# Optimization of Wear Parameters of AA7150-TiC Nanocomposites by Taguchi Technique

**Pagidi Madhukar, N. Selvaraj, Vipin Mishra and C. S. P. Rao**

**Abstract** Wear optimization of titanium carbide reinforced nanocomposite fabricated through the vortex, double stir casting technique was carried out through L25 orthogonal array of Taguchi method. The experimental work was executed on pin on disc tribometer with different input parameters such as weight percentage (0, 0.5, 1.0, 1.5, 2.0%) of titanium carbide, sliding distance (500, 1000, 1500, 2000, 2500 m), sliding speed (0.5, 1.0, 1.5, 2.0, 2.5 m/s), and applied load (5, 10, 15, 20, 25 N) under dry sliding conditions. The analysis of individual parameter influence on responses was investigated through Analysis of Variance (ANOVA) and regression analysis was used to correlate the fit of the model with experimental data of wear.

**Keywords** AA7150 · TiC · Two-step stir casting · Taguchi technique · Wear

## 1 Introduction

This aerospace and automobile sectors are always on the lookout for advanced materials with higher grade of mechanical and tribological properties which combine easy of fabrication with the ability to vary composition of alloy to have a range of desired properties. But virtue of being lightweight and because of high strength and stiffness Al as matrix material is prefered [1–3]. Aluminium metal composite is a suitable candidate for aerospace applications, manufacturing of automobile components, and gas turbine engine. Al–Mg–Cu–Zn alloys are mostly used in aerospace and automobile sectors because of highly corrosion resistant and having high strength. AA7150 finds application in upper and lower wings of aeroplane, upper wings of stringers, floor beams, and seat rails. The strength of AMMNC depends on the size of ceramic particles, interparticle spacing, and nature of matrix and reinforcement

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interface. Therefore, reinforcement of nano-size particles was chosen due to its ability to change morphological and interfacial characteristics of the nanocomposite. Incorporating nanoparticles is a critical issue in high-density liquid due to floating of particles at the liquid metal surface. To prevent the floating, vortex method is introduced, which redirects ceramic particles into the molten liquid. Two-step stir casting process is chosen to fabricate the nanocomposites with uniform distribution of ceramic particles.

Wear is found to frequently appear at mating parts which leads to frequent replacement of components, because of abrasion. Abrasive wear takes place when hard ceramic particles penetrate a soft surface and displace material in the form of elongated chips and slivers [4]. The tribological behaviour of metal matrix composites depends on the interface between the particles and the matrix, composition of the matrix, and particle distribution. These conditions depend in turn on the type of environment, contact area, counter surface, applied load, sliding speed, and geometry [5]. The principle tribological parameters, such as applied load [6–8], sliding speed [9, 10], and percentage of reinforcing particles, control friction and wear performance. To know the parameter influence and its optimization, Taguchi technique was adopted for TiC reinforced nanocomposites. Taguchi method is a useful tool for improving the performance, process, product design, system, and reduction in experimental cost and time [11]. Abbas et al. [12] established the Taguchi technique to deal with output responses influenced by multi-variables. Therefore, this technique can optimize process parameters and optimal combinations through Analysis of Variance (ANOVA) approach [13].

The present study is intended to look into the effects of sliding distance, sliding velocity, load, and wt% of ceramic reinforcement on responses such as wear loss. Titanium carbide (TiC) nanoparticulate reinforced nanocomposites are produced by two-step stir casting process. Wear test is performed with pin on disc apparatus to the most effective control parameter that is identified on the reference variable by using Taguchi method. L25 orthogonal array was used based on parameters and levels. ANOVA was used to investigate design parameters and its effect on wear behaviour of the composites.

## 2 Materials and Methods

In this work, commercially available AA7150 Ingots were used as matrix material and titanium carbide which were used as reinforcements; titanium carbide particles had >99.9% purity and 30–50 nm average particle size. A number of methods are available to produce aluminium metal matrix nanocomposite, and out of these methods, two methods are most extensively used for fabrication. One is a solid-state method. This method is expensive and time-consuming, and large production of AMMNC is difficult to achieve through powder metallurgy method. Liquid-state method (i.e., stir casting) is preferred for fabrication because it is easy, enables mass production, and can generate complex shapes and produce uniform dispersion of reinforcement particle with better particle matrix, easier control of matrix structure, and low cost of processing which are other reasons for choosing liquid-state method.

But the problem of stir casting method with nano-size particles is that when it is added to the molten material, poor wettability and non-uniform dispersion occur because of very high specific area of nanoparticles. To avoid these problems, a new technique called the vertex method is used and this uses a mechanical rotary stirrer. Line diagram of stir casting machine is represented in Fig. 1. Preheated nano ceramic reinforcements and flux are incorporated slowly into the vortex of molten metal alloy to build good wetting between ceramic reinforcement and aluminium alloy melt pool. This melt was poured into die and specimens were machined as per ASTM G99 standard.

Samples were made of cylindrical shape with a length of 30 mm and diameter of 8 mm and used to conduct wear test on pin on disc tribometer by varying applied loads (5, 10, 15, 20, 25 N), sliding velocity (0.5, 1.0, 1.5, 2.0, 2.5 m/s), sliding distance (500, 1000, 1500, 2000, 2500 m), and weight percentage (0.5, 1.0, 1.5, 2.0%) at dry sliding conditions. Figure 2 shows the experimental set-up.

The experimental design was developed by considering four independent parameters and five levels through Taguchi technique. The factorial designs are very effective when a large number of factors are studied, and it is very hard to conduct all test combinations [14]. L25 orthogonal array was used for four factors of the five levels considered, and their interactions were tabulated by Taguchi method. The output

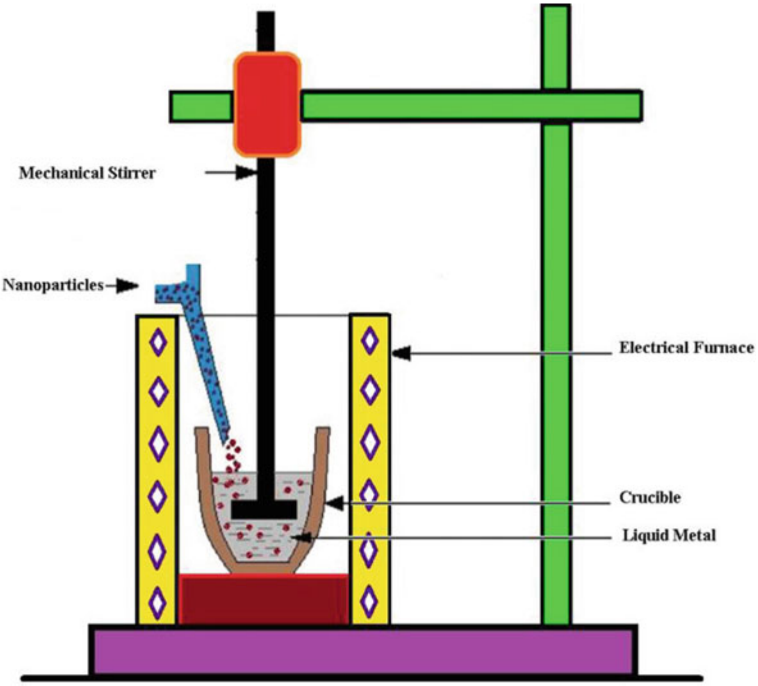

**Fig. 1** Stir casting line diagram

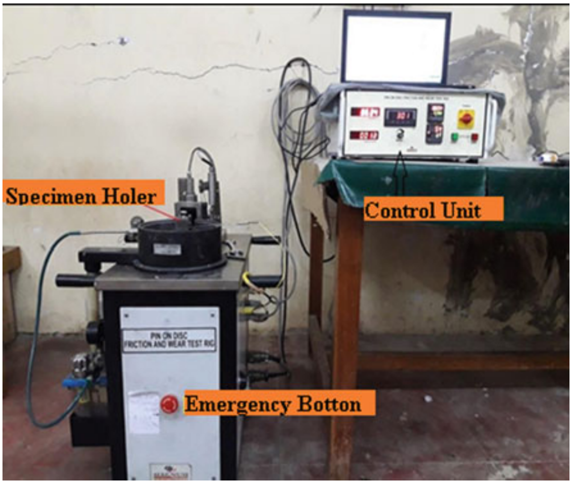

**Fig. 2** Pin on disc tribometer

**Table 1** Levels and factors in the experimental plan

| S. No | Process parameters | Units | Symbol | Levels | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | L1 | L2 | L3 | L4 | L5 |
| 1 | Load | N | L | 5 | 10 | 15 | 20 | 25 |
| 2 | Sliding distance | m | SD | 500 | 1000 | 1500 | 2000 | 2500 |
| 3 | Sliding velocity | m/s | SV | 0.5 | 1 | 1.5 | 2 | 2.5 |
| 4 | Weight % of TiC | wt% | wt% | 0 | 0.5 | 1 | 1.5 | 2 |

response that was created for the model is wear loss. A total of 25 experiments runs were executed based on the runs created by Taguchi model (Table 1).

The analysis part was carried out for experimental data using MiniTab17 software. The results were tabulated into a signal to noise ratio. The main objective of the exercise was to find processes insensitive to noise factors as well as performance. It was applied to calculate quality deviation from the targets [14]. Wear loss from the S/N ratio was determined using “smaller is better”, and it can be measured by logarithmic loss function as shown in the equation below:

$$\mathrm{S/N} = -10\log\left[\frac{1}{n}\left(\sum y^2\right)\right]$$

where

$y$ = experimental data (responses)
$n$ = number of observations

The major objective of the model is to minimize the wear loss of the composite material. ANOVA was then favoured to find out statistically significant parameters.

## 3 Results and Discussions

The wear investigations were carried out as per Taguchi L25 orthogonal array, and weight loss values were tabulated for different combinations of process parameters as shown in Table 2. The experimental values for the wear loss were transferred to S/N ratios to evaluate the quality characteristics, and the results generated are shown in Table 2. The individual parameter influence on output responses as wear loss has been measured using S/N ratio. The individual parameter and its ranking for wear for different levels are tabulated in Table 4.

Figure 3 shows the main effects plot to wear loss of titanium carbide reinforced composites. From the graph, it is confirmed that the wear loss decreases with increase of weight percentages [15] due to hard phase ceramic particles, which promote the

**Table 2** Experimental results of L25 orthogonal array for wear loss

| No. | wt% | SD | SV | Load | Wear Loss | S/N ratio |
|---|---|---|---|---|---|---|
| 1 | 0 | 500 | 0.5 | 10 | 0.0009 | 60.9151 |
| 2 | 0 | 1000 | 1 | 20 | 0.0052 | 45.6799 |
| 3 | 0 | 1500 | 1.5 | 30 | 0.0082 | 41.7237 |
| 4 | 0 | 2000 | 2 | 40 | 0.0143 | 36.8933 |
| 5 | 0 | 2500 | 2.5 | 50 | 0.0291 | 30.7221 |
| 6 | 0.5 | 500 | 1 | 30 | 0.0098 | 40.1755 |
| 7 | 0.5 | 1000 | 1.5 | 40 | 0.014 | 37.0774 |
| 8 | 0.5 | 1500 | 2 | 50 | 0.0265 | 31.5351 |
| 9 | 0.5 | 2000 | 2.5 | 10 | 0.0221 | 33.1122 |
| 10 | 0.5 | 2500 | 0.5 | 20 | 0.0103 | 39.7433 |
| 11 | 1 | 500 | 1.5 | 50 | 0.0131 | 37.6546 |
| 12 | 1 | 1000 | 2 | 10 | 0.0066 | 43.6091 |
| 13 | 1 | 1500 | 2.5 | 20 | 0.0115 | 38.7860 |
| 14 | 1 | 2000 | 0.5 | 30 | 0.0129 | 37.7882 |
| 15 | 1 | 2500 | 1 | 40 | 0.0133 | 37.5230 |
| 16 | 1.5 | 500 | 2 | 20 | 0.0004 | 67.9588 |
| 17 | 1.5 | 1000 | 2.5 | 30 | 0.0073 | 42.7335 |
| 18 | 1.5 | 1500 | 0.5 | 40 | 0.0054 | 45.3521 |
| 19 | 1.5 | 2000 | 1 | 50 | 0.0042 | 47.5350 |
| 20 | 1.5 | 2500 | 1.5 | 10 | 0.0076 | 42.3837 |
| 21 | 2 | 500 | 2.5 | 40 | 0.009 | 40.9151 |
| 22 | 2 | 1000 | 0.5 | 50 | 0.0041 | 47.7443 |
| 23 | 2 | 1500 | 1 | 10 | 0.0033 | 49.6297 |
| 24 | 2 | 2000 | 1.5 | 20 | 0.0011 | 59.1721 |
| 25 | 2 | 2500 | 2 | 30 | 0.0018 | 54.8945 |

**Table 3** Analysis of Variance for wear loss

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | %P |
|---|---|---|---|---|---|---|---|
| wt% | 4 | 0.000549 | 0.000549 | 0.000137 | 8.25 | 0.006 | 40.52 |
| SD | 4 | 0.000125 | 0.000125 | 0.000031 | 1.88 | 0.208 | 9.22 |
| SV | 4 | 0.000267 | 0.000267 | 0.000067 | 4.02 | 0.045 | 19.70 |
| Load | 4 | 0.000281 | 0.000281 | 0.000070 | 4.23 | 0.040 | 20.74 |
| Resid Error | 8 | 0.000133 | 0.000133 | 0.000017 | | | 9.81 |
| Total | 24 | 0.001355 | | | | | |

**Table 4** Response table for means

| Level | wt% | SD | SV | Load |
|---|---|---|---|---|
| 1 | 0.011540 | 0.006640 | 0.006720 | 0.008100 |
| 2 | 0.016540 | 0.007440 | 0.007160 | 0.005700 |
| 3 | 0.011480 | 0.010980 | 0.008800 | 0.008000 |
| 4 | 0.004980 | 0.010920 | 0.009920 | 0.011200 |
| 5 | 0.003860 | 0.012420 | 0.015800 | 0.015400 |
| Delta | 0.012680 | 0.005780 | 0.009080 | 0.009700 |
| Rank | 1 | 4 | 3 | 2 |

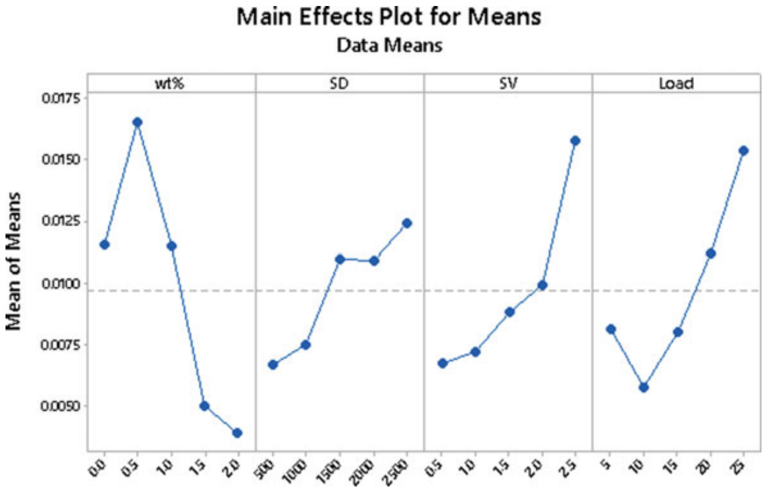

**Fig. 3** Main effective plots for wear loss

hardness in the composite. It is also observed that the sliding distance, velocity, and load follow the same trend in the graph.

Wear loss increases with the increase of sliding distance, velocity, and applied load due to high frictional heat at the surface of the couple which leads to softening material, resulting in more wear loss [16]. It was also observed that the effect of the applied load becomes very critical when the sliding distance becomes high. 2% wt. of TiC, 500 m of SD, 0.5 m/s of SV, and 10 N of load are the optimal values to minimize wear loss.

Table 4 shows the response table for wear loss of AA7150-TiC nanocomposites, and it is observed that the weight percentage has the highest role on wear loss and then applied a load, sliding velocity, and distances. This observation is made by given raking Table 4. The responses are based on delta value, and it is obtained by the difference between highest to the lowest value of the column.

The regression equation for wear loss

$$\begin{aligned} \text{Wear Loss} = & -0.00175 - 0.00538\,\text{wt\%} + 0.000003\,\text{SD} \\ & + 0.00418\,\text{SV} + 0.000402\,\text{Load} \end{aligned} \tag{1}$$

Linear regression was done for wear loss, and it is represented in Eq. (1) where it predicts the correlation with 90.2% adjacent $R2$ value to confirm the goodness of fit for experimental and modelled data. Therefore, 90.0.2% ensures that the model is a good correlation between input parameters to responses.

The strong influence of individual parameters was obtained by different maximum and minimum of mean S/N ratio values. The main effect plots for wear loss are represented graphically in Fig. 3. From the results, analysis was done for the main effects of wear loss, and this gave the optimal parameter combinations for minimum wear loss as 2% of TiC, 500 m of SD, 0.5 m/s of SV, and 10 N of the load.

Analysis of Variance was used to find the most significant influencing parameter for the output response. Table 3 shows the ANOVA values for wear. This analysis is at a level of 95% confidence. The percentage contribution (%P) of individual parameters for the final response can be measured for all variables as the ratio of the individual sum of squares of parameters to the total sum of squares. This can be observed for each parameter as shown in Table 3 with the load having the most impact with high statistical value (40.52%) on wear loss followed by the load (20.74%), SV (19.7%), and SD% (9.22%). Other combined interactions are neglected because their contribution is negligible.

## 4 Conclusion

Wear optimization of AA7150-TiC nanocomposites was investigated through dry sliding wear test using L25 orthogonal array Taguchi method. Linear regression model was developed and confirmed with adjacent $R2$ 90.2% of goodness fit. It was found that 2% of TiC, 500 m of SD, 0.5 m/s of SV, and 10 N of load were the optimal input parameter values to achieve minimum wear loss. From ANOVA analysis, weight percentage was seen as the parameter that most influences wear loss with a percentage of contribution (40.52%) on AA7150-TiC nanocomposites, followed by the load (20.74%), SV (19.7%), and SD% (9.22%), respectively.

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