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# Mechanical and Wear behavior of Al7075/$Al_2O_3$/SiC Hybrid Composite

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**Abstract**

Stir casting process is more advantageous due to good production efficiency. The process-parameters such as $Al_2O_3$, SiC and heat treatment temperature are the major factors in determining the strength of the composites. The main aim was to develop the sound casting of MMC's. In the present study, Taguchi's L9 Orthogonal array used for optimizing the process parameters. The obtained composites were subjected to hardness and wear-rate analysis as per standards. Confirmatory test was performed for the optimized parameters and these results were within the acceptable range when compared with the experimental results.



*Keywords:*Stir casting, Hybrid Composite, Hardness, Ware rate, Taguchi.

## 1. Introduction

Hybrid Metal Matrix Composites are engineering materials reinforced by a mixture of two or more different type of material in order to accomplish the combined benefits of both of them. Alumina ($Al_2O_3$), boron (B),Silicon Carbide (SiC), zirconium (Zr), etc are the most commonly used non-metallic reinforcements, combined with aluminium alloys to obtain aluminium matrix composites and $Al_2O_3$/SiC, in the form of particulates, are found to have tremendous compatibility. In a stir casting process, normally the particulate reinforcement is dispersed into the aluminum melt by mechanical stirring process. Mechanical stirring is a key element of this process. Composites with up to 30% volume fractions can be used in this method. The major advantage of this stir casting process is its

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applicability to mass production. Compared to other fabrication process, stir casting process costs as low as 1/3rd to 1/10th for mass production of metal matrix composites. Due to this reasons, stir casting is the most widely used commercial technique of manufacturing aluminum based composites [1]. Among other parameters, %weight of Alumina ($Al_2O_3$) and Silicon Carbide (SiC) is reported to be the most operative parameters influencing hardness and other mechanical properties of aluminium matrix composites. The tribological and mechanical properties of stir cast aluminum matrix composites having single and multiple-reinforcement. Addition of alumina to aluminum will show the increase in its tribological and mechanical properties. Organic reinforcement like fly ash, coconut ash also improved the tensile and yield strength [1]. Reinforcement particulates may be in interacting electro-chemically or physically with the matrix important to enhanced oxidization (corrosion) [2]. Preferential oxidization along with the particle matrix interface can be lead to the rapid diffusion along the large interfacial regions in composites. The optimization of volume percentage of reinforcements and heat treatment for improving the mechanical properties of Aluminum alloy, $Al_2O_3$ and SiC surface hybrid composites was not reported. The Taguchi method is an efficient methodology proposed for design and analysis of experiments to improving the quality characteristics of process. Currently, it has developed a very popular practical experimentation for improving the excellence of output without increasing the cost of process by reducing the number of experiments.

## 2. Methodology

The main objective of this work is to investigate the hardness and wear rate of aluminium matrix composites produced by stir casting. The material combination that will be studied in detail consists of Al7075/ $Al_2O_3$/ SiC. This specific material combination is relatively has a lot of potential applications in today’s aerospace and marian. Stir casting process helps to bonding of specific material combinations which will be done by conventional methods. To produce a stir casting, the required parameters are been implemented against each other, thereby producing MMCs.

The result of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array experimental design proposed by the Taguchi. Once the parameters disturbing a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. Determining what levels of a variable to test requires an in-depth understanding of the process, including the minimum, maximum and current value of the parameter. If the difference between the minimum and maximum value of a parameter is large, then the values being tested can be further apart or more values can be tested. If the series of a parameter is larger, then the values tested can be more accurate.

Taguchi method has been used to improve the quality of manufactured products. The main objective in the Taguchi method is to design the parameters. The method presented in the study is experimental design process known as Taguchi design method. Based on the design of experiments (DOE) the MMCs was prepared, the machined specimens will be measured for hardness and ware rate value in a calibrated testing machine according to the standards. The optimizing process is the final step in the Design of Experiments (DOE). The purpose of the optimization is to validate the optimum levels of parameters.

## 3. Experimental design

### *3.1. Plan of experiments (DOE)*

In the direction of saving time and material cost involved in investigation, the smaller number of experiments is chosen [4]. Therefore Taguchi’s method is implemented. Experiments are carried out affording to combination levels specified by L9 orthogonal array. The stir casting procedure was studied along with the basic process. Based on this study, $Al_2O_3$, SiC and heat treatment temperature were selected as the varying process parameters. Time for heat treatment of 4 hours and % weight of $Al_2O_3$ was kept constant for all the casted samples. Varying process parameters are tabulated in the Table 1. A standard Taguchi L9 orthogonal array was chosen for this investigation as it can operate up to four parameters, each at three levels. Taguchi's designs aimed to allow better understanding of variation than did many of the designs. Taguchi opposed that conventional sampling is inadequate here as there is no technique of finding a random sample of upcoming conditions. Taguchi proposed extending each experiment with an orthogonal array should be simulate the random environment in which the experiment would function. Adequate details of the effect of different parameter values on experimentations can be achieved by selecting three levels for each parameter to examine. Based on the literature survey the levels of each parameter were selected, a large number of trial runs inspected in order to identify the hardness of the material to study the upper and lower limits of results.

Table 1. Levels of process parameters.

| Process parameters | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| $Al_2O_3$ (% weight) | 2 | 2 | 2 |
| SiC (% weight) | 3 | 6 | 9 |
| Heat treatment temperature ($^{O}$C) | 140 | 160 | 180 |

*3.2. Experimental details*

In the present investigation, Alluminium 7075, $Al_2O_3$ of 100 mesh size and SiC of 220 mesh size particles were been used. According to the conventional method the melting process was done using coke furnace. Once the molten metal is ready, the pre-heated reinforcements were added in to the crucible according to weight %. After the addition of reinforcement, the stirring process was done to get exact mixture of base metal and reinforcements, later the molten metal was poured in to the die continuously. According to the orthogonal array of L9, process was carried out for 9 different castings. Based on ASTM standards the casted parts were machined and same was undergone to the heat-treating process. The hardness test is carried out in Vicker's micro hardness tester as shown in the Fig. 1. The load of 0.5 kg for a period of 10 seconds is applied on specimens. Sliding wear tests were conducted in pin-on-disc wear testing apparatus (model: TR20-LE, Wear and Friction Monitor, Ducom Make, Bangalore, India) under the load of 30N at a fixed sliding speed of 1.66m/s against EN32 steel disc (60 HRc) as shown in the Fig. 2.

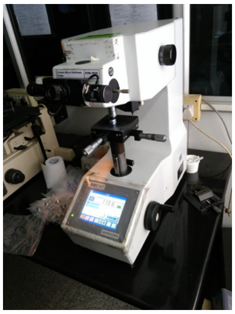

Fig. 1. Vicker's micro hardness tester.


Fig. 2. Pin-on-disc wear testing apparatus.

## 4. Result and discussion

The experimental results are analyzed and tabulated in Table 2. In hardness test 3 indentations were taken on each of specimens and the average value of the hardness for all the specimens are been tabulated along with the corresponding levels of the parameters used for preparation of specimens. Similarly the wear rate is also tabulate in the following Table 2.

Table 2. Experimental results of hardness and wear rate for L9 Orthogonal Array.

| Sample no. | $Al_2O_3$ (% weight) | SiC (% weight) | Heat treatment temperature ($^OC$) | Vickers hardness (VHN) | Wear (µm) |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 140 | 106 | 0.089 |
| 2 | 2 | 3 | 160 | 109 | 0.090 |
| 3 | 2 | 3 | 180 | 113 | 0.081 |
| 4 | 2 | 6 | 140 | 115 | 0.089 |
| 5 | 2 | 6 | 160 | 116 | 0.075 |
| 6 | 2 | 6 | 180 | 116 | 0.074 |
| 7 | 2 | 9 | 140 | 110 | 0.072 |
| 8 | 2 | 9 | 160 | 118 | 0.079 |
| 9 | 2 | 9 | 180 | 120 | 0.068 |

### *4.1 Experimental details*

After carrying out the experiments as per Taguchi's experimental design (DOE), the main effects plots for hardness and wear rate of the composite specimens are been plotted. A main effects is a direct effect on parameters on response and dependent variables. The main effect plots of parameters with respect to hardness and ware rate for composites are shown in Fig. 3 and Fig. 4.

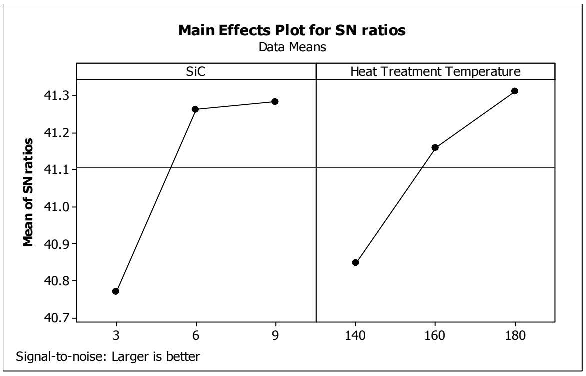


Fig. 3. Main effect plot for hardness.

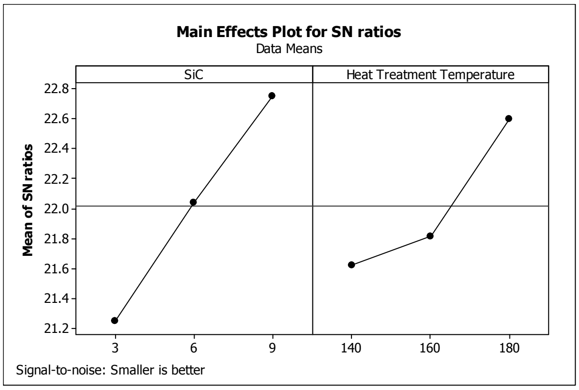


Fig. 4. Main effect plot for wear rate.

### *4.2 Analysis of variance (ANOVA)*

The analysis of variance (ANOVA) has been applied to check the capability of the development. ANOVA can be beneficial for defining influence of any specified input parameters from a series of experimental out puts by design of experiments (DOE) for casting process and it can be used to interpret experimental data. The obtained results are been analyzed by Minitab-16, statistical analysis software which is normally used in many engineering areas. The ANOVA table consists of sum squares, mean squares, degrees of freedom and percentage of contributions. Normally the sum of square is the ratio of sum squares to degree of freedom and F-ratio will be the ratio of mean square to the mean square error. The mathematical models are used to predict the hardness and ware rate which are formulated by response surface regression analysis. The suitability and significance of developed regression model was tested using predictable regression coefficient technique. The influence of hardness and wear rate are discussed with the help of following ANOVA Results.

Table 3. ANOVA results of Hardness Test.

| Source | DF | Seq. SS | Adj. SS | Adj. MS | F | Cont. (%) |
|---|---|---|---|---|---|---|
| SiC | 1 | 66.667 | 0.440 | 0.4399 | 0.05105 | 40.16 |
| Heat Treatment Temperature | 1 | 54.00 | 1.929 | 1.9286 | 0.22382 | 32.53 |
| SiC * Heat Treatment Temperature | 1 | 2.250 | 2.250 | 2.2500 | 0.26112 | 1.35 |
| Error | 5 | 43.083 | 43.083 | 8.6167 | | 25.95 |
| Total | 8 | 166.00 | | | | 100 |

Table 3 shows the ANOVA results of hardness test for the composites. It can be observed that the SiCp is the most significant parameter due to highest percentage (40.16%) contribution among the overall process parameters.

Table 4. ANOVA results of Ware rate.

| Source | DF | Seq. SS | Adj. SS | Adj. MS | F | Cont. (%) |
|---|---|---|---|---|---|---|
| SiC | 1 | 0.0002802 | 0.0000136 | 0.0000136 | 0.53865 | 52.66 |
| Heat Treatment Temperature | 1 | 0.0001215 | 0.0000362 | 0.0000362 | 1.43328 | 22.83 |
| SiC * Heat Treatment Temperature | 1 | 0.0000040 | 0.0000040 | 0.0000040 | 0.15831 | 0.75 |
| Error | 5 | 0.0001263 | 0.0001263 | 0.0000253 | | 23.74 |
| Total | 8 | 0.0005320 | | | | 100 |

Table 4 shows the ANOVA results of ware rate for the composites. It can be observed that the SiCp is the most significant parameter due to highest percentage (52.66%) contribution among the overall process parameters

*4.3 Regression analysis*

Regression analysis is used to calculate the data on the properties of hybrid composite. These regression equations are used to forecasting the hardness and Wear rate within the factors used. The regression equation commonly used is represented by Y = f (X, Y and Z). Y denotes the performance characteristics (Hardness / Wear rate). X, Y and Z are the process parameters. The general regression equations for hardness and wear rate are as follows.

Hardness = 95 - 0.888889 SiC + 0.075 Heat Treatment Temperature + 0.0125 SiC * Heat Treatment Temperature (1)

Wear Rate = 0.145 - 0.00494 SiC - 0.000325 Heat Treatment Temperature + 0.000017 SiC * Heat Treatment Temperature (2)

After conducting the experiments the liner regression models are been developed as shown in Eq. (1 and 2) to forecast hardness and wear rate. These equations are used to forecast the hardness and wear rate of samples used in the experimentations. To confirm the accuracy of such prediction of trials, the enduring experiments are been conducted and the comparison of experimental values and predicted values are been observed through plots. A plot of experimental values vs. predicted values is plotted for all three levels as shown in Fig. 4 and Fig. 5.

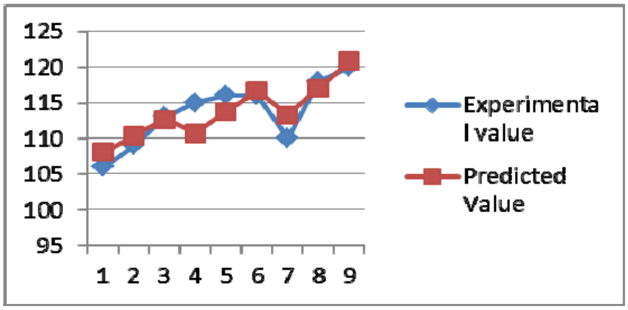


Fig.4: Comparison plot for Hardness.

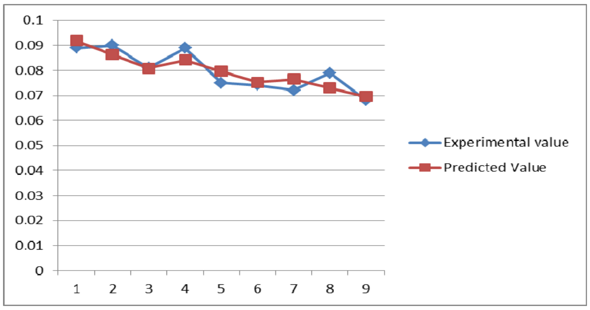


Fig.5: Comparison plot for Hardness.

Based on Hardness and Wear rate results, we can observe that the rank of the factors in response Table 5 and 6 shows that the SiCp is the most influencing factor as deltas of means are designed ranked it 1 of the three factors considered in investigation a typical response of Minitab shown in Table 5 and 6.

Table 5. Response table for signal to noise ratio of hardness results (Larger is better).

| Level | SiC | Heat Treatment Temperature |
|---|---|---|
| 1 | 40.77 | 40.85 |
| 2 | 41.26 | 41.16 |
| 3 | 41.28 | 41.31 |
| Delta | 0.51 | 0.46 |
| Rank | 1 | 2 |

Table 6. Response table for signal to noise ratio of ware rate (Smaller is better).

| Level | SiC | Heat Treatment Temperature |
|---|---|---|
| 1 | 21.25 | 21.63 |
| 2 | 22.04 | 21.82 |
| 3 | 22.75 | 22.60 |
| Delta | 1.50 | 0.97 |
| Rank | 1 | 2 |

*4.4 Confirmatory experiment*

The confirmatory experiment is the final step in the Design of Experiments (DOE). The purpose of the confirmatory experiment is to validate the optimum levels of parameters selected. The confirmatory experiment was performed by conducting a test with the optimum combination of the factors and levels selected. Samples were casted by selecting the optimized parameters from Taguchi method and were subjected to hardness and wear test. From the Taguchi analysis, optimized parameter settings were obtained and are listed in the Table 7 and 8.

Table 7. Optimized parameters combination based on Hardness test from Taguchi analysis

| Process parameter | Optimized values |
|---|---|
| SiC | 9 |
| Heat Treatment Temperature | 180 |

Table 8. Optimized parameters combination based on Wear Rate from Taguchi analysis

| Process parameter | Optimized values |
|---|---|
| SiC | 3 |
| Heat Treatment Temperature | 140 |

Experimentations were carried out for above data and the obtained results of confirmatory test is as tabulated in Table 9 and 10

Table 9. Confirmatory test results for hardness test

| Sample no. | $Al_2O_3$ (% weight) | SiC (% weight) | Heat treatment temperature ($^OC$) | Vickers hardness (VHN) |
|---|---|---|---|---|
| 1 | 2 | 9 | 180 | 119 |

Table 10. Confirmatory test results for wear rate

| Sample no. | $Al_2O_3$ (% weight) | SiC (% weight) | Heat treatment temperature ($^OC$) | Wear (µm) |
|---|---|---|---|---|
| 1 | 2 | 3 | 140 | 0.087 |

## 4. Conclusion

The main aim was to develop the sound casting of MMC's by both constant and varying the process parameters such as % weight of $Al_2O_3$, SiC and heat treatment temperature. The significant outcomes of the study are listed in this section.

- Taguchi experimental design was selected for parameter optimization to achieve sound casting.
- $Al_2O_3$ (2% constant), SiC (3%, 6% and 9%) and heat treatment temperature (140$^O$C, 160$^O$C and 180$^O$C) were found to be significant and hence selected for experimental design.
- Optimum values obtained from analysis for hardness are SiC: 9%, Heat Treatment Temperature: 180$^O$C and for ware rate SiC: 3%, Heat Treatment Temperature: 140$^O$C.
- 1% of hardness difference was observed when the confirmatory test specimen was compared with the experimental trial.
- 2.2% of ware rate difference was observed when the confirmatory test specimen was compared with the experimental trial.

## Reference

[1] Himanshu Kalaa, K.K.S Merb, Sandeep Kumarc, A Review on Mechanical and Tribological Behaviors of Stir Cast Aluminum Matrix Composites, Procedia Materials Science 6 ( 2014 ) 1951 – 1960.

[2] K.S. Alhawaria, M.Z.Omara, M.J. Ghazalia, M.S. Salleha, M.N. Mohammeda, Wear Properties of A356/ $Al_2O_3$ Metal Matrix Composites Produced by Semisolid Processing, Procedia Engineering 68 ( 2013 ) 186 – 192.

[3] T.S.Mahesh Babu, M.S.Aldrin Sugin and Dr.N.Muthukrishnan, Investigation on the Characteristics of Surface quality on machining of hybrid metal Matrix Composite (Al-SiC-$B_4$C), Procedia Engineering 38 ( 2012 ) 2617 – 2624.

[4] A. Devaraju, A. Kumar, B. Kotiveerachari, Influence of rotational speed and reinforcements on wear and mechanical properties of aluminum hybrid composites via friction stir processing, Materials and Design 45 (2013) 576–585.

[5] M.Vamsi Krishnaa, Anthony.M.Xavior, An Investigation on the Mechanical Properties of Hybrid Metal Matrix Composites, Procedia Engineering 97 ( 2014 ) 918 – 924.