Nano World Journal

https://doi.org/10.17756/nwj.2023-s3-156

Research Article

Open Access

Investigation on Mechanical Properties of AA6061-TiC-ZrO_2 Hybrid Composite using Taguchi Approach

Yenda Srinivasa Rao[1], Pushpavathi Sarthavalli Marulasiddappa[2], Veeresha Gouder[3], Tamilselvi Damodaran[4], Gandham Ram Vishal[5], Seenivasan Soundararajan[6] and Satishkumar Palanisamy[6*]

[1]*Department of Mechanical Engineering, Sri Sivani College of Engineering, Srikakulam, Andhra Pradesh, India*
[2]*Department of Mechanical Engineering, Government Engineering College, Ramanagar, Karnataka, India*
[3]*Department of Mechanical Engineering, New Horizon College of Engineering, Bangalore, Karnataka, India*
[4]*Department of Science and Humanities (Chemistry), Rathinam Technical Campus, Coimbatore, Tamil Nadu, India*
[5]*Aeronautical Engineering, Nitte Meenakshi Institute of Technology, Bangalore, Karnataka, India*
[6]*Department of Mechanical Engineering, Rathinam Technical Campus, Coimbatore, Tamil Nadu, India*

[*]Correspondence to:
Satishkumar Palanisamy
Department of Mechanical Engineering,
Rathinam Technical Campus,
Coimbatore, Tamil Nadu, India.
E-mail: sp.sathishkumar10@gmail.com

Received: July 31, 2023
Accepted: November 01, 2023
Published: November 03, 2023

Citation: Rao YS, Marulasiddappa PS, Gouder V, Damodaran T, Vishal GR, et al. 2023. Investigation on Mechanical Properties of AA6061-TiC-ZrO_2 Hybrid Composite using Taguchi Approach. *NanoWorld J* 9(S3): S876-S881.

Published by United Scientific Group

Abstract

Metal matrix composites (MMCs) are being used more frequently in the aerospace, automotive, and biomedical industries due to their low wear rate, high strength-to-weight ratio, etc. The Taguchi approach of design of experiments (DOE) was used to examine the MMC-derived AA6061. Taguchi approaches were used to determine which parameters will provide castings with the best possible tensile strength and hardness. Maintaining tight control over the processing parameters is crucial for producing defect-free castings. Modifications were made to the reinforcement percentage by weight (A), stirring rate (B), and processing temperature (C) before the test samples were prepared. Using an orthogonal array (OA) and analysis of variance (ANOVA), the impact of the process factors on the required attributes was investigated. The best parameters for improving the composites' mechanical properties were found with the use of the Taguchi technique. The fundamental goal of this research is to establish the experimental parameters that, when combined with the desired hardness and UTS for specific uses, will provide defect-free composite casting. To demonstrate the efficacy of the Taguchi optimization method, a confirmation test was conducted using the optimum values for the processing parameters.

Keywords

Stir casting, Metal matrix composites, Taguchi approach, Optimization, Analysis of variance

Introduction

Due to their exceptional wear resistance, low density, and high specific strength, AMC are gaining a lot of attention. Strength, wear resistance, modulus, thermal expansion, workability, and isotropy can all be improved in Al alloys by strengthening them with discontinuous second-stage particles [1]. AMCs provide a superior combination of properties not found in any other monolithic material. Different branches of engineering have experimented with and exploited AMCs for a wide variety of non-structural, structural, and functional uses in the past [2]. The performance, financial, and ecological benefits offered by AMCs are motivating factors in their adoption in various fields. Aluminum-magnesium-cerium-titanium-polymer composites are designed to replace a variety of traditional monolithic materials [3].

The matrix phase of AMCs is aluminum or aluminum alloy, which takes the form of a percolating network. Non-metallic, frequently ceramic reinforcements like TiC and ZrO_2 are typically encased in this aluminum/aluminum alloy matrix. Particulate reinforcements, such as TiC, Al_2O_3, and Gr, are commonly employed in MMCs. Wear resistance in composites is increased when ceramic particles are added to the mix [4]. By adjusting the proportions and types of ingredients, AMCs can take on a wide range of new characteristics. Reduced fuel usage, lower noise levels, and less airborne pollutants are the primary benefits of AMCs in the transportation sector. It has been widely agreed that hybrid composites, as opposed to single reinforcing composites, have superior qualities [5]. A material's hardness can be increased to 1.84 on the Mohs scale and its toughness can be increased to 2.1 times that of unreinforced Al alloy by using TiC. MMCs are stronger than regular matrix metals. The amount of TiCp in a cast composite determines its hardness (titanium carbide particulates). As the amount of TiCp in the cast composite increases, so does its tensile strength. While the proportion of elongation increases with LM6 content, it decreases with TiCp content [6]. In order to improve wear resistance, thermal expansion coefficient, and mechanical qualities, many different hybrid composites have been developed recently. PRAMCs (particulate reinforced amorphous MMCs) are strengthened by the addition of particles, which also affects the majority of their mechanical characteristics [7]. Particle volume fraction (vf), particle shape, particle size, and particle dispersion within the metal matrix all have significant impacts on PRAMCs' mechanical characteristics. The volume fraction (vf) is the most important of these variables [8].

Stir casting's main advantage is that it can be used for mass manufacturing. Among the well-established procedures for producing MMC, stir casting is the most cost-effective. The price of stir casting can be reduced by a factor of three to ten for industrial scale production [9]. As a result, stir casting has replaced conventional techniques for making aluminum-based composites in industry.

Any composite's quality could be impacted by adjusting the processing settings. Particle size, reinforcement percentage, processing temperature, stirring speed, stirring time, etc., should all play a role, but at least a couple of them should have the most of an effect [3]. In order to maximize the technological and financial benefits of a manufacturing process, it must be conducted under ideal conditions. Taguchi optimization is one of the most widely used techniques [10]. High-quality systems can be developed using the Taguchi approach [11, 12]. It's a straightforward, methodical strategy for improving designs in terms of efficiency, quality, and cost.

Optimizing performance by carefully chosen parametric settings, Taguchi design also lessens the impact of variance on overall system output [13]. With the Taguchi method, you can learn as much as possible about your model's individual and combined parameters with as few simulations runs as possible. To better understand how a product or process works, this method employs a series of tests that are carried out in a specific order. Many earlier attempts were found in the literature to improve the characteristics of Al MMCs by utilizing stir casting. The following sections describe the many components of these endeavors.

- Relatively little research has been published on the parameters influencing mechanical qualities like tensile strength of AMCs.
- Very little research has been done to date on the synergistic effect of ZrO_2 and titanium carbide on the characteristics of AMCs.

The effect of varying the parameters of the stir casting process on the UTS and hardness properties of an AA6061/TiC/ZrO_2 hybrid composite was studied.

Experimental Procedure

Methodology

In this iteration, AA6061 serves as the matrix material. Table 1 displays the matrix alloy's chemical composition in weight percentage. In this case, ZrO_2 and TiC particles (220 mesh) are used as reinforcement.

Metal is shaped while molten and then solidifies in the workshop. The integration of dispersed phase order in MMCs results in an increase in the composite's mechanical characteristics. It is important that the liquid matrix and dispersed phase form strong interfacial bonds (wetting) during the procedure. Coating the dispersed phase particles is a potential method for increasing wetting [14, 15]. The liquid matrix and dispersed phase are less likely to react chemically if they are properly coated [16]. Mechanical stirring is used in the stir casting process to evenly disperse reinforcing components (often powder) throughout molten aluminum [17]. Segregation of reinforcing particles can occur if reinforcement particles rise to the surface or settle during the process of melting and casting procedures [18].

Particle dispersion in a molten matrix is affected by a number of variables, including the stirring settings, the geometry of the mechanical stirring, the location of the mechanical stirring within the melt, the melt temperature, and the characteristics of the added particles [1].

As can be seen in figure 1, the AMCs were made using the stir casting procedure. The experimental setup, including a resistive thermocouple, heating boiler, and variable-speed motor driving a mechanical impeller, is depicted in figure 1. The matrix alloy melted at a temperature of 720 °C in the electric furnace depicted in figure 2. Powdered ZrO_2 and titanium carbide are then added to the melt after it has spent two hours in a preheating furnace at 1000 °C. To further disperse the particles, the molten mixture was then whirled at varied speeds inside the furnace for a total of 10 min. A thermocouple was

Table 1: AA6061 chemical composition.

Element	Magnesium (Mg)	Silicon (Si)	Iron (Fe)	Copper (Cu)	Chromium (Cr)	Zinc (Zn)	Titanium (Ti)	Manganese (Mn)	Aluminum (Al)
%	0.8 - 1.20	0.4 - 0.8	0.7	0.15 - 0.4	0.04 - 0.35	0.25	0.15	0.15	Balance

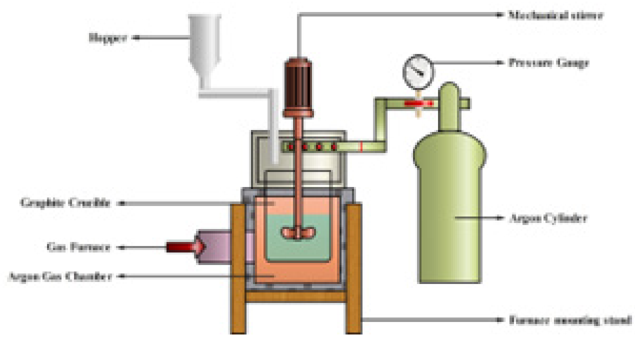

Figure 1: Stir casting setup.

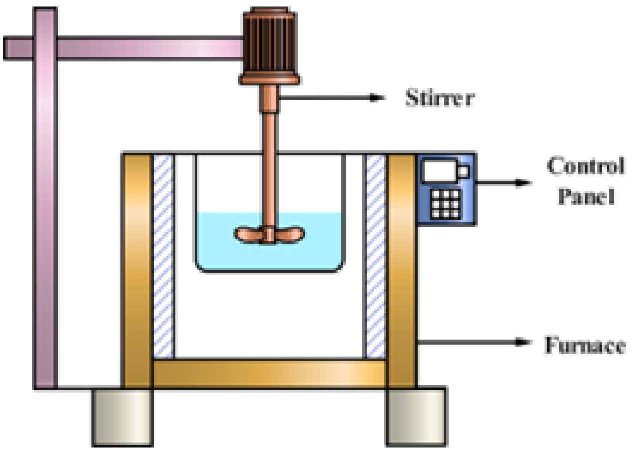

Figure 2: Furnace.

used to control the melting point, and 1% by weight of Mg was added to improve the binding between the alloy of matrix and the reinforcement particles before the melt was poured into a carbon steel die. The fluidity of molten metal alters when pure Mg is added to it. The particle volume fraction was calculated by dividing the composite volume (obtained from the die's internal dimensions) by the particle volume.

Taguchi technique applications

The Taguchi DOE is a method for organizing experiments in the most rational, cost-effective, and statistically sound methods possible. Figure 3 shows the process flow of the Taguchi technique. When it comes to identifying the optimal values for process and performance-influencing variables, Taguchi's variable design is a rigorous and effective procedure. By avoiding further experiments, time, money, and resources are all saved. Three process components, particles (A, B and C), were investigated at three different levels to see the extent to which they influenced the composite preparation method.

In order to examine the impact of a large number of control factors, OA are frequently used in industrial trials [19]. If the columns of independent variables in an experiment are perpendicular to one another, we call the arrangement of those variables an OA.

OA makes analysis easy, which results in significant time and money savings during experiments (Table 2). Number of levels and factors must be specified when describing an OA.

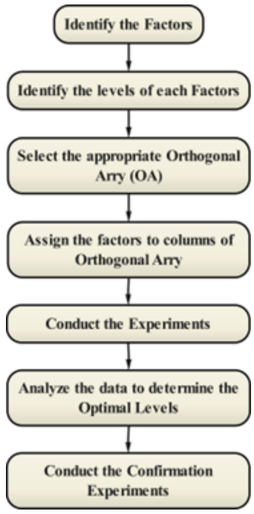

Figure 3: Main steps of execution of Taguchi technique.

Table 2: Input parameters and their levels.

Parameters	Symbol (units)	Levels		
		-1	**0**	**+1**
Composition	A	3% TiC + 3% ZrO_2	6% TiC + 6% ZrO_2	9% TiC + 9% ZrO_2
Stirring speed, B (rpm)	B (rpm)	400	500	600
Processing temperature	C (°C)	720	780	840

Table 3: Experimental design for OA.

Run	Input parameters		
	x1	***x2***	***x3***
1	-1	-1	-1
2	-1	0	0
3	-1	1	1
4	0	-1	0
5	0	0	1
6	0	1	-1
7	1	-1	1
8	1	0	-1
9	1	1	0

Three parameters at each of the three levels have DoF equal to the number of level - 1. For this reason:

$$A,\ DoF = 3 - 1 = 2$$

$$B,\ DoF = 3 - 1 = 2$$

$$C,\ DoF = 3 - 1 = 2$$

In total, 9 separate experiments were conducted on a three-tiered L9 OA. The OA employed in this study is displayed in table 3. The 9 samples of hybrid composites were made in this study by stir casting with the parameters for the process arranged in an orthogonal grid. Milling machines were used to create the tensile and hardness test specimens needed by the ASTM standards.

Results and Discussion

UTS and hardness test

The ASTM E-10-98 test is frequently used to measure the Brinell hardness of metals. In this study, an indenter ball with a diameter of 5 mm is utilized to create indentations with a diameter of 2.5 mm to 6.0 mm. The applied load is 250 kg. The test specimen is clamped between the universal testing machine's end jaws. A moving cross head is used to apply progressively more stress to the specimen until cracking occurs. The load cell is used to measure the load when the test is being performed. Table 4 displays the outcomes of tensile and Brinell hardness tests.

DOE

The Taguchi method reduces variation in quality attributes due to an uncontrollable parameter by focusing on the investigation of variation in response via the S/N ratio. When discussing the output quality features of the Taguchi technique, the terms "signal" and "noise" are used to indicate the desired value (mean) and the unwanted value (standard deviation), respectively. The signal of the intended effect is a change in the quality of the product under study as a result of the presence of a new variable in the experimental design. Noise refers to the influence of uncontrollable external influences on the measured value of the quality attribute. Because improved composite hardness and UTS is a goal of this work, the "larger is better" S/N ratio has been employed to make parameter predictions. S/N ratios were determined using MINITAB software after specimens were produced using the L9 OA. Table 5 and table 6 use equation (1) [20] to display the observed values of mechanical characteristics.

$$(S/N)_t = -10 \log (1/n)\Sigma(1/y^2) \quad (1)$$

Signal-to-noise ratio (S/N) main effect plots

Main effect graphs graphically depict the relationship between the value of a process parameter and the variation in performance attributes. The main effect plot for all three material levels and all three variables are shown in figure 4 and figure 5.

Settings for optimum processing parameter

Table 7 displays the results obtained by using the responses to determine the best combination of processing settings.

ANOVA

ANOVA is used to learn which parameters in a process have the biggest impact on a quality attribute. Through examining their relative relevance, ANOVA helps find the best possible combination of process parameters. The significance level used for the ANOVA was 5%, and the software tool MINITAB 14 was used to conduct the analysis. The p-values for the model's free parameters can be found in the ANOVA table. P-values less than 0.05 indicate statistical significance for the parameter in question. At the 95% confidence level, if the p-values for the three components are less than 0.05, then they are statistically significant. The final columns of table 8 and table 9 show how significant each factor is in explaining the total difference in the mechanical properties. Table 8 and table 9 of the ANOVA show that the percentage of reinforcing wt. is the most crucial processing parameter for raising hardness and UTS, respectively.

Confirmation test

The procedure of designing an experiment concludes with a confirmation test. Optimal UTS and composite hardness

Table 4: UTS and hardness test result.

Run	A	B	C	Hardness	UTS
		rpm	°C	BHN	MPa
1	3% TiC + 3% ZrO_2	400	720	65.3	280
2	3% TiC + 3% ZrO_2	500	780	69.7	287
3	3% TiC + 3% ZrO_2	600	840	72.5	295
4	6% TiC + 6% ZrO_2	400	780	80.3	307
5	6% TiC + 6% ZrO_2	500	840	85.7	314
6	6% TiC + 6% ZrO_2	600	720	82.9	309
7	9% TiC + 9% ZrO_2	400	840	102.5	323
8	9% TiC + 9% ZrO_2	500	720	98.3	319
9	9% TiC + 9% ZrO_2	600	780	107.3	330

Table 5: Singal to noise ratio for hardness test.

Run	Input parameters			Hardness (BHN)	S/N ratio
	A	B	C		
1	2% TiC + 3% ZrO_2	400	720	65.3	36.2983
2	3% TiC + % ZrO_2	500	780	69.7	36.8647
3	3% TiC + 3% ZrO_2	600	840	72.5	37.2068
4	6% TiC + 6% ZrO_2	400	780	80.3	38.0943
5	6% TiC + 6% ZrO_2	500	840	85.7	38.6596
6	6% TiC +6% ZrO_2	600	720	82.9	38.3711
7	9% TiC + 9% ZrO_2	400	840	102.5	40.2145
8	9% TiC + 9% ZrO_2	500	720	98.3	39.8511
9	9% TiC + 9% ZrO_2	600	780	107.3	40.612

Table 6: S/N ratio for UTS.

Run	Input parameters			UTS (MPa)	S/N ratio
	A	B	C		
1	3% TiC + 3% ZrO_2	400	720	280	48.9432
2	3% TiC + 3% ZrO_2	500	780	287	49.1576
3	3% TiC + 3% ZrO_2	600	840	295	49.3964
4	6% TiC + 6% ZrO_2	400	780	307	49.7428
5	6% TiC + 6% ZrO_2	500	840	314	49.9386
6	6% TiC + 6% ZrO_2	600	720	309	49.7992
7	9% TiC + 9% ZrO_2	400	840	323	50.1841
8	9% TiC + 9% ZrO_2	500	720	319	50.0758
9	9% SiC + 9% ZrO_2	600	780	330	50.3703

Table 7: Optimal processing factors for hardness and UTS.

A	B	C
18	600	840

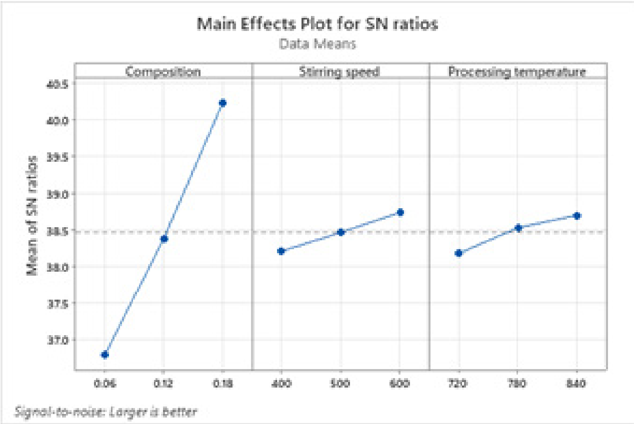

Figure 4: Main effects plots for hardness test.

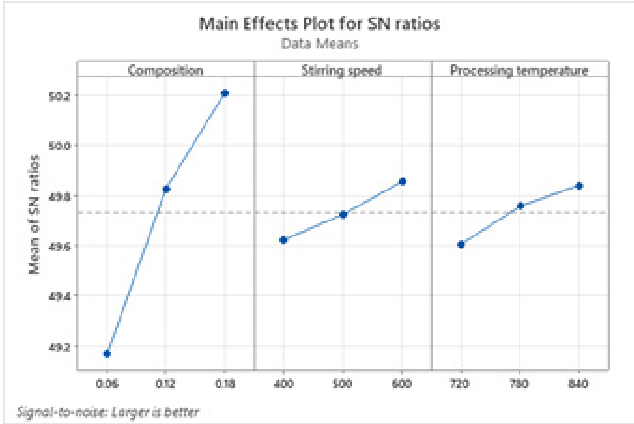

Figure 5: Main effects plots for UTS.

Table 8: ANOVA for hardness.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-value	p-value
Composition	2	1704.33	95.44%	1704.33	852.164	196.45	0.005
Stirring speed	2	36.17	2.03%	36.17	18.084	4.17	0.193
Processing temperature	2	36.65	2.05%	36.65	18.324	4.22	0.191
Error	2	8.68	0.49%	8.68	4.338	-	-
Total	8	1785.82	100.00%	-	-	-	-

Table 9: ANOVA for UTS.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-value	p-value
Composition	2	2054.22	91.10%	2054.22	1027.11	486.53	0.002
Stirring speed	2	96.89	4.30%	96.89	48.44	22.95	0.042
Processing temperature	2	99.56	4.42%	99.56	49.78	23.58	0.041
Error	2	4.22	0.19%	4.22	2.11	-	-
Total	8	2254.89	100.00%	-	-	-	-

were found at 600 rpm stirring speed, 12 wt. percentage reinforcement, and 840 °C processing temperature. The optimal parameters were determined via experimentation. The maximum values of 95 BHN for hardness and 295 MPa for UTS were discovered, and these were compared to calculated values using a regression model. The experimental results for both hardness and UTS are close to the estimated values (± 6%). The resultant equations appear to be accurate enough to be used for forecasting mechanical properties. These mistakes, however, can be mitigated by collecting a larger sample of data on performance attributes.

Conclusion

It was discovered that the mechanical characteristics of AA6061 TiC - ZrO_2 hybrid MMC are affected by the A, B, and C. The ANOVA showed that the percentages of titanium carbide and ZrO_2 in the mixture were the most important factors. It was determined that 12% for A, 600 rpm for B, and 840 °C for C produced the highest UTS and composite hardness. The mechanical property will also be affected by the amount of reinforcement, both in terms of particle size and percentage of weight. The reinforcements were more thoroughly combined with the melt at a B of 600 rpm. The strength and hardness of a composite material can be improved by including reinforcements with a higher hardness. The wettability of the reinforcements is greatly improved at high temperatures, allowing for more consistent mixing.

Acknowledgements

None.

Conflict of Interest

None.

References

1. Sharma OP, Meena A. 2021. Study of mechanical properties and wear behavior of aluminum 6061 matrix composites reinforced with Hematite and Titania. *Mater Today Proc* 44(6): 5028-5036. https://doi.org/10.1016/J.MATPR.2021.01.131
2. Vijayakumar S, Kumar PS, Kumar PS, Manickam S, Ramaiah GB, et al. 2022. The effect of stir-squeeze casting process parameters on mechanical property and density of aluminum matrix composite. *Adv Mater Sci Eng* 2022: 1-10. https://doi.org/10.1155/2022/3741718
3. Pravin T, Somu C, Rajavel R, Subramanian M, Reynold PP. 2020. Integrated Taguchi cum grey relational experimental analysis technique (GREAT) for optimization and material characterization of FSP sur-

face composites on AA6061 aluminium alloys. *Mater Today Proc* 33(8): 5156-5161. https://doi.org/10.1016/j.matpr.2020.02.863

4. Kumar A, Patnaik A, Kumar M, Kukshal V, Pawar MJ, et al. 2021. Analysis of Mechanical and Sliding Wear Performance of AA6061-SiC/Gr/MD Hybrid Alloy Composite Using a PSI Approach for Rotor Applications. In Advanced Materials and Manufacturing Processes. CRC Press, pp 77-94.

5. Ramesh B, Kumar S, Elsheikh AH, Mayakannan S, Sivakumar K, et al. 2022. Optimization and experimental analysis of drilling process parameters in radial drilling machine for glass fiber/nano granite particle reinforced epoxy composites. *Mater Today Proc* 62: 835-840. https://doi.org/10.1016/j.matpr.2022.04.042

6. Srinivasan R, Karunakaran S, Hariprabhu M, Arunbharathi R, Suresh S, et al. 2023. Investigation on the mechanical properties of powder metallurgy-manufactured AA7178/$ZrSiO_4$ nanocomposites. *Adv Mater Sci Eng* 2023: 1-11. https://doi.org/10.1155/2023/3085478

7. Manikandan R, Ponnusamy P, Nanthakumar S, Gowrishankar A, Balambica V, et al. 2023. Optimization and experimental investigation on AA6082/WC metal matrix composites by abrasive flow machining process. *Mater Today Proc* 2023. https://doi.org/10.1016/j.matpr.2023.03.274

8. Mahamani A, Sakthivelon N, Jetti SK, Reddy MVS, Naidu PV, et al. 2014. Influence of electrical discharge machining parameters on surface roughness in machining of AI 6061-TiB_2/ZrB_2 *in situ* metal matrix composite. *Appl Mech Mater* 592: 405-409. http://dx.doi.org/10.4028/www.scientific.net/AMM.592-594.405

9. Natrayan L, Kumar MS, Chaudhari M. 2019. Optimization of Squeeze Casting Process Parameters to Investigate the Mechanical Properties of AA6061/Al_2O_3/SiC Hybrid Metal Matrix Composites by Taguchi and Anova Approach. In Advanced Engineering Optimization Through Intelligent Techniques. Springer Singapore, pp 393-406.

10. Satishkumar P, Mahesh G, Meenakshi R, Vijayan SN. 2021. Tribological characteristics of powder metallurgy processed Cu-WC/SiC metal matrix composites. *Mater Today Proc* 37(2): 459-465. https://doi.org/10.1016/j.matpr.2020.05.449

11. Elsheikh AH, Shanmugan S, Muthuramalingam T, Thakur AK, Essa FA, et al. 2022. A comprehensive review on residual stresses in turning. *Adv Manuf* 10: 287-312. https://doi.org/10.1007/s40436-021-00371-0

12. Satyanarayana G, Narayana KL, Rao BN. 2021. Incorporation of Taguchi approach with CFD simulations on laser welding of spacer grid fuel rod assembly. *Mater Sci Eng B* 269: 115182. https://doi.org/10.1016/J.MSEB.2021.115182

13. Bhasha AC, Balamurugan K. 2020. Multi-objective optimization of high-speed end milling on Al6061/ 3% RHA/ 6% TiC reinforced hybrid composite using Taguchi coupled GRA. In 2020 International Conference on Computational Intelligence for Smart Power System and Sustainable Energy (CISPSSE), pp 1-6.

14. Satishkumar P, Rakesh AJ, Meenakshi R, Murthi CS. 2020. Characterization, mechanical and wear properties of Al6061/Sicp/fly ashp composites by stir casting technique. *Mater Today Proc* 37(2): 2687-2694. https://doi.org/10.1016/J.MATPR.2020.08.530

15. Dharmaiah G, Sridhar W, Balamurugan KS, Chandra K. 2022. Hall and ion slip impact on magneto-titanium alloy nanoliquid with diffusion thermo and radiation absorption. *Int J Ambient Energy* 43(1): 3507-3517. https://doi.org/10.1080/01430750.2020.1831597

16. Pathapalli VR, Reddigari MR, Anna EK, Rao PS, Reddy DVR. 2021. Modeling of the machining parameters in turning of Al-5052/TiC/SiC composites: a statistical modeling approach using grey relational analysis (GRA) and response surface methodology (RSM). *Multidis Model Mater Str* 17(5): 990-1006. https://doi.org/10.1108/mmms-01-2021-0017

17. Abushanab WS, Moustafa EB, Harish M, Shanmugan S, Elsheikh AH. 2022. Experimental investigation on surface characteristics of Ti6Al4V alloy during abrasive water jet machining process. *Alexandria Eng J* 61(10): 7529-7539. https://doi.org/10.1016/j.aej.2022.01.004

18. Reddy GVK, Kumar BKN, Hareesha G, Rajesh AM, Doddamani S. 2023. Investigation of impact energy absorption of AA6061 and its composites: role of post-aging cooling methods. *Frattura Integrita Strutturale* 17(66): 261-272. https://doi.org/10.3221/IGF-ESIS.66.16

19. Naveen E, Ramnath BV, Parswajinan C, Pradeep K, Arun SS. 2019. An investigation on wear behaviour of Cnt reinforced Al-SiC metal matrix composites. *Int J Mech Prod Eng Res Dev* 9(3): 171-182.

20. Suryawanshi GL, Patil SK, Desavale RG. 2021. Evaluation of the mechanical and tribological characteristics of AA6061/TiB2 metal matrix composite and parametric optimisation of its casting process by using Taguchi technique and NSGA-II. *Int J Mater Eng Innov* 12(3): 207-233. https://doi.org/10.1504/ijmatei.2021.116945