue resistance, ductility, strength, and toughness. The chemical composition of AA 7075-T6 is delineated in Table 1.

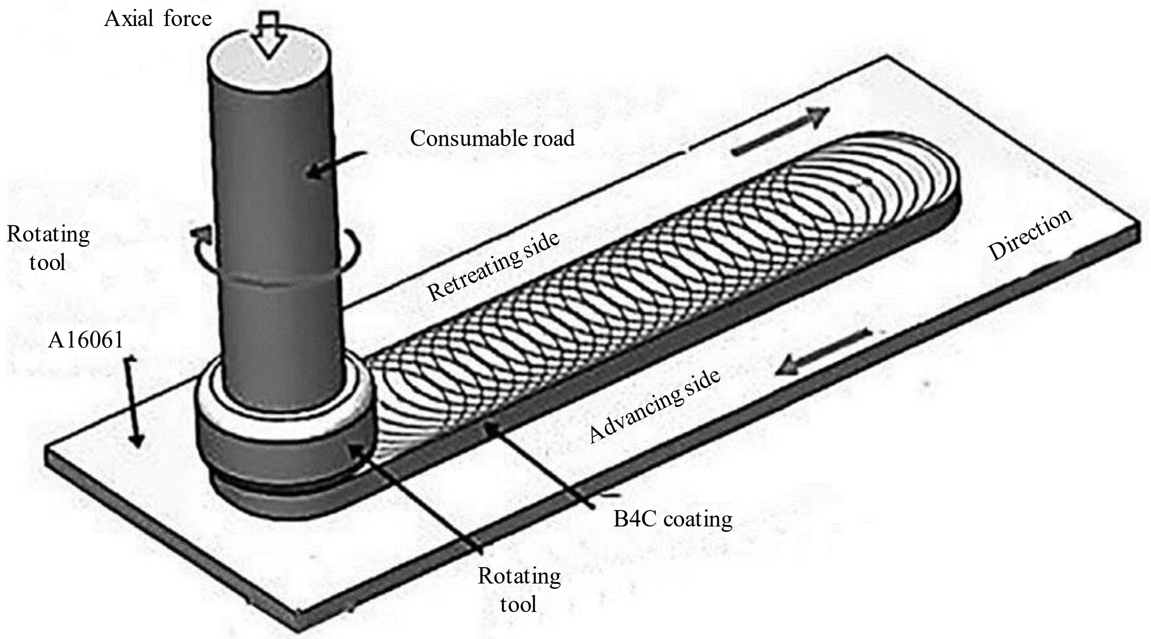

Figure 1. Schematic illustration of FSP (Al6061-B4C) [7].

Table 1. Chemical composition of AA 7075-T6 [3].

Element	Cr	Fe	Si	Mg	Mn	Cu	Zn	Ti	Al
Wt%	0.21	0.25	0.3	2.4	0.05	1.43	5.7	0.01	Bal

Figure 2. (a) H13 tools used in fabrication of Functionally Graded Material (AA 7075-T6); (b) FSP setup; (c) Processed samples of Functionally Graded Material (AA 7075-T6) [3].

Veeramallu *et al*. worked on the parameters as transverse speed of 50, 40 and 30 mm/min and rotational speed of 1000 rpm for samples S1, S2 and S3 respectively [3].

Boopathi *et al*. demonstrated that altering the volume fraction of B4C from 5 to 15% resulted in a significant improvement in tensile strength, with values escalating from 259.8 to 313.4 MPa. This observed increase in tensile strength can be attributed to the reinforcing effect of B4C particles, which induce disparities in thermal coefficients between the Al6061 matrix and B4C components. Consequently, these discrepancies lead to elevated dislocation densities within the material, thus restricting dislocation movements and effectively strengthening the composite (Figures 2 and 3) [7].

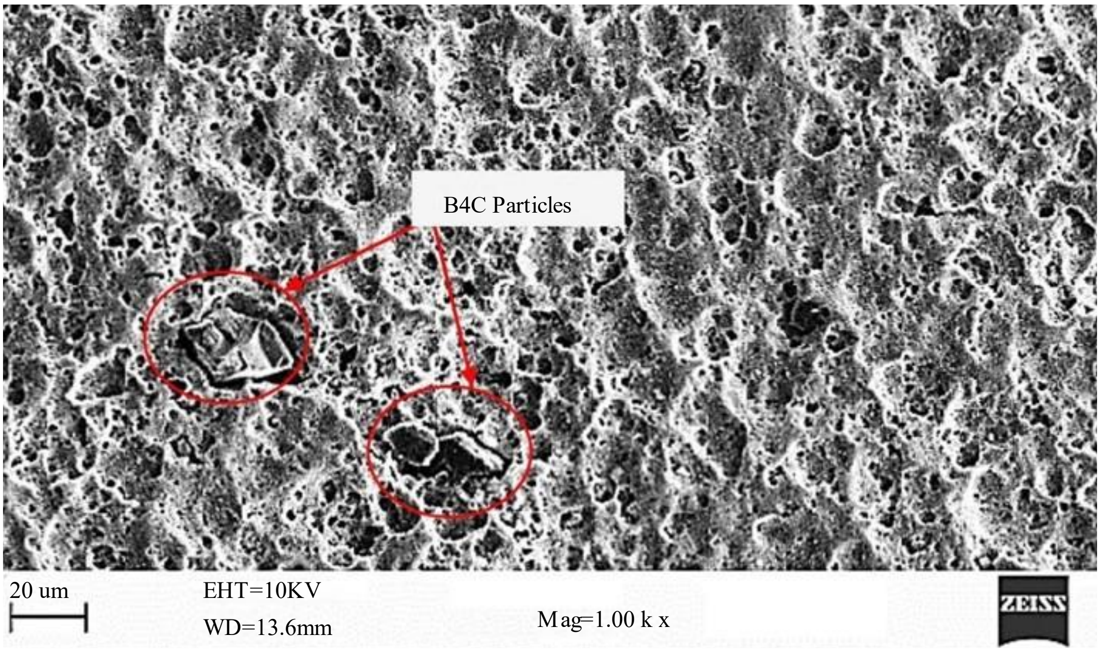

Figure 3. SEM image of Al-B4C composite (15% B4C) at 40 mm/min traversing speed.

Moreover, the uniform diffusion of B4C throughout the AA-matrix via the Orowan process further enhances the material's load-carrying capacity. These findings underscore the crucial role played by the volume fraction of B4C in determining the mechanical properties of the composite, highlighting the potential for tailored improvements in material strength through precise control of reinforcement content. Elevating the rotational speed of the tool augments the frictional heat generated between the tool and the workpiece, leading to plasticization. This process actively improves the grain structure of the aluminium alloy through the action of the stirring pin, consequently boosting tensile strength. Optimal tool traverse speed is critical for optimum tensile strength, as both high and low feed rates and rotational speeds of the tool result in incorrect material moltenization [7].

The microstructures of specimens processed at a rotational speed of 1000 rpm and a traversal speed of 50 mm/min unveil the dispersion of SiC particles within the aluminium matrix (Figure 4(a–c)). Noticeable coarse grains of SiC are apparent in the treated area due to particle aggregation. However, an escalation in traversal speed, resulting in insufficient stirring time, leads to a decline in the homogeneous dispersion of composite particles, as evidenced by the density gradient from the stir zone to the base metal zone. For example, at a traversal speed of 40 mm/min (Figure 4(d–f)), the microstructures portray SiC particles dispersed throughout the matrix in a FGC [3].

This distribution encompasses both coarse and fine SiC particles, with the generation of microscale grains attributed to dynamic recrystallization induced by intense deformation of the material in the region where stirring occurs. This variation in particle concentration is observed across the stir zone to the base metal zone. Similarly, at a traversal speed of 30 mm/min (Figure 4(g–i)), the microstructures depict SiC particles embedded within the aluminium alloy, highlighting the intricate relationship between processing parameters and resulting microstructural features in the composite material [3].

Kumar *et al*. presented "Effects of Threaded and Straight Cylindrical Tool Pin Designs on the Growth of Friction Stir Processing and Friction Stir Welding Zones in Al1100 Alloy". This study examined the effects of threaded and straight cylindrical tool pin designs on the growth of FSP and FSW zones in Al1100 alloy. The researchers investigated the joint elongation and mechanical properties of the processed samples using different tool pin profiles. The study highlights the impact of tool design on the microstructural progression and structural behaviour of FSPed joints [8].

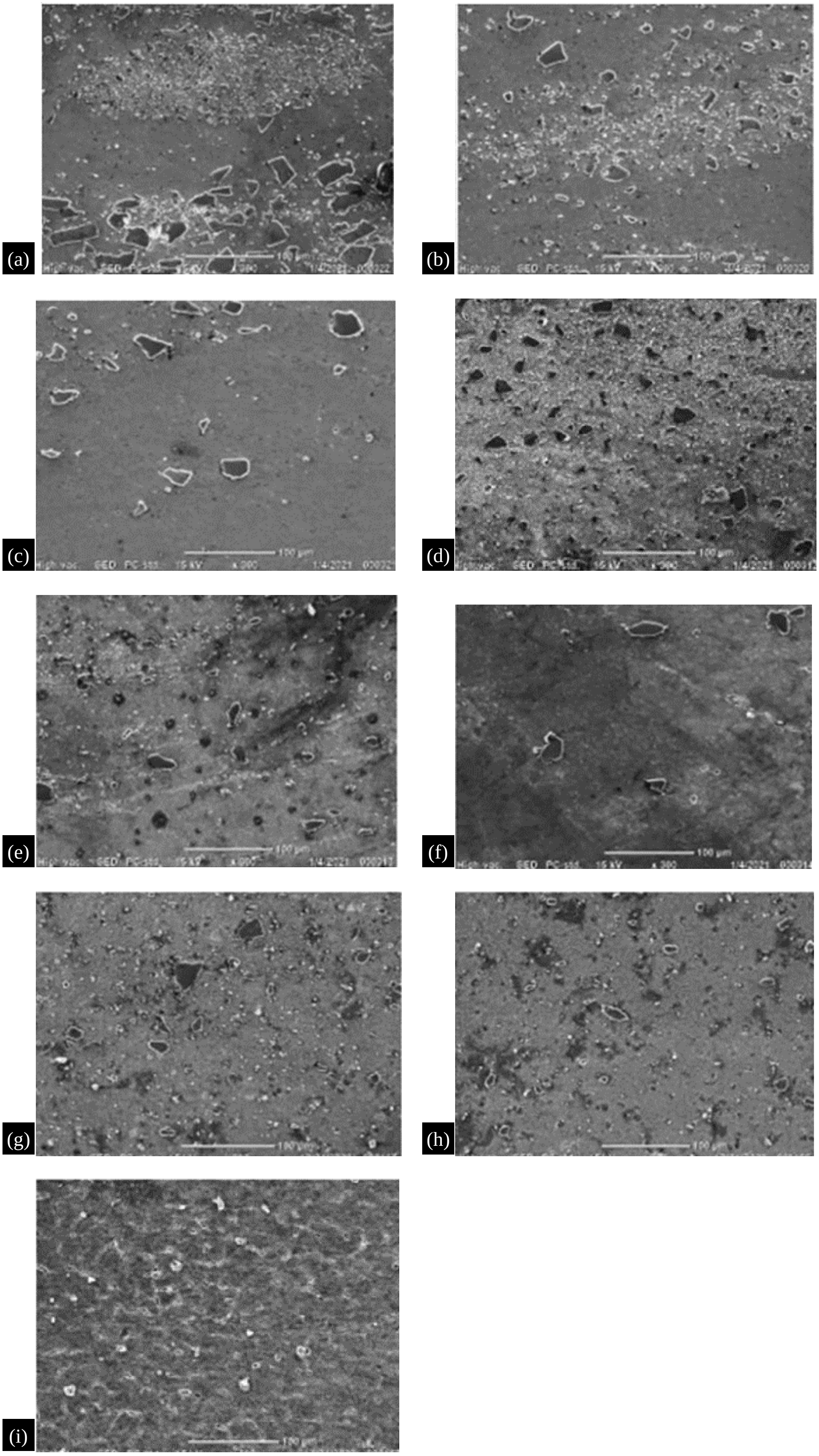

Figure 4. SEM images of FSPed Al7075-T6 [3].

According to Veeramallu *et al*., wear rate of the substrate material outperforms that of the manufactured graded composites due to the inclusion of reinforced SiC particles in the processed specimens [3]. As the hardness increases, there is a corresponding reduction in the wear rate, emphasizing the influential role of material hardness in wear resistance. Furthermore, it is noteworthy that the wear rate of the sample demonstrates a consistent increase with the applied load, underscoring the direct relationship between applied load and wear rate observed in the experimental samples. These findings underscore the effectiveness of incorporating SiC reinforcement in enhancing the wear resistance of the composite material compared to the base material (Figure 4).

According to Boopathi *et al*., the wear of the composite material was found to decrease, with the lowest wear rate recorded at 55 mm, as the volumetric fraction of B4C particles, rotational speed (1200 rpm), and tool feed rate (40 mm/min) increased [7]. Remarkably, the influence of the volumetric fraction of B4C particles on wear characteristics significantly outweighs that of tool traverse and rotational speed. Therefore, the volumetric fraction of B4C emerges as a pivotal factor affecting wear performance in the composite material, highlighting its importance in enhancing wear resistance, as indicated by the study's results.

DISCUSSION OF RESULTS

Based on the analysis of the works of Veeramallu *et al*. [3] and Boopathi *et al*. [7], it can be deduced, in turn, that the specimen of FSPed aluminium-alloy, considering the parametric values and the obtained experimental findings, may be said to:

1. The specimen's surface, post-FSP treatment, shows notable improvement.
2. The macrostructure, having undergone FSP, presents a seamlessly smooth path with no discernible signs of damage.
3. Across various conditions subsequent to friction stir processing, the microstructure exhibits consistent refinement and remains devoid of any fractures.

Singh et al. conducted an extensive study on the microstructure of AA6061/2 wt% SiC and 6 wt% CBP hybrid composites using scanning electron microscopy (SEM). Their analysis revealed a uniform distribution of SiC and CBP particles within the matrix [6]. The study elucidated that the augmentation of CBP weight percentage from 0 to 6% leads to notable improvements in mechanical properties such as tensile strength and hardness, resulting in gains of 29.28 and 18.22% respectively. Additionally, XRD pattern analysis confirmed the absence of undesirable chemicals within the composite, further validating its compositional integrity. Fractography examination unveiled ductile behaviour characterized by the presence of circular and micro-dimple formations, which contribute significantly to the enhancement of tensile strength. Furthermore, elemental analysis conducted on the High-Speed Steel (HSS) tooltip revealed the identification of Aluminium (Al) and Silicon (Si) particles which indicates a thermal transformation occurring during processing between the tool and the AA6061 substrate. These findings collectively underscore the efficacy of SiC and CBP reinforcement in improving the mechanical properties of the composite, while also highlighting the importance of compositional integrity and thermal processing considerations in optimizing material performance [6].

Boopathi *et al*. demonstrated that raising the volume percentage of B4C in Al6061 composite boosts tensile strength through several processes such as producing discrepancies in thermal coefficients and enhancing dislocation densities [7]. Optimal tool parameters, like rotation and traverse speed, were discovered to optimize grain structure, optimizing tensile strength. Microstructural study found that differing processing parameters change the distribution of Silicon Carbide particles, which in turn impacts wear rates.

Veeramallu *et al.* discovered lower wear rates in reinforced composites due to enhanced hardness [3]. Additionally, Boopathi *et al.* revealed that least wear occurs with larger B4C volume percentage and specific tool parameters, demonstrating the substantial influence of B4C on wear attributes [7].

CONCLUSION

Therefore, it is evident from the mentioned citations and references that the characteristics and properties of various aluminium alloys can be enhanced through a variety of methods. These advancements have significant implications for industries such as manufacturing, automotive, and aerospace. Thus, improving these factors is a crucial aspect for various applications across these industries.

REFERENCES

1. Kumar PN, Jayakumar K. Influence of tool pin profiles in the strength enhancement of friction stir welded AA5083 and AA5754 alloys. Mater Res Express. 2022;9. doi: 10.1088/2053-1591/ac5956.
2. Long F, Liu Q, Chen G, Zhou M, Shi Q. Improved corrosion resistance achieved in a friction stir processed Mg-5Zn-0.3Ca alloy with fragmented precipitates. Corros Sci. 2022;208:110675. DOI: 10.1016/j.corsci.2022.110675.
3. Veeramallu K, Sunkari S, Mishikari N. Experimental investigation on microstructure and mechanical properties of functionally graded AA7075 using friction stir processing. Mater Today: Proc. 2022; 56(Pt 3): 1551–1557.
4. Satyanarayana MVNV, Bathula S, Kumar A. Effect of external cooling on fatigue crack growth behaviour of friction stir processed AA6061 alloy. Eng Fract Mech. 2022; 261: 108236.
5. Kumar A, Sharma SK, Pal K, Mula S. Effect of process parameters on microstructural evolution, mechanical properties and corrosion behavior of friction stir processed Al 7075 alloy. J Mater Eng Perform. 2017;26:1122-1134. DOI: 10.1007/s11665-017-2572-3.
6. Gupta P, Singh H, Kumar S. Animal waste powder utilization for Al6061/SiC composite using friction stir processing with scroll shoulder hexagonal tool. Proc Inst Mech Eng E: J Process Mech Eng. 2023; 237(5): 1976–1987.
7. Boopathi S, Thillaivanan A, Pandian M, Subbiah R, Shanmugam P. Friction stir processing of boron carbide reinforced aluminium surface (Al-B4C) composite: Mechanical characteristics analysis. Mater Today: Proc. 2022; 50(Pt 5): 2430–2435.
8. Kumar R, Kumar H, Kumar S, Chohan JS. Effects of tool pin profile on the formation of friction stir processing zone in AA1100 aluminium alloy. Mater Today Proc. 2022;48:1594-1603. DOI: 10.1016/j.matpr.2021.09.491.

