Performance optimization of operating parameters: Al 6061-Red Mud composite under sliding wear

N Panwar¹, S Bala², A Chauhan³

¹Skill faculty of engineering and technology, Shri Vishwakarma Skill University, Dudhola, Palwal, Haryana-121102 (India)
²Department of Physics, SGGS College, Sector-26, Chandigarh-160019 (India)
³Department of Mechanical Engineering, University Institute of Engineering and Technology, Panjab University, Chandigarh-160014 (India)

Email: drchauhan98@gmail.com, drchauhan98@pu.ac.in

Abstract. Aluminium 6061-red mud composite has been fabricated by using stir casting method. Uniform distribution of red-mud particles has been observed by Scanning electron microscopy. Energy dispersive spectroscopy confirms presence of constituent elements of red mud. Wear testing of samples has been done on pin-on-disk type wear tester. The weight loss due to wear first decrease then increase with increasing percentage reinforcement. From experimentation, authors have found that the weight loss first decreases and then increase with aging time. Also, weight loss increases with applied load, sliding speed and sliding distance. In ANOVA analysis, the variables: load and sliding distance are found significant while particle size, aging time, percentage reinforcement and sliding velocity are not found significant. The order of significance is load, sliding distance, percentage reinforcement, sliding speed, aging time and particle size. Optimum value of weight loss is predicted by using Taguchi technique and confirmed by experimentally obtained results.

1. Introduction
Metal matrix composites (MMCs) are the materials in which hard ceramics has been reinforced inside a matrix of metal. Matrix and reinforcement material of MMCs are non soluble in each other and chemically non reactive [1-2]. MMCs have mixture of good properties of constituent materials like good stiffness, better strength, higher corrosion prevention, and more hard, lighter in weight and superior wear resistance [2-5]. MMCs with Aluminium matrix has been utilized in manufacturing parts in auto, aircraft, spacecraft and marine industries because they are lighter in weight and have good heat conducting properties [6-10]. Aluminium metal matrix Composites (AMMCs) reinforced by various types ceramic particles has been highly utilized composite because they can be manufactured and machined similar to conventional metallic materials [11]. Reinforcements used as whiskers, fibres and particles [12]. Aging of MMCs may significantly increase hardness [13-14]. Mostly used ceramic reinforcements in manufacturing AMMCs are carbide, nitride, boride and oxide of different materials. AMMCs can be reinforced with silicon carbide, alumina, boron carbide, titanium carbide, titanium boride, magnesium oxide, TiO₂, zircon, graphite and boron nitride [15-18]. AMMCs has been manufactured by different processes such as stir casting, squeeze casting, liquid infiltration, rheocasting, compocasting and powder metallurgy technique etc. [19-21]. Stir casting has been very simple, cheaper and flexible process out of the discussed methods [22-24]. For microstructure
observation scanning electron microscopy (SEM) and X-ray diffraction can be used [25-26]. Different Design of experiments (DOE) and analysis techniques can be utilized for systematically execution of experiments and analysis [2, 27-30].

Author’s finds in the literature that very few work studies on red mud reinforced aluminium matrix composite has been reported. Therefore the present work aims on the fabrication of desired composite with predefined input parameters. Taguchi method has been implemented for design the experiments incurred wear study.

2. Experimental Procedure

2.1. Material Preparation
Al6061 has been chosen as matrix. Red Mud reinforcement has been brought from HINDALCO, Renukut plant situated in Uttar Pradesh, India. XRF test of both material have been done to find out and verify constituent elements. Number of experiments has been decided by Taguchi Design of experiments technique. The input parameters/variables and their respective levels are given below in Table-1.

| Sr. No. | Variables                      | L-1 | L-2 | L-3 | L-4 | L-5 |
|--------|-------------------------------|-----|-----|-----|-----|-----|
| 1      | Percentage Reinforcement (by wt.) | 4   | 8   | 12  | 16  | 20  |
| 2      | Particle Size (µm)            | 250 | 177 | 149 | 125 | 74  |
| 3      | Ageing Time (hr)              | 0.5 | 6   | 12  | 18  | 24  |
| 4      | Load applied (kg)             | 1   | 2   | 3   | 4   | 5   |
| 5      | Sliding Distance (m)          | 1000| 1500| 2000| 2500| 3000|
| 6      | Sliding Speed (m/s)           | 0.2 | 0.4 | 0.6 | 0.8 | 1   |

2.2. Fabrication of composite
The Al6061 matrix based red-mud composite of current work has been prepared by stir casting process. Aluminium 6061 metal pieces has been heated to 800°C in a crucible made from graphite using electric muffle furnace Fig-1. Mechanical stirrer has been inserted in molten alloy for creating vortex. Red mud reinforcement particles preheated at 400°C in a separate furnace has been injected to vortex. Vortex has been created for obtaining uniform spreading of red mud in the matrix. Magnesium in a small quantity has been incorporated in the mixture for getting superior wettability of red-mud reinforcement with molten Al6061. The molten mixture has been poured inside preheated cylindrical mild steel moulds. Homogenizing of prepared composite has been performed to achieve uniformity the structure and better properties. While homogenizing samples has been heated to a temperature of 525°C for eight hours inside a electric furnace. Quenching of heated composite has been done by water. After those samples has been dried and used for further operation. Aging treatment of fabricated composite specimen has been performed inside furnace at a temperature of 175°C ±5°C. Aging has been done for 0.5, 6, 12, 18 and 24 hrs.

2.3. Wear Test
Wear tests have been done on wear testing machine (pin on disk) under sliding contact (Model: TR-20LE-PHM-CHM400 by DUCOM Bangalore). The equipment can perform wear testing a load up to 200N. The machine have working speed range from 200 to 2000 rpm. Tangential force acting and wear of sample under study has been observed using electronic sensors and displayed on computer screen. The parameter under study has been graphically drawn as function of applied load and rotational speed. The disc dimensions have been 100 mm diameter with a thickness of 8mm. The material of disk is EN-31 and hardness of 60 HRc (surface roughness at 1.6Ra). The samples have been cylindrical pin having dimensions 10 mm diameter with 30 mm length. The weight of the specimens has been taken before the conduction and after the conduction of wear tests by electronic weighing balance (least count = 0.0001 gm).
3. Results and discussion

3.1 Wear

To evaluate the impact of chosen parameters on output i.e. wear, five level of each input parameter have been taken. Wear testing have been conducted as per L25 orthogonal array. Fifty experiments have been carried out with a repetition of two and the outcome as weight loss due to wear (WLDTW) are given in Table-2. In the table, values are given for percentage reinforcement of red-mud i.e. PR, particle size of red-mud i.e. PS, aging time in the furnace i.e. AT, Load i.e. L in kilogram, Sliding distance i.e. SD, sliding speed i.e. SS, weight loss because of wear i.e. WL in grams and Signal to noise ratio i.e. S/N.

There have been three different type of quality characteristics in Taguchi technique given as: smaller the better, nominal the better and larger the better. Smaller the better criteria is chosen for current study out of the three quality characteristics because wear loss should be less for most of engineering application so we try to minimize the weight loss because of wear.

Mean value of WLDTW and signal to noise (S/N) has been evaluated by Minitab software. The calculated values of mean and S/N ratio has been shown in Table 2

| Sr. No. | PR (By wt) | PS (µm) | AT (hr) | L (Kgf) | SD (m) | SS (m/s) | WL mean (g) | S/N       |
|--------|------------|---------|---------|---------|--------|----------|-------------|----------|
| 1      | 4          | 250     | 0.5     | 1       | 1000   | 0.2      | 0.0025      | 52.0412  |
| 2      | 4          | 177     | 6       | 2       | 1500   | 0.4      | 0.0052      | 45.67993 |
| 3      | 4          | 149     | 12      | 3       | 2000   | 0.6      | 0.0133      | 37.52297 |
| 4      | 4          | 74      | 18      | 4       | 2500   | 0.8      | 0.03405     | 29.35766 |
| 5      | 4          | 125     | 24      | 5       | 3000   | 1        | 0.0574      | 24.82176 |
| 6      | 8          | 250     | 6       | 3       | 2500   | 1        | 0.0038      | 48.40433 |
| 7      | 8          | 177     | 12      | 4       | 3000   | 0.2      | 0.0182      | 34.79857 |
| 8      | 8          | 149     | 18      | 5       | 1000   | 0.4      | 0.0053      | 45.51448 |
| 9      | 8          | 74      | 24      | 1       | 1500   | 0.6      | 0.00295     | 50.60356 |
| 10     | 8          | 125     | 0.5     | 2       | 2000   | 0.8      | 0.0117      | 38.63628 |
| 11     | 12         | 250     | 12      | 5       | 1500   | 0.8      | 0.02045     | 33.78613 |
| 12     | 12         | 177     | 18      | 1       | 2000   | 1        | 0.0051      | 45.8486  |
| 13     | 12         | 149     | 24      | 2       | 2500   | 0.2      | 0.00475     | 46.46613 |
| 14     | 12         | 74      | 0.5     | 3       | 3000   | 0.4      | 0.01425     | 36.9237  |
| 15     | 12         | 125     | 6       | 4       | 1000   | 0.6      | 0.0073      | 42.73354 |
| 16     | 16         | 250     | 18      | 2       | 3000   | 0.6      | 0.0086      | 41.31003 |
| 17     | 16         | 177     | 24      | 3       | 1000   | 0.8      | 0.0079      | 42.04746 |
| 18     | 16         | 149     | 0.5     | 4       | 1500   | 1        | 0.0211      | 33.51435 |
| 19     | 16         | 74      | 6       | 5       | 2000   | 0.2      | 0.013       | 37.72113 |
3.1.1 Delta analysis for WLDTW

Delta analysis for the wear test results has been performed by Minitab software. In this average result of every variable at all five levels has been evaluated. After that the difference of highest mean value and lowest mean result has been calculated and has been called delta. More has been the value of delta higher is the impact of the input parameter on outcome. The Table 3, 4 displays the mean of S/N ratios and average result values for WLDTW of the developed Al red-mud composite at every level.

The analysis concludes that the load has maximum impact on wear (rank 1) and particle size has least influence (rank 6). As from the analysis particle size has least influence on wear so not considered for further analysis.

| Level | Percentage | Particle Size | Aging Time | Load | Sliding Distance | Speed |
|-------|------------|---------------|------------|------|------------------|-------|
| 1     | 37.88      | 42.22         | 38.50      | 46.88| 47.76            | 42.74 |
| 2     | 43.59      | 38.38         | 43.48      | 45.71| 41.25            | 41.36 |
| 3     | 41.15      | 41.17         | 41.12      | 41.51| 39.08            | 40.71 |
| 4     | 39.53      | 39.95         | 40.94      | 35.21| 39.73            | 37.34 |
| 5     | 41.81      | 42.24         | 39.92      | 34.65| 36.14            | 41.81 |
| Delta | 5.71       | 3.86          | 4.98       | 12.23| 11.62            | 5.40  |
| Rank  | 3          | 6             | 5          | 1    | 2                | 4     |

Table 4. Response table for Means of WLDTW

| Level | Percentage Re却forcement | Particle Size | Aging Time | Load | Sliding Distance | Speed |
|-------|---------------------------|---------------|------------|------|------------------|-------|
| 1     | 0.022490                  | 0.013150      | 0.015300   | 0.004960| 0.004900         | 0.009160|
| 2     | 0.008390                  | 0.018160      | 0.007300   | 0.006350| 0.011410         | 0.009660|
| 3     | 0.010370                  | 0.010330      | 0.012100   | 0.009320| 0.011920         | 0.011820|
| 4     | 0.011530                  | 0.012670      | 0.012080   | 0.019430| 0.015320         | 0.016260|
| 5     | 0.011900                  | 0.010370      | 0.017900   | 0.024620| 0.021130         | 0.017780|
| Delta | 0.014100                  | 0.007830      | 0.010600   | 0.019660| 0.016230         | 0.008620|
| Rank  | 3                         | 6             | 4          | 1    | 2                | 5     |

Figure 2. Mean values of parameters with respect to WLDTW.
3.1.2 Analysis of variance for WLDTW

The ANOVA analysis concluded that the input variables i.e. applied load and sliding distance has been come out significant but the effect of particle size, aging time, percentage reinforcement and sliding velocity are not found significant. The significance order of the variables is load, sliding distance, percentage reinforcement, sliding speed, aging time and particle size.

| Source                | Degree of Freedom(DoF) | Sum of Squares(SS) | Mean Squares(MS) | F Ratio | P value | % Contribution |
|-----------------------|------------------------|--------------------|------------------|---------|---------|----------------|
| Percentage reinforcement | 4                      | 95.28              | 23.82            | 1.77    | 0.298   | 7.17           |
| Aging Time            | 4                      | 66.82              | 16.70            | 1.24    | 0.420   | 5.03           |
| Load                  | 4                      | 653.44             | 163.36           | 12.11   | 0.017   | 49.22          |
| Sliding Distance      | 4                      | 372.52             | 93.13            | 6.91    | 0.044   | 28.06          |
| Speed                 | 4                      | 85.56              | 21.39            | 1.59    | 0.333   | 6.44           |
| Residual Error        | 4                      | 53.94              | 13.49            |         |         |                |
| Total                 | 24                     | 1327.56            |                  |         |         |                |

R-Sq = 95.9%   R-Sq(adj) = 75.6%, Variance(S) = 3.672

3.1.3 SEM analysis

At lower loads in figure 3e, 3d, 3g abrasive wear is seen more prominent. At higher applied loads in figure 3b, 3c, 3i, 3j, mechanism of wear is adhesive type. At 8% reinforcement figure 3c, 3d least wear debris are visible shows minimum wear and abrasion wear dominates adhesion wear. At lower i.e. 4% and higher reinforcement percentage i.e. 12, 16, 20% more amount of wear can be seen in the images 3a, 3b, 3e, 3f, 3g, 3h, 3i, 3j. At lower sliding distance abrasive grooves are less visible in figure c despite of higher load. AT higher sliding distance grooves are clearer fig 3b, 3f, 3g. Lower sliding speed have high tendency for adhesive wear figure 3i, 3f, 3c while the higher sliding speeds have tendency for abrasion wear figure 3b, 3h.

3.1.4 Estimation of optimum WLDTW

Here, the optimum value of WLDTW and confidence interval of it has been predicted theoretically using Taguchi’s technique. By considering the influence of parameters optimum value of WLDTW have been found out.

The Significant process variables for WLDTW are load at 1st level (L1), sliding distance at 1st level (SD1) The mean value of calculated WLDTW have been expressed as [31]:

\[ W_{wl} = L_1 + SD_1 - T_{wl} \]  ...1

Where, \( T_{wl} \): is Average of all values of WLDTW: 0.012936 g
\( L_1 \): Average value of WLDTW at first level of applied load: 0.00374 g
\( SD_1 \): Average value of WLDTW at first level of sliding distance=0.00482 g
\( W_{wl} \): 0.004376 g

Value of confidence interval has been predicted using below equation [31]

\[ CI = \sqrt{F_{(1, R)} V_e \left( \frac{1}{N_{eff}} + \frac{1}{R} \right)} \]  ...2

Where, CI= Confidence interval; \( F_{(1, R)} \) = The F-ratio at a confidence level of (1-α) against DOF=1 and error DOF (f_e); \( V_e \) = Variance of error; R= no. of samples for confirmation experiment; \( N_{eff} \) = Effective number of replications= N/ [1+total DOF in the estimation of mean]; N = Total experimental results= 50

by putting the below values:
\( N = Total number of experimental results= 50 \)
The total DOF in estimation of mean=8 (Table 5)

\[ n_{\text{eff}} = 8.33 \]

\[ F_{0.05}(1, 8) = 5.32 \]

The confidence interval = 0.0001682 g

The CI of predicted WLDTW at 95% confidence Interval has been =0.004376±0.0001682 g

(0.004544 g-0.004207 g)

The optimum level of input variable parameters for the predicted range of WLDTW are:

Reinforcement: 8%, Grain size: 149 micron, Aging time: 6 hours, Load: 1 kilogram, Sliding Distance: 1000 meter, Sliding Speed: 0.2 meter/second.

3.1.5 Confirmation Experiments

On the basis of analysis presented in last section, estimated results have been verified experimentally by conformation experimentation. The casting was performed and testing has been done at optimum levels of significant variables. The average value of experimental outcome has been shown below in Table 6. The outcome of confirmation experiments was compared with theoretically estimated results. It can be concluded that confirmation experiments result have been close to the estimated values and are in between the limits of confidence interval estimated (± 0.0001682 g). As reported in Table 6 developed composite has less wear than the base alloy under same load, sliding speed and sliding distance.

3.1.6 Effect of selected Parameters on WLDTW

The pattern of WLDTW with variables such as percentage reinforcement, particle size, aging time, load, sliding distance and sliding speed has been discussed in detail with the help of graphical representation.

3.1.6.1 Effect of percentage reinforcement on WLDTW

The WLDTW first decrease then increase with increasing percentage reinforcement. Firstly, the WLDTW reduced that may be due to higher the red-mud content more hard is the material, hence lower wear. But after 8% reinforcement, WLDTW starts increasing that may be due to rubbing reinforcement particle comes out and act as wear catalyst causing three body wear. Suresha and Sridhara [32] have reported similar trend for wear variation in hybrid AMMC with reinforcement of graphite and silicon carbide particulates. Harder reinforcement particles act as abrasive particles between two bodies i.e. plate and the work-piece. In ANOVA analysis of the variables, impact of percentage reinforcement (P=0.298˃0.05) has not been found significant. The percentage reinforcement (7.17%) has been more effective than the sliding speed (6.44%), aging time (5.04%) and particle size but less significant than the load (49.22%) and sliding distance (28.06%).

3.1.6.2 Effect of particle size on WLDTW

Figure 2 shows the variation of WLDTW at each level of particles size. In this figure WLDTW has been displayed at y axis and particle size has been represented at horizontal axis. Varying particle size shows arbitrary trend. This arbitrary trend may be due to dominance of different aspects such as three body wear may occur due to reduction in particle size as number of particles increases, increase in hardness with decrease in particles size may occur due to increase in wettability etc. Particle size of 149 micron has minimum weight loss, whereas particle size of 125 micron has maximum weight loss. From delta analysis it has also been found out that particle size (rank=6) has been least effective factor on WLDTW.

3.1.6.3 Effect of aging time on WLDTW

Graphical representation of variation of WLDTW with respect to aging time has been shown in Figure 2. WLDTW has been represented as ordinate axis and aging time has been represented as abscissa.
The WLDTW first decreases then increases with aging time. This may be due to increment in hardness of the composite with higher aging time.

Figure 3. SEM images of samples after wear for experiment no 3, 5, 8, 10, 12, 14, 16, 18, 19, 22
Table 6. Confirmation experiments result for wear

| Response Characteristics | Optimum level of parameters | Predicted Value of WLDTW | Confidence Interval at 95% | Experimental Value |
|--------------------------|-----------------------------|--------------------------|----------------------------|--------------------|
| WLDTW                    | A₃B₃C₅                    | 0.004376 g               | ±0.0001682 g               | 0.0044 g           |
| WLDTW (Base aluminum 6061) |                            |                          |                            | 0.0052 g          |

But further increase in aging increases WLDTW that may be due to formation of precipitates of reinforcement causes three body wear along with sliding wear. The ANOVA of the parameters concluded that effect of aging time (P=0.420˃0.05) on WLDTW has not been reported significant. When comparing the effect of all input parameters on WLDTW, the aging time (5.03%) has been more effective than the particle size (rank=6) but less effective than the load (49.22%), sliding distance (28.06%), percentage reinforcement (7.17%) and sliding speed (6.44%).

3.1.6.4 Effect of load on WLDTW
The variation of WLDTW with applied load has been shown in Figure 2. The weight loss has been displayed on vertical axis and load has been shown at horizontal axis. WLDTW is higher with higher load. This impact may be because of increase in friction due to larger value of normal load and hence high wear. Similar trend of results has been obtained by Sahin [33] and Adem [34] for aluminum composites. Significant effect of applied load (P=0.017≤0.05) has been found on WLDTW by ANOVA analysis of the variables. Further it has also been revealed by the analysis that the load (49.22%) has been most effective parameter among all selected input parameters.

3.1.6.5 Effect of sliding distance on WLDTW
Figure 2 shows the value of WLDTW at each level of sliding distance. Weight loss has been represented on y-axis and sliding distance has been represented on x-axis. By increasing sliding distance WLDTW increased. This may be because of larger is the sliding distance greater is the surface contact and hence higher erosion similar trend of results has been reported by Suresha and Sridhara [32] for aluminum composite reinforced by graphite and silicon carbide particles. The ANOVA of the variables on WLDTW reported that the influence of sliding distance has been significant. It has also reported by the analysis that the Sliding Distance has been second largest significant variable on weight loss after Load.

3.1.6.6 Effect of sliding speed on WLDTW
The value of weight loss at each level of sliding speed has been shown in Figure 2. The vertical axis in graph represents weight loss and horizontal axis represents sliding speed. By increasing sliding speed WLDTW is become higher similar results has been obtained by Adem [32] for aluminum-copper alloy composite reinforced with silicon carbide. It may be because more is the velocity higher has been the surface area interaction between the sample and disc per unit time, hence higher weight loss. The ANOVA of the input parameters, reveals that the impact of sliding speed on weight loss has not been significant. The ANOVA analysis also reveals that the significance order of the factors has been load, sliding distance, percentage reinforcement, sliding speed, aging time and particle size.

4. Conclusions
By evaluating above experimentation and analysis below mentioned conclusions can be drawn:

1) The WLDTW first decrease then increase with increasing percentage reinforcement. The wear first decrease and then increase with aging time. Varying particle size shows arbitrary trend.

2) WLDTW has been higher with higher applied load, sliding speed and sliding distance. The ANOVA analysis concludes that the parameters i.e. load and sliding distance come out
significant whereas the influence of particle size, aging time, percentage reinforcement and sliding velocity are not found significant. The significance order of the input variables is load, sliding distance, percentage reinforcement, sliding speed, aging time and particle size.

3) ANOVA results reveals that the impact of load and sliding distance have been found significant whereas the impact of percentage reinforcement, particle size, aging time, sliding speed are not found significant. Load is most influencing parameter while particle size is least influencing parameter.

4) Optimum value of WLDTW is estimated with Taguchi method and confirmation has been done by experimentally obtained results.

References
[1] Chawla N and Chawla K K 2005 Metal Matrix Composites 1st edition Springer New York.
[2] Basavarajappa S, Chandramohan G and Davim J P 2007 Application of Taguchi techniques to study dry sliding wear behaviour of metal matrix composites Mater Des. 28 1393-98.
[3] Garcia-Cordovilla C, Narciso J and Louis E 1996 Abrasive wear resistance of aluminium alloy/ceramic particulate composites Wear 192 170-77.
[4] Kok M 2005 Production and mechanical properties of Al2O3 particle-reinforced 2024 aluminium alloy composites J. Mater. Process. Technol. 161 381-87.
[5] Panwar J and Chauhan A 2018 Analyzing on the Effects of Process Parameters on Tensile strength for Al 6061-Red Mud Composite J. of Sci. Ind. Res. 77 (11) 646-51.
[6] Li S, Su Y, Zhu X, Jin H, Ouyang Q and Di Z 2016 Enhanced mechanical behavior and fabrication of silicon carbide particles covered by in-situ carbon nanotube reinforced 6061 aluminum matrix composites Mater Des. 10 7130-38.
[7] Miracle D B 2005 Metal matrix composites-From science to technological significance Compos Sci Technol . 65 2526-40.
[8] Umanath K, Palanikumar K and Selvamani, S T 2013 Analysis of dry sliding wear behaviour of Al6061/SiC/Al2O3 hybrid metal matrix composites Compos. B. Eng. 53 159-68.
[9] Baradeswaran A and Perumal A E 2014 Study on mechanical and wear properties of Al 7075/Al2O3/graphitite hybrid composites Compos. B. Eng. 56 464-471.
[10] Pramanik A 2016 Effects of reinforcement on wear resistance of aluminum matrix composites Trans. Nonferrous Met. Soc. China 26 348-358.
[11] Srivatsan T S, Al-Hajri M, Smith C and Petraroli M 2003 The tensile response and fracture behavior of 2009 aluminum alloy metal matrix composite Mater. Sci. Eng. 346 91-100.
[12] Miyajima T and Iwai Y 2003 Effects of reinforcements on sliding wear behaviour of aluminum matrix composites Wear 255 606-616.
[13] Panwar N and Chauhan A 2019 Parametric behaviour optimisation of macro and micro hardness for heat treated Al 6061-red mud composite J. Mater. Res. Technol. 8 660-69.
[14] Torralba J M, Da Costa C E and Velasco F 2003 P/M aluminum matrix composites: an overview. Journal of Materials Processing Technology J. Mater. Process. Technol. 133 203-06.
[15] Baradeswaran A and Perumal E A 2013 Influence of B4C on the tribological and mechanical properties of Al 7075-B4C composites Compos. B. Eng. 54 146-52.
[16] Ramesh C S and Ahamed A 2011 Friction and wear behaviour of cast Al 6063 based in situ metal matrix composites Wear 271 1928-39.
[17] Zhiquiang S, Di Z and Li G 2005 Evaluation of dry sliding wear behaviour of silicon particles reinforced aluminum matrix composites Mater Des. 26 454-458.
[18] Kumar T S, Subramanian R, Shalini S, Anburaj J and Angelo P C 2016 Synthesis, microstructure and mechanical properties of Al-Si-Mg alloy hybrid (zircon + alumina) composite Indian J. Eng. Mater. Sci. 23 20-26.
[19] Raj R, Singh D and Thakur G 2016 Qualitative and quantitative assessment of microstructure in Al-B4C metal matrix composite processed by modified stir casting technique Arch. Civ. Mech. Eng. 16 949-60.
[20] Kaczmar J W, Pietrzak K and Woosinaski W 2000 The production and application of metal matrix composite materials J. Mater. Process. Technol. 106 58-67.
[21] Deuis R L, Subramanian C and Yellup J M Dry sliding wear of aluminium composites-a review Wear 201 132-144.
[22] Li Y, Li Q, Li D, Liu W and Guo-gang S H U 2016 Fabrication and characterization of stir casting AA6061–31%B₄C composite Trans. Nonferrous Met. Soc. China 26 2304-12.
[23] Gopalakrishnan S and Murugan N 2012 Production and wear characterisation of AA 6061 matrix titanium carbide particulate reinforced composite by enhanced stir casting method Compos. B. Eng. 43 302-308.
[24] Moses J J, Dinaharan I and Sekhar J S 2016 Prediction of influence of process parameters on tensile strength of AA6061/TiC aluminum matrix composites produced using stir casting Trans. Nonferrous Met. Soc. China 26 1498-11.
[25] Rajmohan T, Palanikumar K and Ranganathan S 2013 Evaluation of mechanical and wear properties of hybrid aluminium matrix composites Trans. Nonferrous Met. Soc. China 23 2509-17.
[26] Baskaran S, Anandakrishnan V and Duraiselvam M 2014 Investigations on dry sliding wear behavior of in situ casted AA7075–TiC metal matrix composites by using Taguchi technique Materials and Design 60 184-192.
[27] Prakash S K, Kanagaraj A and Gopal P M 2015 Dry sliding wear characterization of Al 6061/rock dust composite Trans. Nonferrous Met. Soc. China 25 3893-03.
[28] Sahin Y 2005 Optimization of testing parameters on the wear behaviour of metal matrix composites based on the Taguchi method Materials Science and Engineering A 408 1-8
[29] Mahapatra S S and Patnaik A 2009 Study on mechanical and erosion wear behavior of hybrid composites using Taguchi experimental design Materials and Design 30 2791-01.
[30] Baradeswaran A, Vettivel S C, Perumal A E, Selvakumar N and Issac R F 2014 Experimental investigation on mechanical behaviour, modelling and optimization of wear parameters of B4C and graphite reinforced aluminium hybrid composites Mater. Des. 63 620-32.
[31] Ross P J 1998 Taguchi techniques for quality engineering McGraw-Hill Book Company, Singapore.
[32] Suresha S and Sridhara B K 2010 Wear characteristics of hybrid aluminium matrix composites reinforced with graphite and silicon carbide particulates Compos Sci Technol. 70 1652-59.
[33] Sahin Y 2005 The prediction of wear resistance model for the metal matrix composites Wear 258 1717-22.
[34] Onat A 2010 Mechanical and dry sliding wear properties of silicon carbide particulate reinforced aluminium–copper alloy matrix composites produced by direct squeeze casting method J. Alloys Compd. 489 119-24.