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Parametric studies on dry sliding wear behaviour of Al-7075 alloy matrix composite using S/N ratio and ANOVA analysis

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Abstract

Al7075/10 wt% TiO2 alloy composite has been fabricated by the stir casting method to investigate the influence of wear parameters. The microstructure of the produced composite was analyzed by scanning electronic microscopy. A pin-on-disc rig was used to carry out the wear test on produced composite under dry sliding conditions. The three wear control parameters such as load, sliding velocity and sliding distance were chosen to study the effects on the wear rate and coefficient of friction of composite. The experiments were planned as per L9 orthogonal array based on Taguchi’s design of experiments. The signal-to-noise ratio and analysis of variance techniques were employed to determine the optimum combination of parameters and the significant contribution of each parameter on the responses. The results exposed that the load was the most predominant factor affecting the wear rate and coefficient of friction followed by the sliding distance and sliding velocity. Finally, the regression equations were developed to predict the responses. The worn surface morphology of composite noticed that TiO2 reinforcement protects the matrix alloy from removal of material at all conditions. This investigation revealed that the wear resistance of the Al7075 alloy can be enhanced by the incorporation of TiO2 particles.

1. Introduction

In recent decades, metal matrix composites (MMCs) are used to replace the emergent stipulate for light density with high performance materials in advanced manufacturing industries [1]. Among the MMCs, aluminium matrix composites (AMCs) are widely used as an attractive option for aviation, transportation, sports industries and defence applications owing to their favourable characteristics such as high strength-to-weight ratio, high specific modulus, good wear and corrosion resistance and low thermal expansion coefficient [2]. The aluminium and its alloys exhibit very poor tribological properties. In order to improve the tribological properties, aluminium alloys are incorporated with hard ceramic reinforcements like SiC, Al2O3, B4C, TiC, TiO2 and graphite etc [3, 4]. Amongst these available particles, TiO2 is least investigated ceramic particles despite having various attracting features, such as less expensive, easily available, having high hardness and excellent wear resistance [5]. The AMCs are produced by much kind of methods such as powder metallurgy, stir casting, compo casting and liquid infiltration technique etc [6]. Among these techniques, stir casting is the most opt route for the manufacturing of AMCs. Since it is very simple and inexpensive method, flexibility and homogeneous dispersion of ceramic particles can be achieved by mechanical stirring action [7]. Some literatures reported that the effect of different variables on tribological characteristics of AMCs [8–18]. Baskaran et al [8] studied the effects of wear control parameters like reinforcement, load, sliding velocity and sliding distance on wear rate. They concluded that load was the high influencing parameter on wear rate followed by sliding velocity and amount of reinforcement. Kok et al [9] optimized the effect of abrasive wear parameters such as volume fraction of reinforcement, abrasive grain size and sliding distance during abrasive wear process of AA2024 filled with Al2O3 composites. They revealed that the volume fraction of reinforcement was the most decisive factor on wear rate.
parameter on wear rate. Radhika et al [10] investigated the wear and frictional behaviour of Al/alumina/graphite hybrid MMCs and understood that graphite as primary reinforcement increases the wear resistance of the produced composites and sliding distance was the most predominant factor on the output responses. Ramakoteswara Rao et al [11] performed the dry sliding wear and friction behaviour of AA7075 filled with TiC particulates composites and reported that the wear rate and COF decreased with increases the weight percentage of TiC content. Ashiwni Kumar et al [12] carried out the tribological characteristics of Al 7075 alloy-Ni based composite and they observed that 2 wt% nickel powder filled composite enhanced the wear resistance. Mir Irfan et al [13] employed the tribological properties of AA7075 composite incorporated with Si₃N₄ particles developed by stir casting method and concluded that the addition of reinforcement particles improved the wear resistance and reduced the COF. Veeresh Kumar et al [14] conducted the wear behaviour of Al7075/SiC MMCs and reported that the volumetric wear loss of the composites decreased with increases the SiC reinforcement in to the matrix. Ambigai et al [15] produced Al–Si₃N₄ nano composite and Al–Gr–Si₃N₄ hybrid composite and the effect of reinforcement, load and sliding distance on wear rate and COF were analyzed under dry sliding wear conditions. They concluded that the wear rate and COF decreased for hybrid composite when compared with nano composite. It was also noticed that load was the most impact factor among the others. Elango et al [16] studied the tribological characteristics of aluminium alloy LM25 filled with SiC and TiO₂ particulates composites by using pin-on-disc machine. They reported that the wear rate and COF decreases with increasing the TiO₂ content, the reason is lubricating nature and hardness property of the TiO₂ particles improved the wear resistance. Jawahar Chandran et al [17] conducted the dry sliding wear process of Ti₅S₂ reinforced LM13 aluminium alloy MMCs through liquid metallurgy route. It concluded that the load was a factor which had a most impact on the wear rate. The worn surface morphology showed the more wear occurred at high load due to higher surface damages. Sakip Koksal et al [18] analyzed the dry sliding wear parameters on Al/AlB₂ composites using Taguchi method. It was found that the normal load and reinforcement ratio were the most decisive factor on specific wear rate followed by sliding velocity. From the detailed literatures, the assessment of wear behaviour of composites is a complex phenomenon because it depends upon various factors like reinforcement, load, sliding velocity and sliding distance. Therefore, scientific assessment of wear behaviour of AMCs is very important using the statistical technique in order to reduce the time and cost. Further, the exhaustive literature survey revealed that no experimental and statistical work is directed towards the study of morphological and wear behaviour of Al7075–TiO₂ alloy composite fabricated through stir casting technique.

Hence, this research work aims to investigate the dry sliding wear behaviour of TiO₂ particulates filled Al7075 alloy composite developed by a stir casting method. A pin-on-disc apparatus was used to perform the experiments by considering different control parameters such as load, sliding velocity and sliding distance. Taguchi technique was employed to identify the optimum level of parameters on the wear rate and COF of the composite specimen. Moreover, the percentage contribution of parameters was determined by ANOVA. Scanning electron microscope (SEM) was performed to study the microstructure as well as worn surfaces of the produced composite.

2. Materials and method

2.1. Fabrication of composite

In the current investigation, Al7075 alloy was used as the matrix material. The chemical compositions of Al7075 alloy is provided in table 1. Titanium dioxide (TiO₂) was selected as the reinforcement material. It has density of 4510 kg m⁻³ and melting point is 1850°C. The reason for selecting this reinforcement is that, the TiO₂ particles is one of the most widely used oxides because of its very good mechanical property, superior wear and corrosion resistance and better thermal stability properties. As received Al7075 alloy matrix and TiO₂ reinforcement particulates are shown in figures 1(a), (b). The SEM micrograph of as received TiO₂ particles is shown in figure 1(c).

The detail of fabrication of composite was reported in the paper [4]. Al7075 alloy incorporated with 10 wt% of TiO₂ ceramic particulates composite was developed by stir casting technique. Initially, the measured quantity of Al7075 alloy was charged in to a graphite crucible and it was heated up to 850°C using electrical furnace. The measured TiO₂ particles were preheated to a temperature of 200°C in to the muffle furnace about 1 h to remove the impurities. The preheated TiO₂ particles were fed into the aluminium melt pool through a steel tube and the
composite slurry was stirred at 280 rpm about 10 min by mechanical stirring action. Finally, the composite slurry was poured in to a preheated mild steel mould to solidify at room temperature. Three batches of samples were produced for the various studies. The detailed microstructure analysis was carried out for the casted samples using scanning electron microscope to identify the defects. The defect free samples were used for the wear studies.

2.2. Plan of experiments

Based on the literatures, there are three wear control parameters namely load (N), sliding velocity (m/s) and sliding distance (m) were selected as the predominant factors on the wear rate and COF of the aluminium matrix composites [19]. The control parameters and their levels are depicted in table 2. The selection of orthogonal array depends on the number of parameters and their levels involved. According to the table 2, a standard Taguchi L9 (3^3) array was considered to perform the experiments.

2.3. Dry sliding wear test

Dry sliding wear test was carried out as per the ASTM G-99 standards by using pin-on-disc apparatus (Wear & Friction Monitor TR-20, DUCOM, Bangalore). Figure 2a shows the pin on disc apparatus and Figure 2b shows the wear samples used for the present study. The counter disc was made of EN-31 hardened steel having a hardness of 60 HRC. The test specimens with dimensions of 8 mm × 8 mm × 30 mm pins were prepared from the cast composite. Before the testing, the specimen surface was polished by using grit paper. A mass loss of specimen was calculated by weighing the specimen before and after the test. The tangential force (F_T) was directly noted from the test rig. The wear rate and COF of the composite specimen was calculated by using equation (1) and (2). The measured output responses for all the experiments are presented in table 3.

| Control parameters | Units | 1     | 2     | 3     |
|--------------------|-------|-------|-------|-------|
| Load (A)           | N     | 9.81  | 19.62 | 29.43 |
| Sliding velocity (B)| m/s   | 0.94  | 1.88  | 2.82  |
| Sliding distance (C)| m     | 1000  | 1500  | 2000  |
Wear rate mm m$^{-1}$

$\Delta m$—mass loss of specimen (grams), $\rho$—density of the produced composite (g mm$^{-3}$), $D$—sliding distance (m), $F_T$—tangential force (N) and $F_N$—normal force (N).

2.4. Taguchi technique

Taguchi’s technique is an attractive statistical method which provides systematic and efficient approach for determining the optimum parameters in any process or performance [8]. In general, there are three types of quality characteristics are possible to evaluate the $S/N$ ratio such as smaller-the-better, nominal-the-better and larger-the-better [20]. In this study, we require minimum wear rate and COF of the composite; hence ‘smaller-the-better’ $S/N$ ratio was used to predict the optimum parameters and the equation (3) was represented as

$$S/N~ratio = -10 \log_{10}(1/n) \sum_{k=1}^{n} Y_{ij}^2$$

Where $n$—number of observations, $Y_{ij}$—observed responses value where $i = 1, 2, 3, \ldots n; j = 1, 2, 3, \ldots k$.

The experimental responses were transformed into $S/N$ ratio values by using the Minitab 17 statistical software. The evaluated $S/N$ ratio values are depicted in Table 3. ANOVA is a statistical tool to determine the analysis of experimental data and also commonly used to identify the performance on a group of process parameters under investigation [21]. In present study, ANOVA was successfully applied to determine the percentage contribution of each control parameters on the wear rate and COF.
3. Result and discussions

3.1. Microstructural examination

The SEM micrograph of unreinforced Al7075 alloy and reinforced Al7075 alloy −10 wt% TiO$_2$ composite are shown in figures 3(a), (b). From the figure, it can be revealed that the two different regions were identified. The black surface indicates the matrix material and the white colour indicates the addition of reinforcement particulates. In figure 3(a) represented that the SEM micrograph of unreinforced Al7075 alloy and it was ensured that they have not found in TiO$_2$ reinforcement particles in the matrix alloy. It was also found that the small voids are presented in some regions. From figure 3(b), it can be understood that the two different regions were noticed. It was evident that the presences of TiO$_2$ particles are homogeneously distributed in to the matrix Al7075 alloy[4]. The TiO$_2$ particles are well dispersed in the grain boundary of Al7075 alloy. The EDS and XRD analysis of the fabricated composites are previously reported[4].

![Figure 3. SEM micrograph (a) Al7075 alloy and (b) Al7075 alloy-10 wt% TiO$_2$ composite.](image)

3.2. Influence of control parameters on the wear rate

The response table for S/N ratio and means of wear rate is presented in table 4. From the table, it was clearly understood that the load has most influencing factor on wear rate, followed by sliding distance and sliding velocity. The Archard’s law obeyed that, the variation of wear rate is proportional to the load on the pin surface. The higher applied load produce more wear loss due to continuous contact between the surfaces. Therefore, increase in load to developed the maximum contact pressure between the test specimen surface and the counter disc material, thus produces more elevated temperature at the interface which resulting in, increased the wear rate[11, 22]. It is also understood that, increasing the sliding distance increases the wear rate. The presence of

| S/N ratio of wear rate | Load (A) | Sliding velocity (B) | Sliding distance (C) |
|-----------------------|----------|----------------------|---------------------|
| Level                 |          |                      |                     |
| 1                     | 52.10    | 49.81                | 50.88               |
| 2                     | 49.97    | 49.94                | 50.16               |
| 3                     | 47.99    | 50.31                | 49.02               |
| Delta (A)             | 4.10     | 0.50                 | 1.86                |
| Rank                  | 1        | 3                    | 2                   |

| Mean of wear rate     |          |                      |                     |
|-----------------------|----------|----------------------|---------------------|
| Level                 |          |                      |                     |
| 1                     | 0.002488 | 0.003357             | 0.002901            |
| 2                     | 0.003191 | 0.003233             | 0.003156            |
| 3                     | 0.004007 | 0.003095             | 0.003629            |
| Delta (A)             | 0.001519 | 0.000262             | 0.000728            |
| Rank                  | 1        | 3                    | 2                   |
TiO$_2$ reinforcement acts as load supporting elements in the soft Al7075 alloy matrix for preventing the wear process. Figures 4(a)–(c) displays the mean S/N ratio graph for wear rate with respect to control parameters such as load, sliding velocity and sliding distance on wear rate. From the figure, it can be observed that the minimum wear rate is achieved by the optimum level of parameter combinations are $A_1B_3C_1$, which indicates that the load at level 1 (9.81 N), sliding velocity at level 3 (2.82 m s$^{-1}$) and sliding distance at level 1 (1000 m). Table 5 shows the ANOVA results for wear rate. From the table, it was also confirmed that load was the most significant parameter with contribution of 79.54% followed by sliding distance 18.18%. The sliding velocity was the less significant parameter with contribution of 2.27%. The R-sq value is 98.85% of wear rate understood that the model is able to predict the response with high accuracy. The similar observations were reported for the dry sliding wear behaviour of Al 7075 reinforced with TiC in-situ composites [8].
The interaction effect of control parameters such as load, sliding velocity and sliding distance on wear rate is shown in figures 5(a)–(c). From the graph, the parallel line indicates no interaction of parameter and the non parallel line indicates significant interaction of parameters on the wear rate. In figure 5(a), it can be observed that the interaction of load with sliding velocity is significant at higher loads (29.43 N) and insignificant at lower
applied loads (9.81 N), the reason is that, while considering higher applied load increases the wear rate for all the sliding velocity. In figure 5(b), the interactions of applied load with sliding distance were found to be insignificant which indicates the lines of interaction was almost parallel. It was also clearly demonstrated that the increase in sliding distance increases the wear rate at higher applied load (29.43 N). The interaction between the sliding velocity and sliding distance clearly indicates in figure 5(c), which reveals that the increase in sliding distance increases the wear rate at higher level of sliding velocity (2.82 m s\(^{-1}\)). Consequently, the wear rate of composite specimen were reduced for high sliding distance (2000 m) in case of low load (9.81 N) and low sliding velocity (0.94 m s\(^{-1}\)). However, the high load and high sliding velocity combinations wear rate was increased with the increase of the sliding distance. The moderate level of sliding velocity (1.88 m s\(^{-1}\)) gives the minimum wear rate (0.0024 mm\(^3\) m\(^{-1}\)) of the composite at any sliding distance. The increase in sliding distance smoothened the TiO\(_2\) reinforcement particles and it leads to the formation of a self lubricating layer which aids in the reduction of wear rate of the composite [23].

Figures 6(a)–(c) illustrates the contour plots for the wear rate with respect to variable control parameters. In figure 6(a) display the response of load and sliding velocity on wear rate. It was clearly reveals that, the wear rate gradually increases with increase in load at any sliding velocity. However, at the lower load, when the sliding velocity started to increase the wear rate to be less in the composite. It was revealed that the minimum wear rate (0.0025 mm\(^3\) m\(^{-1}\)) was obtained at the low level of load and the lower value of sliding velocity. Figure 6(b) demonstrated the response of load and sliding distance on wear rate. It was observed that, the higher value of sliding distance and the maximum load condition produces more wear rate due to more contact between the sample and counter disc. It can be observed that the maximum wear rate (0.0045 mm\(^3\) m\(^{-1}\)) was obtained at the high level of load and the higher value of sliding distance. Figure 6(c) presented the response on wear rate with respect to sliding velocity and sliding distance. It can be understood that, the sliding velocity was insignificant variable which means the response of wear rate doesn’t depend on the parameter. However, the higher value of sliding distance increases the wear rate at any sliding velocity remained constant. It clearly noticed that the low wear rate (0.0025 mm\(^3\) m\(^{-1}\)) was achieved at the middle level of sliding velocity and sliding distance.

3.3. Influence of control parameters on the COF

Table 6 presented the response table for S/N ratio and means of the COF. From the table, it clearly noticed that load was the most decisive factor on COF, followed by sliding distance and sliding velocity. The increase in applied load and sliding distance smoothened the presence of TiO\(_2\) reinforcement particles in the composite and it leads to the formation of a mechanically mixed layer (MML) which aids in the reduction of COF [8, 15]. It was also noticed that, increasing the sliding velocity increases the COF. Figures 7(a)–(c) shows the mean S/N ratio graph for COF with respect to different control parameters such as load, sliding velocity and sliding distance. It was explored that the minimum COF is obtained by the optimum level of parameter combinations are A\(_1\)B\(_1\)C\(_3\), which indicates that the load at level 1 (9.81 N), sliding velocity at level 1 (0.94 m s\(^{-1}\)) and sliding distance at level 3 (2000 m). Table 7 illustrate the ANOVA results for COF. It was also observed that, load was considered as the most impact parameter with the contribution of 66.08\% followed by sliding distance 30.71\%. Sliding velocity was insignificant parameter with contribution of 1.61\%. The R-sq value is 98.40\% of COF indicates that the model is able to predict the response with high accuracy. Similar results were made by Dhanalakshmi et al. (2018) who carried out the dry sliding wear process of AA7075 composites reinforced with Al\(_2\)O\(_3\) and B\(_4\)C [22].

The interaction effect of load, sliding velocity and sliding distance on the COF is shown in figures 8(a)–(c). From the interaction graph, the parallel lines indicate no interaction of parameters and the non parallel lines indicate significant interaction of parameters on the COF. In figure 8(a), it was observed that the interaction of load with sliding velocity is significant at higher applied loads (29.43 N). The applied load creates a continuous contact on the specimen thus produce maximum COF (0.560). While considering higher sliding velocity (2.82 m s\(^{-1}\)) increases the friction between the contacting surfaces for the entire applied load (9.8–29.43 N). The interactions of load with sliding distance are observed (In figure 8(b)) to be insignificant as the lines of interaction are almost parallel. It was also noticed that the increase in sliding distance decreases the COF at any conditions of load. Subsequently, the COF of composite specimens were decreased at a lower load (9.81 N) with the higher sliding distance (2000 m). In figure 8(c), the interaction between the sliding velocity and sliding distance on COF which clearly demonstrated that the increase in sliding velocity decreases the COF at lower and medium level of sliding distance (1000–1500 m). The moderate level of sliding velocity (1.88 m s\(^{-1}\)) increases the COF at the lowest sliding distance (1000 m).

Figures 9(a)–(c) shows the contour plots for the COF with function of the different control parameters. In figure 9(a) illustrate the response of load and sliding velocity on COF. It clearly observed that, the minimum COF value (0.48 to 0.50) was enhanced at the middle level of load and the higher value of sliding velocity. At the lower load and higher sliding velocity observed the low COF (<0.48). This means the value of the COF decreases with respect to load up to the middle level which was endorsed to occurring less frictional force. Figure 9(b)
represents the response of load and sliding distance on COF. It was display that, the observed COF value increased with increase in load at any sliding distance. However, the low COF value (<0.48) was observed at a maximum sliding distance with the lower load conditions. The result of figure 9(c) represented that the observed COF value increased with function of the sliding velocity and sliding distance. While considering the higher value of sliding velocity and sliding distance the low COF value (<0.48) was low.
3.4. Prediction of output responses

The predicted value of the output responses such as wear rate (WR) and coefficient of friction (COF) along with their respective confidence interval (CI) was estimated. The confirmation experiment results are also presented to validate the optimal parameter results. The 95% CI for the mean of population (CI_{POP}) and of confirmation

| Table 6. Response table for COF. |
|----------------------------------|
| S/N ratio of COF                 |
| Level | Load (A) | Sliding velocity (B) | Sliding distance (C) |
|-------|----------|----------------------|----------------------|
| 1     | 6.273    | 5.866                | 5.500                |
| 2     | 5.829    | 5.734                | 5.722                |
| 3     | 5.285    | 5.788                | 6.165                |
| Delta(A) | 0.988    | 0.132                | 0.665                |
| Rank  | 1        | 3                    | 2                    |

| Mean of COF                     |
|---------------------------------|
| Level                           |
| 1                               |
| 2                               |
| 3                               |
| Delta(A)                        |
| 0.4858                          |
| 0.5113                          |
| 0.5447                          |
| Rank                            |
| 1                               |
| 3                               |
| 2                               |

Figure 7. Mean of S/N ratio graph for COF (a) load, (b) sliding velocity and (c) sliding distance.
experiments (CI_CE) were calculated by using the equations (4) and (5).

\[
CI_{POP} = \sqrt{F_0(1, f_e) V_e \frac{1}{\eta_{eff}}}
\]

(4)

\[
CI_{CE} = \sqrt{F_0(1, f_e) V_e \left(\frac{1}{\eta_{eff}} + \frac{1}{R}\right)}
\]

(5)

Where, \(F_0(1, f_e)\)—is the F-ratio at the confidence level of \((1-\alpha)\) against DF, \(f_e\)—is error degrees of freedom, \(V_e\)—is error variance.

\[
\eta_{eff} = \frac{N}{1 + \text{DoF associated in the estimate of mean response}}
\]

3.4.1. Wear rate (WR)

The predicted value of wear rate \(\mu_{WR}\) was estimated at the selected optimum level of control parameters as stated above viz load \((A_1)\), sliding velocity \((B_3)\) and sliding distance \((C_1)\). The predicted value of wear rate \(\mu_{WR}\) can be calculated in equation (6)

\[
\mu_{WR} = A_1 + B_3 + C_1 - 2\Sigma_{WR} = 0.002026 \text{ mm}^3 \text{ m}^{-1}
\]

where, \(\Sigma_{WR}\) — overall mean of wear rate = 0.003229 \text{ mm}^3 \text{ m}^{-1}

\[
N = 9 \times 1 = 9 \text{ (treatment = 9, repetitions = 1)}
\]

\[
f_e = 8 - 6 = 2 \text{ (table 5)} \text{ and } V_e = 0.00000005 \text{ (table 5)}
\]

\[
F_{0.05}(1, 2) = 18.51 \text{ (Tabulated F-value)}
\]

So, \(CI_{POP} = \pm 0.000851\) and \(CI_{CE} = \pm 0.001283\)

Therefore, the 95% CI for the mean of population of wear rate should be given by

\[
(\mu_{WR} - CI_{POP}) < \mu_{WR} < (\mu_{WR} + CI_{POP})
\]

\[
(0.002026 - 0.000851) < 0.002026 \text{ (mm}^3 \text{ m}^{-1}) < (0.002026 + 0.000851)
\]

\(CI_{POP} = 0.000175\) < 0.002026 \text{ (mm}^3 \text{ m}^{-1}) < (0.002877)

The predicted CI for confirmation experiment of wear rate is given by

\[
(\mu_{WR} - CI_{CE}) < \mu_{WR} < (\mu_{WR} + CI_{CE})
\]

\[
(0.002026 - 0.001283) < 0.002026 \text{ (mm}^3 \text{ m}^{-1}) < (0.002026 + 0.001283)
\]

\(CI_{CE} = 0.000743\) < 0.002026 \text{ (mm}^3 \text{ m}^{-1}) < (0.003309)

3.4.2. Coefficient of Friction (COF)

The predicted value of COF \(\mu_{COF}\) was estimated at the selected optimum level of control parameters as stated above viz load \((A_1)\), sliding velocity \((B_3)\) and sliding distance \((C_3)\). The predicted value of COF \(\mu_{COF}\) can be calculated in equation (7)

\[
\mu_{COF} = A_1 + B_3 + C_3 - 2\Sigma_{COF} = 0.458988
\]

where, \(\Sigma_{COF}\) — overall mean of COF = 0.513956

\[
N = 9 \times 1 = 9 \text{ (treatment = 9, repetitions = 1)}
\]

\[
f_e = 8 - 6 = 2 \text{ (table 7)} \text{ and } V_e = 0.00000005 \text{ (table 7)}
\]

\[
F_{0.05}(1, 2) = 18.51 \text{ (Tabulated F-value)}
\]

So, \(CI_{POP} = \pm 0.03027\) and \(CI_{CE} = \pm 0.04572\)
Therefore, the 95% CI for the mean of population of COF should be given by

\[
(\mu_{\text{COF}} - \text{Cl}_{\text{POP}}) < \mu_{\text{COF}} < (\mu_{\text{COF}} + \text{Cl}_{\text{POP}})
\]
Figure 9. Contours plots of COF (a) load versus sliding velocity, (b) load versus sliding distance and (c) sliding velocity versus sliding distance.

\[(0.458988 - 0.03027) < 0.458988 < (0.458988 + 0.03027)\]

\[C_{\text{FOP}}: (0.428718) < 0.458988 < (0.489258)\]
The predicted CI for confirmation experiment of COF is given by
\[
(\mu_{\text{COF}} - CI_{\text{CE}}) < \mu_{\text{COF}} < (\mu_{\text{COF}} + CI_{\text{CE}})
\]
\[
(0.458988 - 0.04572) < 0.458988 < (0.458988 + 0.04572)
\]
\[
CI_{\text{CE}}: (0.413268) < 0.458988 < (0.504708)
\]

3.5. Regression equation
The regression equation was developed based on the experimental output responses and this establishes a
correlation between the input process parameters. The regression equations (8) and (9) gives the correlation
between the considered control parameters to attain minimum wear rate and COF. Figures 10(a) and (b) shows
the comparison plots for experimental and regression predicted values of wear rate and COF.

\[
\text{Wear rate} \text{mm}^3 \text{m}^{-1} = 0.000857 + 0.000078 \text{ load (N)} - 0.000135 \text{ sliding velocity (m s}^{-1}) + 0.000001 \text{ sliding distance (m)}
\]

(8)

\[
\text{COF} = 0.5081 + 0.003007 \text{ load (N)} + 0.00284 \text{ sliding velocity (m s}^{-1}) - 0.000039 \text{ sliding distance (m)}
\]

(9)

3.6. Worn surface morphology
Figures 11(a)–(d) shows the SEM micrograph of the worn out surface of Al7075 alloy–10 wt% TiO₂ composite
with varying input parameter conditions. Figures 11(a) and (b) shows the initial condition of the worn surface of
composite at an applied load of 19.62 N, sliding velocity of 0.94 m s\(^{-1}\) and sliding distance of 2000 m. From the graph, it was clearly seen that the creation of wear track on the top surface of the composites. The surface indicates the deep grooves are formed in the sliding direction due to severe plastic deformation of materials. As the load increases, the long deep grooves and more ploughs are formed along with the sliding direction which leads to more removal of material from the specimen surface [24]. For the higher applied load, the increase in interfacial temperature is developed between the disc counter face and specimen surface due to their higher frictional contact. This causes increased the wear rate and COF [25].

Figures 11(c) and (d) depicts the optimum condition of the worn out surface of Al7075 alloy – 10 wt% TiO\(_2\) composite by applying load of 9.81 N, sliding velocity of 2.82 m s\(^{-1}\), sliding distance of 1000 m. From the images, it can be noticed that the small cavities and cracks are visible on the surface of the composite. At high sliding velocities, the temperature over the sliding surface increases resulting in oxidization of material and thus material transfer occurs between the pin and counter face which leads to the formation of mechanical mixed layer (MML). This layer helps in achieving good tribological properties over high sliding velocities. The incorporation of TiO\(_2\) particles increases on the surface of matrix alloy, which significantly reduce the plastic deformation because of the TiO\(_2\) reinforcement particles act as an impediment to the moment of displacements, thus giving more wear resistance [23]. At the lower load conditions, it is understood that small shallow grooves, fine scratches occurred at few regions resulting in a lower wear rate and COF due to the restriction of contact between the pin and counter surfaces [26, 27].
4. Conclusions

This work was presented to investigate the dry sliding wear control parameters like load, sliding velocity and sliding distance on the wear rate and COF of stir casted Al7075 alloy-TiO2 composite. The following conclusions were made:

- The Al7075 alloy matrix incorporated with 10 wt% of TiO2 particles were successfully developed through stir casting route. SEM micrograph evident the uniform distributions of TiO2 particles in to the matrix Al7075 alloy.
- Taguchi technique of S/N ratio was employed to identify the optimal control parameters on dry sliding wear behaviour of composite with an objective to minimize the wear rate and COF. Regression equations were developed to predict the responses.
- The optimal parameters for minimum wear rate obtained are, load at 9.81 N, sliding velocity of 0.94 m s\(^{-1}\) and sliding distance of 1000 m. Similarly, the optimal parameters for minimum COF attained are, load at 9.81 N, sliding velocity of 0.94 m s\(^{-1}\) and sliding distance of 2000m.
- ANOVA results revealed that load was the most influencing parameter on the wear rate and COF of the produced composite followed by sliding distance. The increase in load and sliding distance leads to an increase in the wear rate of composite. But, the addition of TiO2 particles to the composite reduces the wear rate.
- The worn surface morphology of optimal parameters conditions showed that the small cracks and fine scratches on the top surface of the composite. Furthermore, the development of mechanically mixed layer (MML) at the mating surfaces enhanced the wear resistance of the composite specimen.
- The present research on the dry sliding wear behaviour of Al7075/TiO2 alloy composite can be used for applications in automotive and aerospace engine components such as cylinder liner, piston, bearings, gears and sprockets, where wear resistance is the major consideration.
- In the future, other optimization methods such as Genetic algorithm and Particle swarm optimization method can be used in to optimize the parameters on wear rate of the composite.

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