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Investigation on mechanical and tribological behaviour of titanium diboride reinforced martensitic stainless steel

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Abstract

The role of metal matrix composites (MMCs) has gained huge momentum in various researches as well as in industrial applications due to their high stiffness and higher strength to weight ratio. It helps in achieving enormous weight reduction without compromising the strength of the material. In this study, a novel attempt was made to fabricate MMCs with martensitic stainless steel as matrix and titanium diboride (TiB2) as reinforcement. The AISI 420 matrix with different weight percentages (1%, 2%, and 4%) of TiB2 reinforcement was fabricated by vacuum induction melting technique (VIM). The aim of this study was to analyze the influence of TiB2 particle addition on the mechanical and tribological properties of AISI 420 composites. X-ray diffraction studies revealed the presence of TiB2 phase in the composite along with peak shifting and broadening of the steel matrix due to induced strain. Optical microscopy showed the distribution of TiB2 particles in the matrix along with a significant amount of grain refinement of the composite due to the addition of TiB2. Microhardness results showed that the presence of TiB2 improved the hardness with AISI 420/4%TiB2 composite possessing the maximum hardness. Tensile test results indicated a significant improvement in the ultimate tensile and yield strength of the composite with the addition of TiB2. The wear tests were carried out on a pin on disc tribometer for various loads at a different sliding distance for steady sliding velocity. The dispersion of TiB2 particle helped in achieving better wear resistance of the composites. Wear surface morphology was carried out to explore the wear mechanisms. Among the various wear mechanisms, abrasion and oxidation phenomena dominated in the composites. Taguchi optimization technique predicted that wt% of TiB2 and applied load as influencing factors on the wear rate of the material.

1. Introduction

AISI 420 martensitic stainless steel (MSSs) grade has good mechanical properties combined with moderate corrosion resistance [1]. This grade of stainless steel finds its applications in different temperature ranges as its properties could be tailored successfully by heat treatment [2]. AISI 420 grade finds its real applications in the parts of steam generators, in pipelines of the oil and gas industry, pressure vessels, valves, cutting devices, turbines blades, shafts, impellers [1–5]. Because of its insufficient hardness and average wear resistance, the application of this grade of stainless steel has been limited in extreme conditions. Hence, it is required to improve the hardness, tribological and mechanical properties of AISI 420 SS [6]. Metal matrix composites (MMCs) reinforced with secondary phase ceramic particles are being studied universally in the past years, due to their promising properties suitable for many structural and functional applications [7, 8]. The homogeneous distribution of the reinforcement phase along with its size is vital since the particle interaction with dislocations turns significant and results in the strengthening of the material. Steel composites have shown the outstanding physical, mechanical and tribological property when compared to the conventional grades of steel. Steel MMC
has been comprehensively explored to fabricate advanced materials with striking applications in the field of automobile, aerospace industries [9].

TiB$_2$ is regarded as one of the supreme candidates for reinforcement in MMC. It is due to its extremely high specific modulus, high stiffness and oxidation stability [10]. The noteworthy characteristics of TiB$_2$ are its stability in liquid metal unlike other ceramic materials, which react with the liquid metal. In addition to the mentioned properties, TiB$_2$ also has extreme hardness and exceptional tribological characteristics [10–13]. Its hardness value of 3400 HV is superior to many of the well-established ceramic reinforcements. Also, it has a lower thermal expansion coefficient than steel and holds higher thermal conductivity [14, 15].

MMCs are fabricated by various methods such as solid-state metallurgy, mechanical alloying, spray deposition, infiltration, and liquid metallurgy techniques. In the liquid metallurgy route, techniques such as squeeze casting, liquid infiltration, conventional casting, and vacuum induction melting (VIM) were adapted to develop steel MMC [6]. Among these techniques, the commercial VIM technique has been adopted to synthesize reactive elements inside an evacuated atmosphere. This process is highly flexible, presenting the option to control parameters such as pressure, temperature and time. Also, a uniform stirring of the melt can be achieved through the natural induction process. Hence VIM gives accurate control over the composition of the elements and uniformity of the alloy than the other methods. It is also a cleaner and safer process [10].

Only limited research is available on the wear behavior of martensitic grade stainless steel. Yun-tao Xi et al, studied the effect of wear resistance of AISI 420 after plasma nitriding. The results revealed that the anti-wear property of the steel nitried at 350 °C is much more excellent than that at 550 °C [16]. Shoichi Kikuchi et al, have done research on the effect of simultaneous surface modification process on wear resistance of AISI 440 C and the results indicated enhanced wear resistance of the material due to combined effect of induction heating with fine particle peening [17]. Prieto et al, projected that the wear resistance of AISI 420 can be enhanced by means of cryogenic treatment [18]. Enhancement of wear resistance by means of reinforcement addition was not attempted in the previous studies. Accordingly, in the present work, the synthesis of AISI 420/TiB$_2$ composite is carried out using vacuum induction melting route. The fabricated composite is investigated on microscopy, mechanical, and dry sliding wear studies to find the effect of the TiB$_2$ particle on the stainless-steel composite. The fabrication of this new material and testing has not been reported in any of the previous researches to the best of our knowledge.

2. Materials and methods

In this investigation, starting matrix material AISI 420 stainless steel round bars were purchased from Bharat Aerospace alloys, India. TiB$_2$ particle (99% Purity, Particle size 10 $\mu$m) was purchased from Innovative growth enterprise, India. The AISI 420/TiB$_2$ composite was developed using vacuum induction technique at 1550 °C under a high vacuum of $2 \times 10^{-5}$ mbar. The materials were prepared for varying compositions of TiB$_2$ (1 wt%, 2 wt% and 4 wt%). The X-ray diffraction study (XRD) was performed using Rigaku Ultima III XRD set up in order to confirm the formation of titanium boride phase along with the matrix phase and to know their respective crystal structure. Optical microscopy was carried out using Olympus BXX1M metallurgical microscope to find out the dispersion of TiB$_2$ and grain size. By using a Matsuzawa MMT-X7B semiautomatic digital microhardness tester, hardness test was carried out. The testing was carried out as per ASTM: E384-17. Tensile testing was carried out in an INSTRON 8801 device at a strain rate of 1 mm min$^{-1}$ under room temperature as per the ASTM E8/E8M standard. Wear tests were conducted in a DUCOM pin-on-disc wear-testing apparatus under room temperature and as per the ASTM: G99 standard. The specimen was prepared for wear study with the dimension 10 mm diameter and 15 mm height. The contact surfaces of the pins were polished using SiC 600-grit paper followed by cleaning with acetone. Complete contact between the samples and the disc surface was maintained. The disc material was an oil hardened non-shrinking steel. The tests were performed by varying applied normal loads viz. 15 N, 30 N, 45 N and 60 N and by varying different sliding distances viz. 750 m, 1000 m, 1250 m and 1500 m for a constant velocity of 1.2 m s$^{-1}$ at room temperature. The influence of the various process parameters on dry sliding wear behavior was analyzed using the Taguchi technique. The list of factors and levels selected is mentioned in table 1. From the factors and levels, L16 orthogonal array was constructed for optimization. The experimental results were converted into signal to noise (S/N) ratio. The objective of ‘smaller the better’ was chosen for lesser wear rate of the material.

The formulas used to calculate the wear rate are

\[
\text{Volume loss (mm}^3\text{)} = \left(\frac{\text{Weight loss (g)}}{\text{Density (g mm}^{-3}\text{)}}\right) \times 1000
\]
Where $F$ is the frictional force and $P$ is the applied normal load.

3. Results and discussion

3.1. X-ray diffraction studies

It can be witnessed in figure 1 that the composite consists of $\alpha$-Fe (ICDD ref: 11–1936) and TiB$_2$ (ICDD ref: 08-5405) peaks. Higher intensity of TiB$_2$ peak corresponding to higher addition of reinforcements is clearly visible from the image. The shifting of the matrix peak can be seen with an increase in the TiB$_2$ content. The position of the $\alpha$-Fe matrix peak shifted due to the distortion of the $\alpha$-Fe lattice by TiB$_2$ particles. The variation in the lattice constants results in the displacement of the matrix peak. The peak shifting was accompanied by a peak broadening. This was due to the incoherent strain involved due to the addition of secondary phase particles [19, 20]. There was no other peak apart from Fe and TiB$_2$ peaks suggesting the absence of any intermetallic phases. The inset picture shows the peak shift of the $\alpha$-Fe matrix peak between 0% and 4% along with the peak broadening. The presence of TiB$_2$ peak near Fe matrix peak is also highlighted in the inset picture.

3.2. Microscopy

Figure 2 outlines the optical microstructural images of AISI 420/TiB$_2$ composite. The dispersion of TiB$_2$ reinforcements in the matrix can be seen from the optical micrographs. TiB$_2$ particles were distributed within
and on the grain boundaries which led to the grain refinement of the composite. Grain refinement was attained due to the creation of heterogeneous nucleation sites [21]. It can be clearly seen from the image, that 4 wt% TiB₂ composites underwent a substantial amount of grain refinement when compare to an unreinforced alloy. TiB₂ reinforcements were uniformly scattered in the steel matrix due to the electromagnetic induction effect accomplished through vacuum induction melting process. Figure 2(e) shows the scanning electron micrograph (SEM) of AISI 420/TiB₂ composite. The dispersion of the TiB₂ particle can be seen in the SEM image. Figure 2(f) illustrates the EDS spectrum of AISI 420/4 wt% TiB₂ composite showing the existence of elements in their respective weight and atomic percentage; thereby ensuring the presence of TiB₂ particles in the matrix.

3.3. Microhardness

The microhardness results of the fabricated AISI 420/TiB₂ composites are revealed in figure 3. Monolithic as-cast AISI 420 material exhibited lowest hardness value of 580.62 HV. But with the addition of TiB₂ particles, the hardness value of the steel increased considerably. It was due to the homogeneous distribution and high hardness of the TiB₂ particles distributed in the steel matrix. The hardness value increased proportionally with
the amount of reinforcement added. When compared to the unreinforced alloy, the addition of 1 wt%, 2 wt% and 4 wt% of TiB₂ has improved the hardness of the composite by 21% (to 702.9 HV), 57% (to 909.6 HV) and 110% (to 1223.24 HV) respectively.

3.4. Tensile studies
The room temperature tensile properties of fabricated AISI 420/TiB₂ composite is shown in figure 4. Both ultimate tensile strength (UTS) and yield strength (YS) of the composite increased significantly with the addition of TiB₂. UTS increased by 19.3% (563.47 MPa), 45.5% (687.08 MPa), 61.1% (761.14 MPa) in AISI 420/1%TiB₂, AISI 420/2%TiB₂ and AISI 420/4% TiB₂ composite respectively when compared to the unreinforced alloy (472.18 MPa). YS improved by 39.3% (399.66 MPa), 78.3% (511.64 MPa), and 125.4% (646.66 MPa) in AISI 420/1%TiB₂, AISI 420/2%TiB₂, and AISI 420/4%TiB₂ respectively than the unreinforced alloy (286.88 MPa). With the addition of TiB₂ reinforcement, there was a significant enhancement in the UTS and YS with a decrease in the ductility which led to a reduction in the fracture strain. The proper interfacial bonding between the matrix and reinforcement helped in better load transfer [10, 14]. It was the major reason for the improved tensile property of composite. The improved tensile property of the composite can be primarily attributed to four strengthening mechanisms, (a) Grain refinement (b) dispersion strengthening (c) forest strengthening (due to coefficient of thermal expansion (CTE) mismatch between matrix and reinforcement) (d) Load bearing.

3.5. Wear studies
The tribological behavior of the AISI 420/TiB₂ composites shown in figure 5 exhibited a decrease in value of wear rate and coefficient of friction with the addition of TiB₂ particles. The lower wear rate was observed in AISI 420/4%TiB₂ composite and higher wear rate in unreinforced AISI 420 material for all experimental conditions during the present investigation. The dispersion of TiB₂ particle on the surface of the matrix resisted plastic deformation, crack formation and acted as an effective barrier to the dislocation motion. It resulted in the composite possessing better resistance to wear than the base alloy [15].

3.5.1. Effect of TiB₂ reinforcement on the wear rate
Figures 5(a)–(d) displays the disparity in the wear rate as a function of applied loads and sliding distance for both unreinforced AISI 420 and AISI 420/TiB₂ composites. The percentages of TiB₂ reinforcement were 1%, 2% and 4% wt%. The wear rate was calculated in order to understand the degree of changes in weight loss with respect to distance traveled. After every interval of sliding distance, the weight losses were calculated. The coefficient of friction was recorded continuously in a plotter attached to the tribometer. The variation in the coefficient of friction with respect to the concentration of TiB₂ addition is displayed in figure 6.

Wear rate increased with increasing sliding distance and with the increase in applied load for all compositions. With an increase in applied loads, there was an increase in the volumetric wear rate of the
Wear rate decreased with an increase in wt% of TiB₂ particles for a given load and sliding distance. The wear rate observed in the composites reinforced with TiB₂ was lesser than unreinforced alloy for all applied loads and at all operating conditions as witnessed in figures 5(a)–(d). The composites with higher wt% of TiB₂ particles exhibited lower wear rates which can be credited to the strong interfacial bonding between the matrix and TiB₂ reinforcement. The distribution of TiB₂ particle in the Fe matrix can be seen in figure 2. Also, the higher peak hardness of TiB₂ helped in achieving better wear resistance in the composites. The wear pattern among different weight percentages of reinforcements indicated that the stainless-steel matrix was protected efficiently by hard TiB₂ particles during sliding. Improvement in the wear resistance in composites can also be accredited to the better load-bearing capacity of TiB₂, which restricted plastic deformation and fracture of the composite [22, 23].

Figure 4. (a) Strength of AISI 420/TiB₂, (b) % Elongation of AISI 420/TiB₂.

At all applied loads, the rate of wear for alloy and composites varied, with 4% TiB₂ composite illustrating a substantial decrease in the wear rate as revealed in figure 5(d). The wear rate of pure AISI 420 at 15 N load for 1500 m sliding distance was $15.889 \times 10^{-5}$ mm$^3$ m$^{-1}$ (figure 5(a)). The wear rate at the same dry sliding condition for AISI 420/1%TiB₂, AISI 420/2%TiB₂ and AISI 420/4%TiB₂ were $13.568 \times 10^{-5}$ mm$^3$ m$^{-1}$, $12.058 \times 10^{-5}$ mm$^3$ m$^{-1}$ and $10.252 \times 10^{-5}$ mm$^3$ m$^{-1}$ respectively (figures 5(b)–(d)). The reduction in wear rate with higher wt% of TiB₂ was observed to be nonlinear. It was due to the various wear mechanism that the
Figure 5. (a) Wear rate of pure AISI 420, (b) wear rate of AISI 420/1%TiB$_2$, (c) wear rate of AISI 420/2%TiB$_2$, (d) wear rate of AISI 420/4%TiB$_2$.

Figure 6. Coefficient of friction of AISI 420/TiB$_2$ composites at (a) 15 N, (b) 30 N, (c) 45 N, (d) 60 N.
material experienced during sliding contact. A study on the wear surfaces would be useful to know the wear mechanism that occurred in the composite.

3.5.2. Effect of TiB₂ reinforcement on the coefficient of friction (COF)

Figures 6(a)–(d) shows the coefficient of friction as a function of sliding distances and concentrations of TiB₂ for all the applied loads. The average values of the friction coefficient for unreinforced AISI 420, AISI 420/1%TiB₂, AISI 420/2%TiB₂ and AISI 420/4%TiB₂ composites at a sliding velocity of 1.2 m s⁻¹ at 15 N load for a sliding distance of 1500 m were 0.66, 0.56, 0.54 and 0.45 respectively. The average friction coefficient values for the similar four compositions for 1000 m sliding distance were 0.70, 0.65, 0.63 and 0.55 respectively (figure 6(a)). Thus, the average value of the friction coefficient decreased with an increase in the sliding distance for all prepared composites. Similarly, the coefficient of friction value decreased with an increase in the applied load. The average values of the friction coefficient for unreinforced AISI 420, AISI 420/1%TiB₂, AISI 420/2%TiB₂ and AISI 420/4%TiB₂ composites at a sliding velocity of 1.2 m s⁻¹ at 60 N load for a sliding distance of 1500 m were 0.57, 0.48, 0.44 and 0.41 respectively (figure 6(d)). TiB₂ reinforced AISI 420 composites were having a lower coefficient of friction compared to the unreinforced AISI 420. This was due to the good adhesion between the matrix and reinforcement. The friction coefficient fluctuated around the mean level and decreased with the increase in the sliding distance. The uniqueness in the coefficient of friction among various composite was due to inappropriate contact between the disc and pin. A lower coefficient of friction can be noted in figures 6(c), (d) for a higher load at a steady velocity. The normal load of 15 N had demonstrated a higher friction coefficient compared to the 30 N, 45 N and 60 N applied loads. Similarly, the sliding distance of 750 m showed the highest coefficient of friction for all the composition than 1000 m, 1250 m, and 1500 m. At higher load and higher sliding distance, surface roughness and the quantity of wear debris increased which reduced the coefficient of friction [23].

3.5.3. Worn surface morphologies and wear mechanism

The major wear mechanisms observed during dry sliding wear testing were oxidation, delamination, ploughing, and abrasion. The presence of wear debris, macro and micro-cracks were also observed. Figures 7 and 8 shows the SEM images of the worn surfaces of AISI 420/TiB₂ composites at various sliding distances for different
applied loads. The worn surfaces were examined to determine the effect of all the parameters such as sliding distance, applied load, and percentage of reinforcements. Abrasion or sliding wear mechanism dominated mostly at the lower load with wear patterns acting parallel to the direction of sliding. Removal of small strips from the pin surface indicated the abrasion type of wear [22–24]. For all the composites, grooves were visible along the sliding direction. The depth of the groove indicated the penetration of the counter disc. It can be seen in figures 7(a)–(d) and 8(a)–(d), the depth of penetration was shallower in the case of composites due to hard TiB2 particle which had better abrasion resistance whereas deeper grooves can be seen in the unreinforced alloy due to severe plastic deformation. Also, the grooves formed in composites with TiB2 addition were thinner as well as discontinuous whereas continuous grooves can be observed in case of unreinforced alloy.

Delamination can be found with an increase in loads for all the composite, but it was observed severely in the unreinforced alloy as seen in figures 7(a) and 8(a). Due to plastic deformation, the severity of delamination increased at higher loads. Shear deformation took place near the subsurface region mainly in the softer pure SS alloy. During the deformation, wear debris occurred because of the delamination of fragments from the pin which was a sign of delamination wear [22, 23]. Severe delamination led to the formation of cracks in the composite. Delamination wear remained absent once the wt% of TiB2 increased, as seen in figures 7(d) and 8(d). It was due to the resistance of TiB2 to shear deformation. Micro ploughing can be observed in composites with 2 wt% and 4 wt% of TiB2 as shown in figures 7(c), (d) and 8(c), (d). This was due to the presence of TiB2 particle which made the surface rough and thereby prevented delamination of the surface.

Another dominant wear mechanism was oxidation. Usually, oxidation happens at a higher load. The oxidation phenomena occur due to surface charging [25, 26]. The frictional heat generated during the sliding process resulted in the formation of oxide films. The presence of stable oxide film prevented direct metal to metal contact between the pin and the disc resulting in lesser wear [22, 27]. It can be witnessed in the figure 8(d). The composite possessed better wear resistance than the pure 420 SS, due to their ability to maintain oxide film and better load-bearing capacity [22, 23]. The energy dispersive spectroscopy (EDS) analysis done on the composites confirmed the presence of the oxide layer with a high-intensity peak of oxygen which is shown in figure 9.
Figure 9. EDS of worn surface morphology of AISI 420/4%TiB₂ at 60 N, 1500 m (a) SEM image corresponding to scanning area, (b) EDS spectrum.

Figure 10. S/N ratio of mean effect plot.
3.5.4. Wear rate optimization using Taguchi technique

The wear test carried out for L16 orthogonal array is shown the table 2. The weight loss obtained from the experiments for different parameters was converted into the wear rate using the formulae mentioned. The S/N ratio for the mean data plots is shown in figure 10. The highest response in the S/N curve showed the optimal results since the objective chosen was ‘smaller the better’ for the lowest wear rate. The S/N ratio response given in table 3 shows the most and least influencing factors. As seen in the experimental results, the dominating factor influencing the wear rate was the weight percentage of TiB2 particles. With the higher TiB2 content in the composite, a lower wear rate was witnessed as shown in table 2 and in the wear rate graphs displayed in figure 3.

The second most influencing factor in determining the wear rate was applied load and the least influencing parameter as suggested by the response table was sliding distance. The dominating or the influencing factor was determined by the obtained delta value.

The ANOVA table 4 shows the results generated by the response table. Apart from the individual influencing parameters, the effect of combined parameters or factors is also shown in the ANOVA table. Among the individual factors, the composition of TiB2 was the most dominant factor with 12.95% and the sliding distance was the least influencing factor with 0.85 % as was in the case of S/N response table. The combined factor of load and composition was the most dominant determining factor for the wear rate with a contribution of 64.79 %. The R² value obtained was 97.17% which was well within the confidence level of 95% and the level of significance of 0.05. This implies that the factors with P-value above 0.05 were considered insignificant [28]. The regression equation gave the overall effect of all the individual and combined factors for the wear rate of material.

Regression equation

\[
\text{Wear rate (mm}^3\text{m}^{-1}) = 5.85 - 0.022 \text{ Load} + 0.00122 \text{ Sliding Distance} \\
- 1.66 \text{ Composition} + 0.000169 \text{ Load} \times \text{ Sliding Distance} \\
+ 0.001 \text{ Load} \times \text{ Composition} + 0.00064 \text{ Sliding Distance} \times \text{ Composition} \\
- 0.000007 \text{ Load} \times \text{ Sliding Distance} \times \text{ Composition}
\]

| S.No | Load (N) | Sliding distance (m) | Composition of TiB2 (wt%) | Wear rate \( \times 10^{-5} \) (mm\(^3\)/m) |
|------|----------|----------------------|---------------------------|-----------------------------------------------|
| 1    | 15       | 750                  | 0                         | 8.332                                         |
| 2    | 15       | 1000                 | 1                         | 8.298                                         |
| 3    | 15       | 1250                 | 2                         | 10.972                                        |
| 4    | 15       | 1500                 | 4                         | 10.252                                        |
| 5    | 30       | 750                  | 1                         | 9.963                                         |
| 6    | 30       | 1000                 | 0                         | 13.963                                        |
| 7    | 30       | 1250                 | 4                         | 11.569                                        |
| 8    | 30       | 1500                 | 2                         | 14.956                                        |
| 9    | 45       | 750                  | 2                         | 9.262                                         |
| 10   | 45       | 1000                 | 4                         | 9.879                                         |
| 11   | 45       | 1250                 | 0                         | 21.409                                        |
| 12   | 45       | 1500                 | 1                         | 20.482                                        |
| 13   | 60       | 750                  | 4                         | 9.482                                         |
| 14   | 60       | 1000                 | 2                         | 13.568                                        |
| 15   | 60       | 1250                 | 1                         | 21.589                                        |
| 16   | 60       | 1500                 | 0                         | 25.41                                         |

Table 2. Experimental results of L16 orthogonal array.

| Level/factors | Load (N) | Sliding distance (m) | Composition of TiB2 (wt%) | Wear rate \( \times 10^{-5} \) (mm\(^3\)/m) |
|---------------|----------|----------------------|---------------------------|-----------------------------------------------|
| 1             | -18.06   | -18.64               | -22.28                    |
| 2             | -20.08   | -19.70               | -21.86                    |
| 3             | -21.71   | -20.95               | -20.48                    |
| 4             | -22.53   | -23.08               | -17.76                    |
| Delta         | 4.48     | 4.44                 | 4.53                      |
| Rank          | 2        | 3                    | 1                         |

Table 3. Response table for wear rate.
4. Conclusion

The investigations on microstructural, mechanical and dry sliding wear behaviour were carried out on different weight percentages of TiB₂ reinforced AISI 420. XRD confirmed the presence of α-Fe and TiB₂ peaks along with the shifting and broadening of matrix peak. Micrographs revealed the dispersion of TiB₂ particles and grain refinement of composites. Microhardness and tensile properties improved after the addition of TiB₂ particles with AISI 420/4%TiB₂ composite showing the best property with a hardness of 1233.24 HV and UTS of 761 MPa. Wear rate increased with an increase in sliding distance and load for all composites, but lower weight loss was observed with TiB₂ addition in AISI 420 matrix. The friction coefficient decreased with an increase in the wt% of TiB₂ particles due to better adhesion with the matrix. The worn surface morphologies clearly identified abrasion, delamination, oxidation and ploughing as dominant wear mechanisms, with oxidation dominating at higher loads. Taguchi optimization technique showed that TiB₂ concentration and load were the most influencing factor on the wear rate of the material with AISI 420/4%TiB₂ composite showing best wear resistance at 15 N load and 750 m sliding distance.

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Table 4. Analysis of variance for wear rate.

| Parameters                              | DOF | Adj SS  | Adj MS  | F-Value | P-Value | Contribution % |
|----------------------------------------|-----|---------|---------|---------|---------|----------------|
| Load                                   | 1   | 0.078   | 0.0784  | 0.07    | 0.679   | 2.07           |
| Sliding distance                       | 1   | 0.032   | 0.0319  | 0.03    | 0.866   | 0.85           |
| Composition                            | 1   | 0.485   | 0.4853  | 0.46    | 0.033   | 12.95          |
| Load” Sliding distance”                | 1   | 0.194   | 0.1860  | 0.29    | 0.041   | 5.17           |
| Load” Composition”                     | 1   | 2.428   | 2.4216  | 2.51    | 0.028   | 64.79          |
| Sliding distance” Composition”         | 1   | 0.127   | 0.1266  | 0.12    | 0.046   | 3.39           |
| Load” Sliding distance” Composition”   | 1   | 0.034   | 0.0344  | 0.03    | 0.866   | 0.92           |
| Error                                  | 8   | 0.369   | 1.0462  | 0.12    | 0.058   | 9.86           |
| Total                                  | 15  | 3.747   | 100     |         |         |                |
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