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Effect of Adding Novel SiC Nanoparticles to the Stir Zone of AZ31B Magnesium Alloy Joined by Double-sided Friction Welding Process

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Abstract

The principal aim of this research is to systematically examine the effects arising from the addition of SiC (Silicon carbide) nanoparticles into the stir zone of AZ31B magnesium alloy during the process of double-sided friction welding. The study utilized two groups of sample specimens - the control group consisting of AZ31B magnesium alloy joined by double-sided friction welding (N = 20), and the experimental group consisting of AZ31B-SiC composite joined by double-sided friction welding (N = 20). The G-power analysis was employed with a power of 80% and $\alpha = 0.05$ to calculate the sample size, resulting in a total sample size of 40. The analysis of double-sided friction welding for AZ31B-SiC composite resulted in a measured tensile strength of 215.40 MPa, while the AZ31B alloy achieved a tensile strength of 190.78 MPa. The observed outcomes revealed a statistically significant distinction between the two groups, with a calculated p-value of 0.001 ($p < 0.05$). The incorporation of novel SiC nanoparticles into the stir zone of AZ31B magnesium alloy during the double-sided friction welding process yields a substantial enhancement in the properties of the joint. This improvement is evident through the higher tensile strength achieved by the AZ31B-SiC composite compared to the AZ31B alloy. The obtained results highlight the prospective efficacy of SiC nanoparticle reinforcement in augmenting the mechanical properties of double-sided friction welded AZ31B magnesium alloy, thereby positioning it as a promising and viable approach for a diverse range of engineering applications.

Keywords

Double-sided friction stir welding, Magnesium alloy AZ31B, Novel SiC nanoparticles, Mechanical properties, Sustainable production

Introduction

Magnesium alloys have garnered substantial prominence in diverse industries, including aerospace, automotive, and biomedical, due to their remarkable strength-to-weight ratio. However, their low ductility makes them susceptible to cracking and fracture during fabrication and usage. To enhance their properties, one promising approach is the addition of reinforcing nanoparticles, like SiC, to magnesium alloys. This research paper aims to investigate the impact of incorporating novel SiC nanoparticles into the stir zone of AZ31B magnesium alloy using a double-sided friction welding process. The primary focus is to evaluate the resulting composite material's microstructure, mechanical properties, and fracture behavior. By studying these aspects, the researchers aim to understand the potential benefits and limitations of using SiC-reinforced magnesium-based materials. The outcomes of this study could hold significant implications for the development of advanced magnesium-based materials with improved mechanical properties. These findings may pave the way for their application in various industries, leading to the creation of more durable and high-performance materials in aerospace, automotive, and other sectors [1].

Magnesium alloys represent a promising and innovative class of lightweight structural materials with outstanding mechanical properties. However, their widespread application is hindered by their inherent shortcomings in wear and corrosion resistance. To address this limitation, one approach is to enhance these properties by incorporating reinforcing nanoparticles into the magnesium matrix, such as SiC. This study is dedicated to the examination of the effects resulting from the introduction of novel SiC nanoparticles into the stir zone of AZ31B magnesium alloy using the double-sided friction welding technique. The main objective is to thoroughly assess the resulting composite material's microstructural, mechanical, and wear properties. By comprehensively analyzing these aspects, the research aims to pave the way for the development of advanced lightweight materials with significantly improved mechanical and wear properties. Such advancements hold immense significance for a diverse range of engineering applications where the need for lightweight, durable, and wear-resistant materials is of paramount importance [2].

The effectiveness of the novel SiC nanoparticles in the study may be influenced by specific processing conditions. Variations in welding speed or pressure could lead to different outcomes in the material's mechanical properties. Moreover, the distribution of nanoparticles within the magnesium alloy might not be uniform, resulting in variations in mechanical properties throughout the material. Clumping and agglomeration of nanoparticles could reduce their effectiveness in improving the alloy's mechanical properties. Weak bonding between nanoparticles and the magnesium alloy matrix could lead to poor load transfer and reduced mechanical performance. To address these challenges and ensure sustainable production, efficient and responsible use of resources and energy is essential. Sustainable production techniques, such as incorporating renewable energy sources and minimizing waste and emissions, can reduce the environmental impact during the manufacturing of novel SiC nanoparticles and AZ31B magnesium alloy. The implementation of sustainable practices can also enhance the longevity and durability of the final product, reducing the need for constant maintenance or replacement and minimizing waste generation. Considering the critical role of sustainable production in this research, it becomes pivotal in lessening the environmental impact of the manufacturing process and guaranteeing the long-term viability and sturdiness of the resulting composite material [3]. By integrating sustainable practices, the study's findings can be even more relevant in advancing lightweight materials with improved mechanical properties while maintaining environmental responsibility for current and future generations.

Materials and Method

The primary objective of this study is to investigate the consequences arising from the incorporation of novel SiC nanoparticles into the stir zone of AZ31B magnesium alloy using the double-sided friction welding process. To accomplish this, a series of techniques were employed to prepare the materials, conduct the welding process, and analyze the resulting welded joint. The sheet of AZ31B magnesium alloy was initially cleaned using acetone to eliminate any oil or dirt, ensuring a clean surface for the subsequent processes. Following this preparation, the AZ31B magnesium alloy sheet was cut into smaller pieces to facilitate the welding procedure. In order to characterize the novel SiC nanoparticles, two analytical techniques, namely scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX), were employed. SEM facilitated the examination of the nanoparticles' morphology and structure, affording detailed insights into their size, shape, and distribution. EDX, on the other hand, enabled the elemental analysis of the nanoparticles, verifying the presence and composition of SiC in the synthesized material. The novel SiC nanoparticles were produced using a chemical vapor deposition method, which involves the chemical reaction of precursor gases to deposit SiC particles onto a substrate. Through the utilization of SEM and EDX to characterize the nanoparticles, the researchers acquire crucial information regarding their physical and elemental properties. This data proves essential in assessing their potential influence on the mechanical properties of the AZ31B magnesium alloy during the friction welding process [4].

In the preparation stage before welding, ethanol chemical was utilized to clean the plates thoroughly, ensuring the removal of any surface impurities or contaminants. The cleaned plates, each having a thickness of 4 mm, were then mounted on a vertical milling machine with a capacity of 10 HP and a rotation speed of 3000 rpm, specifically intended for friction stir welding (FSW). The welding equipment used in the process was constructed from Tool Steel, known for its durability and suitability for FSW applications. Prior to commencing the FSW process, meticulous insertion of SiC particles was executed into a groove on the plate, following several predefined scenarios. These SiC particles function as reinforcing nanoparticles, intended to enhance the mechanical properties of the resultant composite material. The actual welding procedure was carried out utilizing a vertical milling machine, ensuring meticulous control and stability during the entire process. The experimental setup employed in this study, along with the use of specific welding equipment, enables a comprehensive investigation into the effects arising from the incorporation of SiC nanoparticles into the AZ31B magnesium alloy through the FSW technique [5].

The FSW process involved the insertion of the tool into an 18 mm-diameter tool holder. Initially, unstepped machined plates measuring 100 mm x 50 mm of magnesium alloy AZ31B without reinforcement were welded. The welding operation was conducted on a vertical milling machine, operating at a rotational speed of 1400 rpm and a feed rate of 25 mm/min [6]. To introduce reinforcement particulates, the ends of the workpieces were milled into stepped shapes. A groove was formed at the point of convergence between the two stepped ends of two plates, resulting in a butt joint. The dimensions of the groove, including its width and depth, were determined based on the desired volume percentage variation of the reinforcement particulates. Magnesium alloys, comprising magnesium, the lightest structural metal, and other elements such as aluminum, zinc, manganese, silicon, copper, rare earth elements, and zirconium, exhibit unique properties influenced by their hexagonal lattice structure. Due to the complexity of plastic deformation in hexagonal lattice metals compared to cubic lattice metals like aluminum, copper, and steel, magnesium alloys are primarily utilized as cast alloys. However, since 2003, there has been a significant expansion in research on wrought alloys [7]. The use of FSW and the integration of reinforcement particulates in this study present opportunities for enhancing the properties of magnesium alloys, potentially leading to advancements in industries that require lightweight and high-strength materials.

Statistical analysis

In the course of the study, an independent t-test was performed, and the resulting data was collected and recorded in an Excel spreadsheet. To perform a more detailed statistical analysis, the data from the Excel sheet was imported into the SPSS (Statistical Package for the Social Sciences) software. The independent variables in this analysis are the feature extracted values, while the dependent variables are accuracy, specificity, and sensitivity. SPSS is a robust software extensively employed for statistical analysis across diverse research domains. By importing the data from the Excel sheet into SPSS, researchers can perform a comprehensive statistical evaluation, including measures such as means, standard deviations, confidence intervals, and hypothesis testing, to assess the significance of the differences in accuracy, specificity, and sensitivity based on the feature extracted values [8, 9]. Through this analysis, the researchers aim to gain deeper insights into the relationships between the independent and dependent variables, contributing to a more robust understanding of the impact of feature extracted values on accuracy, specificity, and sensitivity in the study conducted by Wang et al. [10].

Results

Table 1 presents the outcomes of measuring the performance of novel silicon nanoparticles upon their addition to AZ31-B within the stir zone during the process of double-sided FSW. For this test, the samples were examined 20 times, and the findings were recorded in MPa. Magnesium has a lower MPa rate (204.27) than silicon, which has a greater MPa rate of (260.14).

Table 2 encompasses the statistical analysis of mean, standard deviation, and mean standard error for the performance measurement when incorporating silicon nanoparticles into AZ31-B for stir zones using double-sided FSW methods. Tensile strength is a factor that is used in the t-test. Table 3 presents independent samples t-test for mechanical properties using FSW for AZ31B SiC alloy with filter and AZ31B magnesium alloy without filter.

Figure 1 SPSS mean accuracy comparison between magnesium nanoparticles and silicon nanoparticles. The first bar indicates the accuracy MPa rate of magnesium (-27.35350) and second bar indicates accuracy MPa rate (-27.35350). For this graph X-axis is considered as two algorithms and Y-axis is considered as mean accuracy with error bars +/- 1 standard deviation. Figure 2 represents tensile strength scientific diagram.

Table 1: The performance of novel silicon nanoparticles added to AZ31-B for stir zone with double-sided friction stir welding was measured. The samples were tested 20 times for this test, and the results were recorded in MPa. Silicon has a higher MPa rate of (260.14) than magnesium, which has a lower MPa rate of (204.27).

S. No.	Samples	Tensile strength (MPa)	
		AZ31-B/Mg (Group 1)	AZ31-B/SiC (Group 2)
1	Sample 1	150.16	156.55
2	Sample 2	152.38	164.34
3	Sample 3	154.57	172.54
4	Sample 4	158.58	174.63
5	Sample 5	160.51	178.97
6	Sample 6	162.58	180.30
7	Sample 7	164.72	185.84
8	Sample 8	168.40	188.38
9	Sample 9	170.89	194.64
10	Sample 10	174.82	198.98
11	Sample 11	178.66	202.36
12	Sample 12	180.86	205.86
13	Sample 13	182.36	208.62
14	Sample 14	186.29	212.44
15	Sample 15	190.78	215.40
16	Sample 16	194.39	224.38
17	Sample 17	196.29	270.47
18	Sample 18	198.66	232.47
19	Sample 19	200.39	250.34
20	Sample 20	204.27	260.14

Table 2: Group statistics results mean of SiC fiber without filter 230.12 is more compared to AZ31B alloy with 168.23 and standard error mean for SiC fiber is 27.98154 and for AZ31B alloy is 12.05774.

S. No.	Group	N	Mean	Std. deviation	Std. error mean
1	AZ31-B/Mg	20	176.5290	17.27343	3.86246
2	AZ31-B/SiC	20	203.8825	31.39156	7.01937

Table 3: Independent samples t-test for mechanical properties using FSW for AZ31B SiC alloy with filter and AZ31B magnesium alloy without filter. There is a significance mean difference between two methods with p = 0.040 < 0.05.

		Levene's test for equality of variances		T-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% CI of the difference	
									Lower	Upper
Tensile strength	Equal variance assumed	4.511	0.040	-3.414	39	<0.001	-27.35350	9.01197	-43.57268	-11.13432
	Equal variance not assumed			-3.414	29.540	<0.001	-27.35350	9.01197	-43.57268	-10.98038

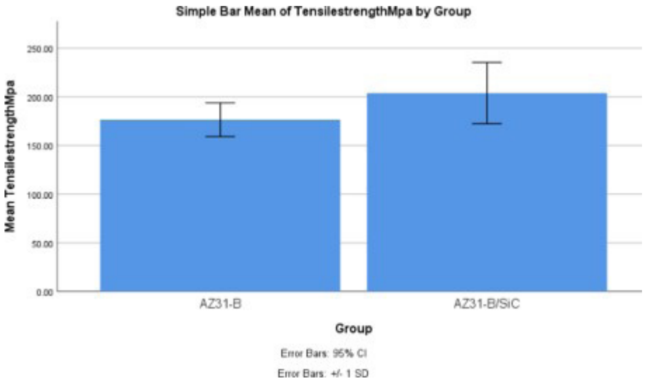

Figure 1: SPSS mean accuracy comparison between magnesium nanoparticles and silicon nanoparticles.

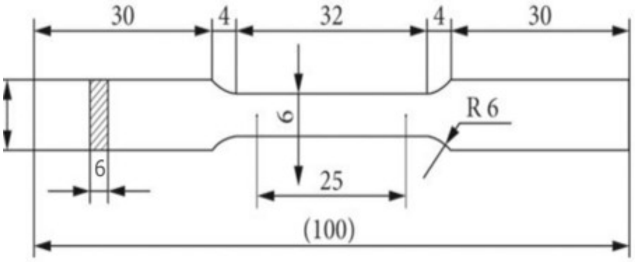

Figure 2: Tensile test scientific diagram.

Discussion

The friction stir welded joint sample with added SiC particles in the weld region exhibits a consistent and uniform distribution of SiC particles within the nugget zone. Moreover, the application of stirring action during the FSW process induces recrystallization, resulting in the refinement of grain sizes within the nugget zone. This phenomenon contributes to the alteration of microstructures in both weld conditions, i.e., without and with the inclusion of SiC particles [11]. The homogeneous dispersion of SiC particles in the weld region, coupled with grain refinement prompted by recrystallization, has the potential to enhance the mechanical properties and overall performance of the friction stir-welded joint. Such microstructural changes are of significant interest in assessing the impact of incorporating SiC nanoparticles on the material's structural integrity and mechanical behavior during FSW, as investigated by Mironov et al. [11].

During the FSW process, the dynamic movement, multiplication, and alignment of dislocations at high-angle boundaries give rise to the formation of a cell structure characterized by a small grain size. In the case of unreinforced friction stir welded joints, the grain size is smaller than that of the base material [12, 13]. However, in friction stir welds reinforced with SiC, an even smaller grain size is observed in comparison to unreinforced welds. This reduction in grain size in the reinforced welds can be attributed to the presence of SiC nanoparticles. The grain size refinement in the reinforced friction stir welds holds significant implications for their mechanical properties, as the mechanical properties of the welds are improved due to this grain size refinement [14]. Furthermore, the incorporation of SiC at the weld interface plays a pivotal role in suppressing grain growth, which further contributes to the enhancement of the mechanical properties in the welded region. The findings from the study conducted by Babu et al. [15] underscore the favorable impact of SiC reinforcement on the microstructure and mechanical properties of friction stir welded joints. The grain size refinement and prevention of grain growth are key factors in strengthening the welds, rendering them highly suitable for demanding engineering applications.

Conclusion

Successful FSW of magnesium alloy AZ31B was achieved in both cases, with and without SiC reinforcement. Notably, when SiC particles were incorporated as reinforcement at the weld interface during the FSW process of the magnesium alloy AZ31B, there was a substantial improvement in the mechanical properties. Specifically, the mechanical properties of SiC itself experienced an enhancement ranging from 10% to 25% due to this reinforcement. However, as the SiC percentage was further increased from 25% to 30%, there was a loss in properties. The study ascertained that the optimal volume proportion of SiC to enhance the mechanical properties of friction stir-welded joints made of magnesium alloy AZ31B was 25%. At this proportion, the grain size in the magnesium alloy AZ31B reinforced friction stir-welded joints was observed to be smaller in comparison to the unreinforced welded joints. This grain size refinement significantly contributes to the enhanced mechanical properties of the welds. Based on the study's findings, it is recommended to utilize the FSW process with the addition of SiC particles to the weld zone to achieve improved mechanical properties in AZ31 magnesium alloy welds. This approach can lead to stronger and more durable joints, making them suitable for various engineering applications [16].

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None.

Conflict of Interest

None.

References

1. Rahmatian B, Dehghani K, Mirsalehi SE. 2020. Effect of adding SiC nanoparticles to nugget zone of thick AA5083 aluminium alloy joined by using double-sided friction stir welding. *J Manuf Process* 52: 152-164. https://doi.org/10.1016/j.jmapro.2020.01.046
2. Fu B, Qin G, Li F, Meng X, Zhang J, et al. 2015. Friction stir welding process of dissimilar metals of 6061-T6 aluminum alloy to AZ31B magnesium alloy. *J Mater Process Technol* 218: 38-47. https://doi.org/10.1016/j.jmatprotec.2014.11.039
3. Mansoor B, Dorbane A, Ayoub G, Imad A. 2016. Friction Stir Welding of AZ31B Magnesium Alloy with 6061-T6 Aluminum Alloy: Influence of Processing Parameters on Microstructure and Mechanical Properties. In Mishra RS, Mahoney MW, Sato Y, Hovanski Y (eds) Friction Stir Welding and Processing VIII. Springer, Cham, pp 259-266.

4. Padmanaban G, Balasubramanian V. 2009. Effect of tool materials on tensile properties of friction stir welded AZ31B magnesium alloy. *Indian Weld J* 42(1): 25-32. https://doi.org/10.22486/iwj.v42i1.177979
5. Thakur A, Sharma V, Bhadauria SS. 2023. Improving tensile properties by varying the welding conditions of the passes of the double-sided friction stir welding of AZ31B magnesium alloy. *Mater Today Commun* 34: 105406. https://doi.org/10.1016/j.mtcomm.2023.105406
6. Baghdadi AH, Selamat NFM, Sajuri Z, Kokabi AH. 2018. Effect of travel speed on quality and welding efficiency of friction stir welded AZ31B magnesium alloy. *Int J Eng Technol* 7(3): 94-99. https://doi.org/10.14419/ijet.v7i3.17.16629
7. Thakur A, Sharma V, Bhadauria SS. 2021. Effect of tool tilt angle on weld joint strength and microstructural characterization of double-sided friction stir welding of AZ31B magnesium alloy. *CIRP J Manuf Sci Technol* 35: 132-145. https://doi.org/10.1016/j.cirpj.2021.05.009
8. Kumar VV, Raja K, Ramkumar T, Selvakumar M, Senthilkumar TS. 2021. Studies on mechanical property and wear behaviour of AA7075 hybrid composites prepared by a conventional casting method. *Proc Inst Mech Eng Part E J Process Mech Eng* 235(6): 2180-2188. https://doi.org/10.1177/09544089211034939
9. Kumar SS, Pandian RS, Ponnambalam SG, Pitchipoo P, Senthilkumar TS. 2023. Investigation of wear and wire electrical discharge machining characteristics of Al-Mg-MoS_2 composites using response surface method. *J Test Eval* 51(2): 828-857. https://doi.org/10.1520/JTE20220327
10. Wang X, Morisada Y, Fujii H. 2020. Flat friction stir spot welding of AZ31B magnesium alloy using double side adjustable tools: microstructure and mechanical properties. *Sci Technol Weld Join* 25(8): 644-652. https://doi.org/10.1080/13621718.2020.1802896
11. Mironov S, Ito T, Yun X, Motohashi Y, Funami K, et al. 2005. 312 features of stir zone structure resulted from friction stir welding of a ZK60 magnesium alloy. *Proc Ibaraki Dist Conf* 2005: 65-66. https://doi.org/10.1299/jsmeibaraki.2005.65
12. Balasubramanian B, Udayakumar T, Kumar VV, Raja K. 2022. Study of natural cellulose fiber's characters in *Holoptelea integrifolia* tree bark. *J Nat Fibers* 19(16): 13574-13581. https://doi.org/10.1080/15440478.2022.2101576
13. Balasubramanian B, Raja K, Kumar VV, Ganeshan P. 2022. Characterization study of *Holoptelea integrifolia* tree bark fibres reinforced epoxy composites. *Nat Product Res* 1-10. https://doi.org/10.1080/14786419.2022.2137505
14. Yokeswaran R, Vijayan V, Karthikeyan T. 2020. Study of various types cladding and the evolvement of the techniques through years and the future scope–a review. *Mater Today Proc* 21: 773-776. https://doi.org/10.1016/j.matpr.2019.06.756
15. Babu SR, Nithin M, Pavithran S, Parameshwaran B. 2017. Friction stir spot welding of AZ31B magnesium alloy. *Appl Mech Mater* 867: 105-111. https://doi.org/10.4028/www.scientific.net/AMM.867.105
16. Cojocaru R, Botila LN, Daşcău HF. 2022. Friction stir welding in inert gas environment (FSW-IG) of AZ31B magnesium alloy. *Defect Diffus Forum* 416: 21-29. https://doi.org/10.4028/p-cf7451