Nano World Journal

https://doi.org/10.17756/nwj.2023-s3-004

Research Article

Open Access

Experimental Investigation on Tribological Properties of AA7178 Reinforced ZrO_2/Fly Ash Metal Matrix Composite Using Novel Encapsulate Technique

Konka Mahesh[1], Lakshmaiya Natrayan[1*] and Titus Richard[2]

[1]Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India

[2]Department of English, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India

***Correspondence to:**
Lakshmaiya Natrayan
Department of Mechanical Engineering,
Saveetha School of Engineering,
Saveetha Institute of Medical and Technical Sciences,
Saveetha University,
Chennai, Tamil Nadu, India.
E-mail: natrayanl.sse@saveetha.com

Received: July 26, 2023
Accepted: September 25, 2023
Published: September 28, 2023

Citation: Mahesh K, Natrayan L, Richard T. 2023. Experimental Investigation on Tribological Properties of AA7178 Reinforced ZrO_2/Fly Ash Metal Matrix Composite Using Novel Encapsulate Technique. *Nano World J* 9(S3): S16-S21.

Published by United Scientific Group

Abstract

The goal of this research is to compare the wear characteristics of as-cast AA7178 alloy and AA7178 alloy reinforced with hybrid composites of fly ash and zirconium oxide ZrO_2 (5% and 5%) by using a novel encapsulating feeding of reinforcements in a stir-casting technique. The samples for both groups were fabricated using a novel encapsulating approach in the stir-casting method. A hybrid composite of fly ash (5%), ZrO_2 (5%), and AA7178 were mixed to prepare group 2 samples, whereas AA7178 as-cast was used for group 1. The samples were prepared following ASTM E92 standards, and their wear properties were examined using pin-on-disc equipment. Each group contains 20 samples. The G-power for this procedure is 80%, $\alpha = 0.05$ per set for determining sample size, and the sum of two sample size groups is 40. The maximum wear rate in as-cast AA7178 alloy material made with 0% reinforcement exhibits a 73.82% wear rate compared to the material made with AA7178 alloy with 5% fly ash and 5% ZrO_2. T-test statistical analysis shows a significant $p = 0.00$ ($p < 0.05$) difference in the mean-variance of wear rate between groups 1 and 2. Within the limitations of this study, it is noticed that adding 5% fly ash and 5% ZrO_2 reinforcement with AA7178 alloy significantly decreases the wear rate of a material.

Keywords

AA7178, Fly ash, Hybrid composite, Modern energy, Novel encapsulate, Stir casting, Wear rate, Sustainability

Introduction

Many experiments are being conducted in the aerospace industry to improve efficiency, lower fuel consumption, lower emissions, and increase aircraft payload capacity. One such study on reducing weight while increasing aircraft strength is only possible using advanced materials. These advanced material properties improved to meet current safety and operational standards in compliance with technological advancements [1] because of current technology demands and consumer expectations for systems and equipment that are more energy efficient, stronger, lighter, and less expensive. There will always be a demand for new and advanced materials. Aluminum metal matrix composites are considered more advanced materials in a variety of industries, including shipbuilding, aircraft, structural applications, electrical appliances, food packaging, and transportation, due to their high strength-to-weight ratio, corrosion resistance, and attractive mechanical properties obtained through thermal processing [2]. Aluminum is often considered the best metal for aircraft production in the aerospace industry due to its corrosion resistance, high strength, and low density. Aluminum metal matrix composites (MMCs) metals that have been reinforced with other metals, ceramics, or organic components to improve the base metal aluminum can be achieved by distributing reinforcements throughout the metal. Reinforcements are frequently used to enhance the base metal's properties like hardness, strength, stiffness, conductivity, corrosion resistance, and wear resistance while minimizing the weight of the base metal [3-6].

Over the last five years, several investigations on aluminum7178 and its wear properties have been undertaken. There are 247 research publications in Google Scholar and 43 articles in Science Direct about the AA7178 and its wear attributes. Effect of ZrB_2 on microstructural, mechanical, and corrosion behavior of aluminum (AA7178) alloy matrix composite prepared by the stir casting route. Machinability studies of aluminium-7075 alloy-based hybrid composites. An integrated artificial neural network and Taguchi approach to optimize the squeeze cast process parameters of AA6061/Al_2O_3/SiC/Gr hybrid composites prepared by a novel encapsulation feeding technique [7]. Synthesis of zinc oxide and CNT in AA7178 aluminum alloy composite impression on characteristics. The role of artificial neural networks in prediction of mechanical and tribological properties of composites-a comprehensive review. Research summary on the processing, mechanical and tribological properties of aluminum matrix composites as affected by fly ash reinforcement [8]. A review on mechanical properties and tribological characteristics of stir cast aluminum MMCs. A case study of mechanical and tribological properties with different reinforcements in aluminum based MMCs. The study on the novel feeding approach in squeeze casting is rated as one of the finest, in which they introduced a new technique in feeding reinforcement to strengthen aluminum characteristics by minimizing casting faults and produced good results compared to earlier studies. This analysis of a novel feeding method also enhances MMC with a lesser wear rate compared to earlier studies that employ the same reinforcement material producing a lower wear rate, compared to our study that uses a novel feeding technique with stir-casting.

Only a few studies have been published on hybrid MMCs produced by novel encapsulating techniques. This research aims to develop an AA7178/5% fly ash/5% ZrO_2 hybrid composite employing novel encapsulating feeding in stir casting technique. The wear rate of AA7178 alloy as-cast and AA7178 alloy with hybrid composites were examined, outcomes shown in table 1.

Materials and Method

This research was conducted at the Institute of Mechanical Engineering, Saveetha Industries, Saveetha School of Engineering, and Saveetha Institute of Medical and Technical Sciences, Chennai (Tamil Nadu, India). In this study, two groups of samples were fabricated for comparing wear properties: one group of samples is made up of as-cast AA7178, and the other group samples are prepared with reinforcement materials of 5% fly ash and 5% ZrO_2, as shown in figure 1. To compare wear qualities, 8 mm diameter and 30 mm long pieces of as-cast AA7178 metal and AA7178 with reinforcements metal employed in the experiment shown in figure 2. There are two groups of 40 samples each. G-power was revealed to be


Figure 1: Reinforcements of 5% fly ash and 5% ZrO_2.

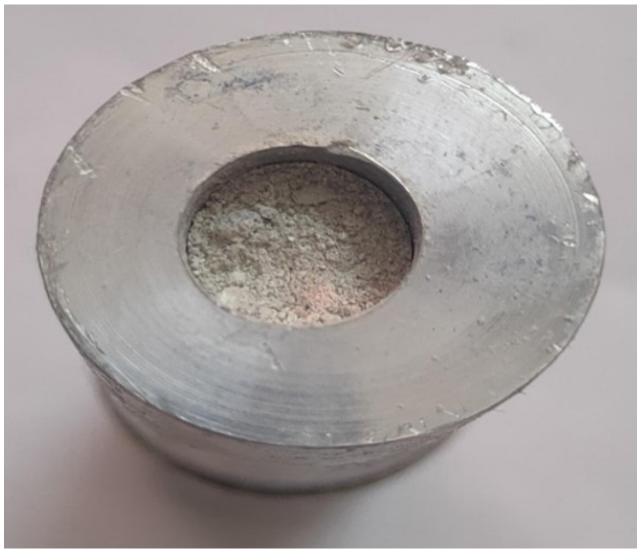
Figure 2: Feeding of 5% fly ash and 5% ZrO_2 to novel encapsulated AA7178.

80% after testing samples from each group of 20 [9-10].

For fabricating the 20 samples in group 1 of this study, a 20 mm diameter rod of the as-cast aluminum alloy 7178 was utilized as the material. To get a good surface finish and to eliminate the metallic burrs on the ends of the rod, the rod is first machined on a lathe [11]. After the machining procedure, these AA7178 rods are deposited inside the graphite crucible. The graphite crucible is then placed within the furnace and allowed to heat up to 700 °C. The aluminum alloy entirely melts and converts into a molten state at this temperature, as shown in figure 3. The crucible is taken out of the furnace, and the molten aluminum metal is poured into the die under gravity and enables solidification [12]. The solidified aluminum is finally removed from the die and sliced into pieces 8 mm in diameter and 30 mm in length to test the samples' wear properties.

For fabricating the 20 samples in group 2 with hybrid reinforcement material of 5% fly ash and 5% ZrO_2 used in this study shown in figure 1. Initially, a 20 mm diameter AA7178 rod needs to be machined on a lathe to get rid of metallic burrs on the ends. A 2 mm drill bit is used to drill a hole in the center of one end of the rod. These holes are enlarged by using drill bits of the 4 mm, 6 mm, and 10 mm sizes to drill holes on all the rods that have a depth of 50 mm. These holes were filled with reinforcements of 5% fly ash and 5% ZrO_2, then holes were sealed with a lathe-machined 15 mm thick cap known as the novel encapsulates feeding technique shown in figure 2. Following this novel encapsulation feeding, all AA7178 rods encased by caps are kept within the crucible. The crucible is brought into the furnace and warmed to 700 °C to bring the AA7178 rods into the molten state illustrated in figure 3. This molten aluminum MMC is agitated to ensure its reinforcements are consistently blended [13, 14]. Then the molten aluminum is allowed to solidify in the die. Finally, enhanced metal is extracted from a die, and the solidified metal is divided into 8 mm diameter and 30 mm length pieces for testing the sample's wear properties.

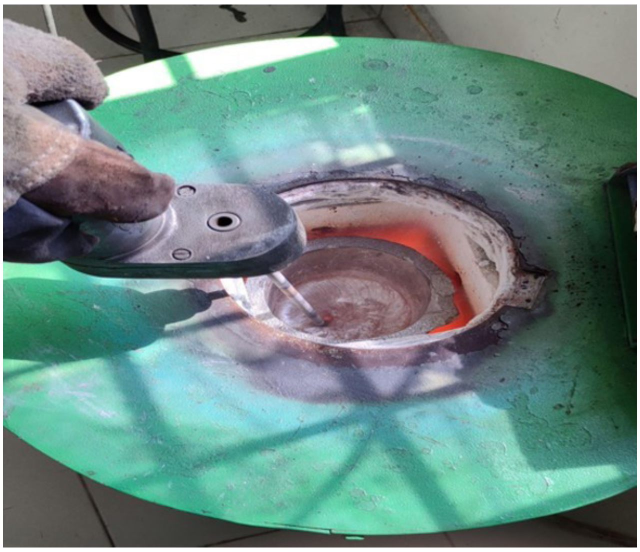

Figure 3: Stir casting setup.

Using pin-on-disc equipment shown in figure 4, a wear resistance test is conducted on both as-cast AA7178 samples and samples of AA7178 reinforced with hybrid composite. According to the ASTM E92 standard for wear properties testing, each of the 20 samples in two groups is sliced into pieces in 8 mm diameter and 30 mm height. In figure 5, the counter surface of the pin-on-disc machine is made up of oil hardened nickel steel with specifications of 55 mm diameter and 60 HRc hardness shown in figure 5. The test employed a variety of loads that are 20 N, 40 N, and 60 N and sliding speeds of 0.6, 0.8, and 1.0 m/s conducted along a continuous sliding distance of 2000 m [15]. This test is carried out at a room temperature of 30 °C. Figure 6 shows the reinforced specimen after undergoing wear testing.

The above approach will be followed for all 20 samples in each group. Table 1 depicts the wear resistance values of all 20 samples of as-cast AA7178 without reinforcements, whereas table 2 reveals the wear resistance values of all 20 samples of AA7178 with reinforcements

Figure 4: Pin-on-disc equipment.

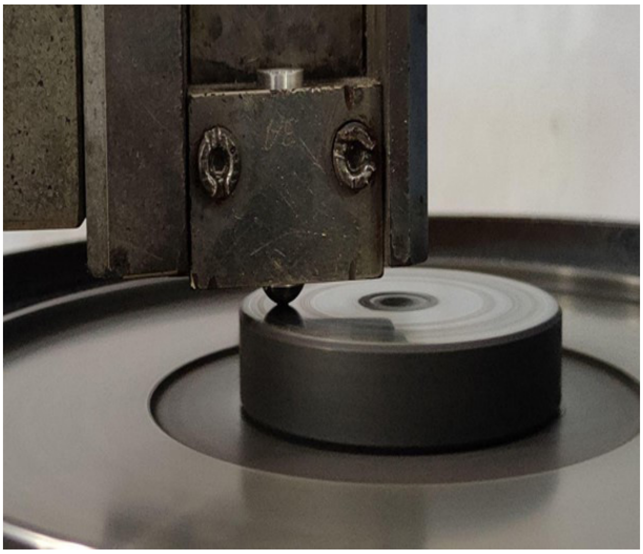

Figure 5: Specimen is undergoing wear test on the counter surface of pin-on-disc equipment.

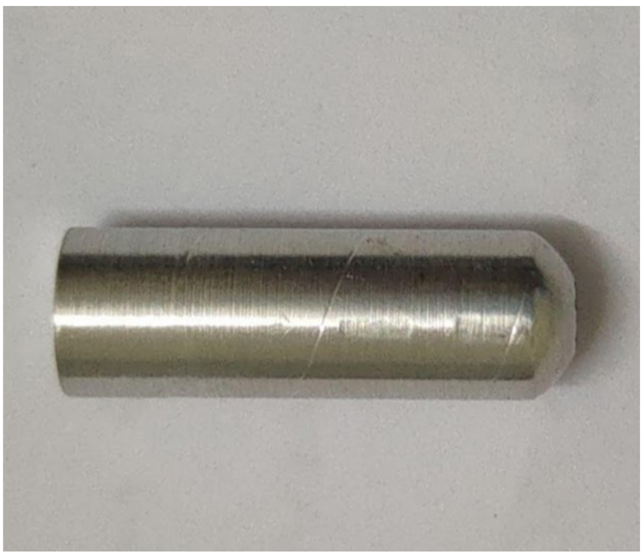

Figure 6: Reinforced specimen after wear testing.

Table 1: The wear rate of as-cast AA7178 and AA7178 reinforced with 5% of ZrO_2 and 5% of fly ash.

Sample number	As-cast AA717 (10^{-5})	AA7178 with 5% of fly ash and 5% of ZrO_2 (10^{-5})
1	3.372	0.956
2	3.334	0.918
3	3.347	0.931
4	3.313	0.897
5	3.324	0.908
6	3.338	0.922
7	3.315	0.899
8	3.309	0.893
9	3.306	0.890
10	3.263	0.847
11	3.273	0.857
12	3.235	0.819
13	3.248	0.832
14	3.214	0.798
15	3.225	0.809
16	3.239	0.823
17	3.216	0.800
18	3.210	0.794
19	3.207	0.791
20	3.164	0.748

Table 2: Group statistics of wear rate in as-cast AA7178 without reinforcement and AA7178 with reinforcement of 5% of fly ash and 5% of ZrO_2.

Group statistics		N	Mean	Std. deviation	Std. error mean
Wear rate	As-cast AA7178 without reinforcement	20	3.2726	0.05810	0.1299
	AA7178 with 5% of fly ash and 5% of ZrO_2	20	0.8566	0.05810	0.1299

Statistical analysis

Using the SPSS software (Statistical Package for the Social Sciences), t-test is carried out on wear resistance values obtained from the samples of both groups. The statistical tool SPSS generates descriptive and Bonferroni analyses. In this experiment, the independent variables are the stirring speed and the weight percentage of reinforcement, while the dependent variable is wearing resistance. Additionally, the analysis provides the standard deviation, significance, and mean values.

Results

Table 1 displays the wear rates comparison between as-cast AA7178 and as-cast AA7178 reinforced with 5% fly ash and 5% ZrO_2. Table 2 shows the group statistics of the wear rate of as-cast AA7178 and AA7178 with reinforcement of 5% fly ash and 5% ZrO_2. Table 3 lists the independent samples test on wear rate for both the groups with and without reinforcements. Table 4 shows the descriptive of the wear rate between as-cast AA7178 and AA7178 with reinforcement of 5% fly ash and 5% of ZrO_2.

Hence wear rate data has been shown from the above-listed tables between two groups of samples made with and without reinforcement materials. The samples fabricated without added reinforcements found a maximum wear rate of 73.82% compared to samples made with reinforcements of ZrO_2 and fly ash shown in figure 7.

The mean wear rate value for metal without reinforcement shows a maximum wear rate of 73.82% compared to the met-

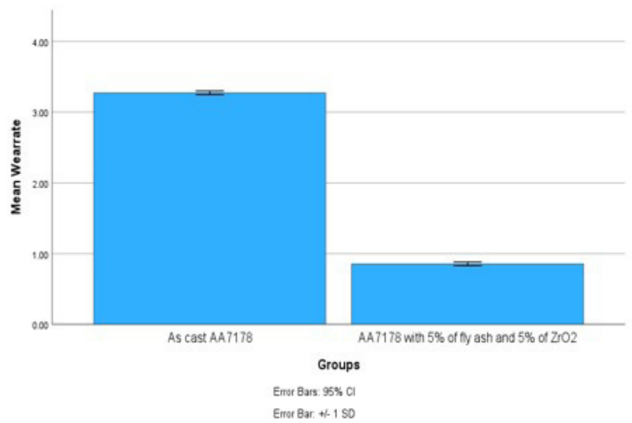

Figure 7: Comparison of the mean wear rate between AA7178 alloy with and without reinforcement material.

Table 3: Independent samples test of the wear rate in as-cast AA7178 without reinforcement and AA7178 with reinforcement of 5% of fly ash and 5% of ZrO_2.

		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
Wear rate	Equal variances assumed	0.000	1.000	131.500	38	0.000	2.41600	0.01837	2.37881	2.45319
	Equal variances not assumed			131.500	38	0.000	2.41600	0.01837	2.37881	2.45319

Table 4: Descriptive of the wear rate in as-cast AA7178 without reinforcement and AA7178 with reinforcement of 5% fly ash and 5% of ZrO_2.

	N	Mean	Std. deviation	Std. error	95% CI for mean		Minimum	Maximum
					Lower bound	Upper bound		
As-cast AA7178 without reinforcement	20	3.2726	0.05810	0.01299	3.2454	3.2998	3.16	3.37
AA7178 with reinforcement of 5% fly ash and 5% of ZrO_2	20	0.8566	0.05810	0.01299	0.8294	0.8838	0.75	0.96
Total	40	2.0646	1.22473	0.19365	1.6729	2.4563	0.75	3.37

al with reinforcement materials. On the X-axis, there are two groups: as-cast AA7178 vs AA7178 with 5% fly ash and 5% ZrO_2. The Y-axis displays the mean wear rate with a standard deviation error of +/-1 and a confidence interval (CI) of 95%.

Discussion

Our research outcomes revealed a significant drop-in wear rate in hybrid composites reinforced aluminum MMC fabricated with 5% fly ash and 5% ZrO_2 compared to as-cast AA7178. We noticed that the minimum wear rate is found in the material with reinforcement compared to the metal without any reinforcement materials. We also examined our results with recently published studies on wear rates. Tribological properties of aluminum MMCs (AA7075) reinforced with titanium carbide (TiC) particles [16]. Effect of ZrB_2 on microstructural, mechanical, and corrosion behavior of aluminum (AA7178) alloy matrix composite prepared by the stir casting route [17]. Influence of nano-TiO_2 particles on the microstructure, mechanical and wear behavior of AA7178 alloy matrix fabricated by stir casting technique [18]. No appreciable variations in tribological properties were discovered between the base metal and experimental metal created with composites compared to the studies mentioned above. However, our analysis found the maximum wear rate of 73.82% in as-cast AA7178 metal compared to AA7178 made with hybrid composites of 5% fly ash and 5% ZrO_2 using novel encapsulate feeding in stir casting. By this casting improper mixture of molten aluminum mixes uniformly results in a homogeneous mixture of molten metal with proper proportion [19].

The primary aspects that impact our research are the pouring mechanism, stirrer impeller, impeller size, and impeller angle. The fundamental drawback of this study is that casting flaws such as blow holes, mis-runs, and shrinkage cavities can form as molten metal flows into the casting dies under gravity. To overcome these casting issues in future investigations, squeeze casting is suggested to avoid future casting defects.

Conclusion

Within the limitations of this research, we noticed that novel encapsulate feeding of reinforcement with stir casting minimizes the wear rate of the aluminum MMC made by AA7178 with 5% of fly ash and 5% of ZrO_2 comparing to as-cast AA7178 alloy. As predicted, the wear rate of AA7178 metals with and without composite materials, the as-cast AA7178 without reinforcements found a maximum wear rate of 73.82% compared to the as-cast AA7178 with added reinforcements as a result of the decreased wear rate observed in AA7178 MMC was created using hybrid composites of 5% fly ash and 5% ZrO_2, so it can be used in the fabrication of military bridges motorcycles, airplane components and also used in making automobile engines parts.

Acknowledgements

The authors thank Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences (Formerly Saveetha University) for providing the necessary infrastructure to carry out this work successfully.

Conflict of Interest

There is no conflict of interest in this manuscript.

Funding

We thank the following organizations for providing financial support that enabled us to complete the study: GP Engineering (Chennai), Saveetha University, Saveetha Institute of Medical and Technical Sciences, and Saveetha School of Engineering.

References

1. Krishnan AM, Dineshkumar M, Marimuthu S, Mohan N, Venkatesh R. 2022. Evaluation of mechanical strength of the stir casted aluminium metal matrix composites (AMMCs) using Taguchi method. *Mater Today Proc* 62: 1943-1946. https://doi.org/10.1016/j.matpr.2022.02.036
2. Baskar S, Maridurai T, Arivazhagan R, Sivachandran S, Venkatesh R. 2022. Thermal management of solar thermoelectric power generation. *AIP Conf Proc* 2473(1): 020010. https://doi.org/10.1063/5.0096456
3. Sivasankaran ST, Shanmugakani SK, Vijayakumar VK, Subbiah R, Lakshmanan S, et al. 2023. Worn surface analysis and wear map mechanism of AA4032 composites. *J Test Eval* 51(2): 1151-1165. https://doi.org/10.1520/JTE20220149
4. Yokeswaran R, Vijayan V, Karthikeyan T, Loganathan M, Antony AG. 2020. Microstructure analysis of IS2062 plates cladded with SS2594 by TIG welding process. *J New Mater Electrochem Syst* 23(4): 269-273.
5. Venkatesh R, Christraj W. 2014. Performance analysis of solar water heater in multipurpose solar heating system. *Appl Mech Mater* 592: 1706-1713. https://doi.org/10.4028/www.scientific.net/AMM.592-594.1706
6. Senthilkumar TS, Venkatesh SA, Kumar R, Kumar SS. 2016. Evaluation of mechanical properties of Al-6082 based hybrid metal matrix composite. *J Chem Pharm Res* 8(1S): 58-64.
7. Veeman D, Shree MV, Sureshkumar P, Jagadeesha T, Natrayan L, et al. 2021. Sustainable development of carbon nanocomposites: synthesis and classification for environmental remediation. *J Nanomater* 2021: 5840645. https://doi.org/10.1155/2021/5840645
8. Yogeshwaran S, Prabhu R, Natrayan L, Murugan R. 2015. Mechanical properties of leaf ashes reinforced aluminum alloy metal matrix composites. *Int J Appl Eng Res* 10(13): 11048-11052.
9. Kumar KS, Karthikeyan S, Rahesh RG. 2020. Experimental investigation of wear characteristics of aluminium metal matrix composites. *Mater Today Proc* 33: 3139-3142. https://doi.org/10.1016/j.matpr.2020.03.778
10. Kumar SD, Ravichandran M, Jeevika A, Stalin B, Kailasanathan C, et al. 2021. Effect of ZrB_2 on microstructural, mechanical and corrosion behaviour of aluminium (AA7178) alloy matrix composite prepared by the stir casting route. *Ceram Int* 47(9): 12951-12962. https://doi.org/10.1016/j.ceramint.2021.01.158
11. Magesh S, Niveditha VR, Rajakumar PS, Radha RS, Natrayan L. 2020. Pervasive computing in the context of COVID-19 prediction with AI-based algorithms. *Int J Pervasive Comput Commun* 16(5): 477-487. https://doi.org/10.1108/IJPCC-07-2020-0082
12. Sabarinathan P, Annamalai VE, Vishal K, Nitin MS, Natrayan L, et al. 2022. Experimental study on removal of phenol formaldehyde resin coating from the abrasive disc and preparation of abrasive disc for polishing application. *Adv Mater Sci Eng* 2022: 6123160. https://doi.org/10.1155/2022/6123160
13. Saravanan R, Gnanavel C, Rajesh S, Kamatchi T, Daniel SAA, et al. 2022. Synthesis of zinc oxide and CNT in AA7178 aluminium alloy

composite impression on characteristics. *Mater Today Proc* 62: 1973-1976. https://doi.org/10.1016/j.matpr.2022.02.197

14. Midhun S, Ramesh C, Chellamuthu K, Yokeswaran R. 2022. Dissimilar resistance spot welding process on AISI 304 and AISI 202 by investigation metals. *Mater Today Proc* 69: 1213-1217. https://doi.org/10.1016/j.matpr.2022.08.262

15. Yokeswaran R, Vijayan V, Karthikeyan T, Kumar BS, Kumar GS. 2019. Comprehensive analysis of surface modification process parameters by using tungsten inert gas welding process comprehensive analysis of surface modification process parameters by using tungsten inert gas welding process. *J New Mater Electrochem Syst* 22(1): 45-49.

16. Kumar VV, Raja K, Chandrasekar VS, Ramkumar T. 2019. Thrust force evaluation and microstructure characterization of hybrid composites (Al7075/B_4C/BN) processed by conventional casting technique. *J Braz Soc Mech Sci Eng* 41: 1-14. https://doi.org/10.1007/s40430-019-1728-5

17. Sivasankaran ST, Shanmugakani SK, Subbiah R. 2023. Performance analysis of conventional and DMLS copper electrode during EDM process in AA4032-TiC composite. *3D Print Addit Manuf* 10(3): 569-583. https://doi.org/10.1089/3dp.2021.0030

18. Selvarajan L, Venkataramanan K, Rajavel R, Senthilkumar TS. 2023. Fuzzy logic optimization with regression analysis on EDM machining parameters of Si_3N_4-TiN ceramic composites. *J Intell Fuzzy Syst* 44(6): 8869-8888. https://doi.org/10.3233/JIFS-223650

19. Raja K, Chandrasekar VS, Kumar VV, Ramkumar T, Ganeshan P. 2020. Microstructure characterization and performance evaluation on AA7075 metal matrix composites using RSM technique. *Arab J Sci Eng* 45: 9481-9495. https://doi.org/10.1007/s13369-020-04752-8