



PREDICTION OF REGRESSION BASED WEAR BEHAVIOUR MODELS OF ALUMINIUM ALLOY 356 – ZrSiO₄ COMPOSITES

Althaf Hasan Khan J, Akmal Jahan S, Biju Kumar A, Murali V and *Arul Marcel Moshi A

Department of Mechanical Engineering, National Engineering College, Kovilpatti, Tamil Nadu-628 503, India

ABSTRACT

The term composite is a combination of two materials with different physical and chemical properties. When combined, they create a specialised material to do a certain job, for instance, to become stronger, lighter or resistant to electricity. They can also improve strength and stiffness. Metal matrix composites have much improved properties, including high tensile strength, toughness, hardness, low density and good wear resistance compared to alloys or any other metal. Aluminium alloys are becoming important today, especially in the automobile, space and electrical industries. Unfortunately, due to poor wear resistance, aluminium alloy can deteriorate quickly. So the present investigation aims at developing Aluminium 356 alloy (AA356) composites reinforced with 5 wt.% Zirconium Silicate (ZrSiO₄) with better wear resistance. The composites have been fabricated using the ‘stir-casting’ method in which the particles were added to molten metal during the stirring process at a rotating speed of 700 rpm. A wear test has been performed on a pin on the disc apparatus. Three process parameters have been considered: normal load, sliding velocity, and sliding distance at three different levels. An experimental plan has been made using Taguchi’s L9 orthogonal array table. The output responses such as wear rate and coefficient of friction have been considered for the investigation. Regression models have been generated for each output response. Using the generated regression models, one can predict the value of the output parameters even without actually performing the experimentation within the range of input factor combinations.

Keywords: *Metal Matrix Composites; Stir Casting Process; Wear Behaviour Analysis.*

1. Introduction

Metal matrix composites are used in a wide range of high-performance applications today. Researchers’ interest in aluminium-based metal matrix composites (MMCs) has increased. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include stronger, lighter, or less expensive compared to traditional materials. Among Aluminium alloys, Aluminium-Silicon (Al-Si) alloys are most versatile materials, comprising 85% to 90% of the total aluminium cast parts produced for the automotive industry, depending on the Si concentration in weight percent (wt.%) in the Al-Si alloy systems.

2. Literature Survey

Composite materials are better choices for satisfying the researchers’ expectations for different structural applications. Various research works are being carried out with metal matrix composites (MMC)

by incorporating suitable reinforcing agents in order to achieve better desirable properties [1].

A356 is a hypoeutectic aluminum alloy. This alloy material is widely used for the fabrication of automotive, aircraft, flow and structural components. The mechanical and surface properties of A356 alloy are improved by fabricating Aluminum Metal Matrix Composites (AMMC’s) with ceramic reinforcements [2].

Dwivedi et al. (2014) analyzed the micro structure and mechanical properties of A356/SiC composites fabricated by electromagnetic stir casting. The composition is based on A356 aluminium alloy reinforced with silicon Carbide (SiC). It has been observed that the tensile strength, hardness are increased with the addition of silicon carbide [3].

Kumar et al. (2019) had carried out a study on effect of chill casting on A356 reinforced with Hematite metal matrix composite and it is observed that uniform distribution of Hematite particulates in A356 alloy with good bonding with A356 matrix the strength and hardness of the A356 and hematite particulate chilled

*Corresponding Author - E-mail: moshibeo2010@gmail.com

composite increased with increase in weight percentage of reinforcement [4].

Sundara Bharathi et al. (2019) had generated Regression models for the considered output responses viz. Material Removal Rate (MRR) and Surface Roughness (SR) against the considered input parameters such as spindle speed, feed rate and depth of cut. Also, the authors had analyzed the correlation between the process variables using the generated 3D surface plots [5].

Hariharasakthisudhan et al. (2019) had prepared AA6061/Al₂O₃/Si₃N₄/graphite hybrid nanocomposites and tested their tribological characteristics. The experiments were designed and the results were optimized using Taguchi L9 orthogonal array. The authors had developed regression equations for the predicted output responses such as wear rate and coefficient of friction [6].

Venkatesn et al. (2018) had prepared aluminium alloy 7050 / graphene metal matrix composites using the stir casting process. The authors had analyzed the tensile behaviour of the prepared composites and reported that the inclusion of 0.3 wt.% of graphene yielded maximum tensile strength for the proposed metal matrix composites [7].

Sundara Bharathi et al. (2020) had generated regression equations for the output responses of machining stainless steel 303 material. The regression equations were generated using Design Expert software. The generated equations were found to be perfectly fit with the obtained experimental results [8].

This report reported significant research on aluminium alloy 356 MMCs reinforced with 5 wt.% of ZrSiO₄ particles as reinforcement. The reason for choosing 5 wt.% reinforcement is that literature reported that 5 wt.% ZrSiO₄ reinforcement inclusion improved the mechanical properties of the AA356 MMCs. Hence the present study aims to achieve the better wear resistance characteristics of the 5 wt.% ZrSiO₄ reinforced AA356 metal matrix composites.

3. Experimental Analysis and Regression Model Generation

The proposed composite specimens were fabricated using the stir casting process. An image captured during the fabrication process is presented in Figure 1. The extracted specimens were then machined following the ASTM G9 standard to obtain the wear specimens.



Fig. 1 Stir Casting Process

The proposed wear behaviour analysis was performed on a pin on disc apparatus available at National Engineering College, Kovilapatti. The experimental setup is shown in Figure 2. Normal load, sliding velocity and sliding distance were chosen as the significant control variables for the wear behavior analysis. The selected control variables were considered at three different levels, as shown in Table 1.



Fig. 2 Pin on Disc Apparatus

Table 1 Control factors and levels considered for the wear test

S. No.	Factors	Levels		
		1	2	3
1	Normal load (N)	20	40	60
2	Sliding velocity (m/s)	1	2	3
3	Sliding distance (km)	1	2	3

The experimental plan was made using Taguchi's L9 orthogonal array table. The wear behaviour analysis test was conducted using a pin on the disc apparatus. The output responses, wear rate and coefficient of friction values have been noted for the planned experimental runs. The multiple regression models for the individual output responses considered in work, such as wear rate and coefficient of friction, have been obtained with the aid of Design-Expert software 7.0, which are presented in Equations (1) and (2).

$$\text{Wear rate} = +0.26390 - (0.012736*A) - (0.058476*B) - (0.056476*C) + (0.00197143*A*B) + (0.00262143*A*C) + (0.004*B*C) + (0.00008*A^2) \quad (1)$$

$$\text{COF} = +0.59905 - (0.00123810*A) - (0.24548*B) + (0.00857143*C) - (0.000119048*A*B) - (0.019048*B*C) + (0.075000*B^2) \quad (2)$$

Where,

- A – Normal load in N
- B – Sliding velocity is m/s
- C – Sliding distance in km

R-Squared values provide the degree of level of acceptance of the generated equations. In the present analysis, the regression equations have been obtained with the R-Squared value of 0.9653 for wear rate and 0.89 for COF, respectively. The obtained R-Squared values in the current analysis also ensured the level of accuracy of the relationship expressions. Therefore the generated regression equations can be used to determine the approximate results of wear rate and coefficient of friction analytically within the considered ranges of input factors.

Instead of testing the R-squared values for confirming the reliability of the generated regression models, correlation plots can be drawn and analyzed between the values calculated using the regression models and the experimental results. These regression equations can predict the output responses for all the possible combinations of input factor levels. From the results, the optimal combination of input factors that offers a minimal wear rate and coefficient of friction can be identified. Further, this study can be extended by adopting suitable optimization algorithms to interpret the research outcomes.

4. Conclusions

Aluminium alloy (AA356) metal matrix composites were prepared by including 5 wt.% of the ZrSiO₄ particles using the stir casting process. The

experimental design was planned based on Taguchi's L₉ orthogonal array design, and the planned experiments were conducted on the pin-on-disc apparatus. The output responses such as coefficient of friction and wear rate were considered. The following conclusions were derived from the carried-out wear study on the prepared metal matrix composites. The regression models were generated for the output responses viz. wear rate and coefficient of friction which were validated by the R-squared values.

References

1. S.Granesan, S.Deepak Ganesh and A.Arul Marcel Moshi, "Characterization of Metal Matrix Composites reinforced with suitable reinforcement agents – A Comprehensive Review", *IOP Conference Series: Materials Science and Engineering*, 988, 2020, pp. 012029.
2. K.Logesh, P.Hariharasakthisudhan, A.Arul Marcel Moshi, B.Surya Rajan and K.Sathickbasha, "Mechanical properties and microstructure of A356 alloy reinforced AlN/MWCNT/graphite/Al composites fabricated by stir casting", *Materials Research Express*, 7, 2020, pp. 015004.
3. Shashi Prakash Dwivedi, Satpal Sharma and Raghvendra Kumar Mishra, "Microstructure and Mechanical Properties of A356/SiC Composites Fabricated by Electromagnetic Stir Casting", *Procedia Materials Science*, 6, 2014, pp. 1524-1532.
4. Vipin Kumar Sharma and Vinod Kumar, "Development of rare earth oxides based hybrid AMCs reinforced with SiC / Al₂O₃ mechanical & metallurgical characterization", *Materials Research and Technology*, 8 (2), 2019, pp. 1971-1981.
5. S.R. Sundara Bharathi, D. Ravindran, A. Arul Marcel Moshi, R. Rajeshkumar, R. Palanikumar, "Multi objective optimization of CNC turning process parameters with Acrylonitrile Butadiene Styrene material", *Materials Today: Proceedings*, 27 (1), 2019, pp. 2214-7853.
6. P Hariharasakthisudhan, A. Arul Marcel Moshi, S.R. Sundara Bharathi, K. Logesh, "Regression and Grey relational analysis on friction and wear behavior of AA6061/Al₂O₃/Si₃N₄/graphite hybrid nano composites", *Materials Research Express*, 6 (8), 2019, pp. 085017.
7. S.Venkatesan, M.Anthony Xavior, "Tensile behavior of aluminum alloy (AA7050) metal matrix composite reinforced with graphene fabricated by stir and squeeze cast processes", *Science and Technology of Materials*, 30 (2), 2018, pp. 74-85.
8. S.R. Sundara Bharathi, D. Ravindran, A. Arul Marcel Moshi, "Multi-response optimization of CNC turning parameters of austenitic stainless steel 303 using Taguchi-based grey relational analysis", *Transactions of the Canadian Society for Mechanical Engineering*, 44 (4), pp. 592-601.