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RESEARCH

# Wear and Friction Behavior of Stir Cast Al-$TiB_2$ Metal Matrix Composites with Various Lubricants

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A B S T R A C T

*Al- $TiB_2$ metal matrix composites are fabricated using stir cast method and its tribological characterization is done using three different lubricants. Tribological studies are performed in a multi-tribotester using block-on-roller configuration under 25-75 N loads and 400-600 rpm rotational speeds. Four different weight percentages of $TiB_2$ are considered in this study. Comparison between dry condition and lubricated conditions is gleaned to differentiate wear and friction characteristics and SEM images are taken to fortify them. Lubricated conditions yield large reduction in wear and friction compared to dry condition.*



## 1. INTRODUCTION

Aluminum alloy based ceramic particulates reinforced metal matrix composites are active area of research for last few years [1-3]. The reason behind wide acceptance of metal matrix composites as engineering materials is the excellent combinations of properties which are difficult to achieve by individual alloy phase or particulates. Metal matrix composites are mainly combination of two or more phases among which base one is metallic alloy based matrix phase and reinforcements are ceramic type particulates or short fiber or whisker [4-6]. Applications of MMCs are established in aerospace industry, automobile industry, marine industry and also in chemical and transportation industries [7-8]. As one of the onerous yardsticks in new age materials is good strength to weight ratio combined with high wear resistance, soul aluminum alloys are lagging behind aluminum based metal matrix composites in terms of industry usage focus on materials [9-12]. Various literatures reveal that aluminum alloy based metal matrix composites show better hardness, Young’s modulus, yield strength, ultimate tensile strength and wear resistance in comparison to other alloy i.e. Mg, Cu based metal matrix composites [13]. Considering all of these properties aluminum based metal matrix composites are gradually becoming potential alternative materials in connecting rods, cylinder blocks, gears, shafts etc. [14-15].

In spite of all great potentials of metal matrix composites, main challenge is to get proper uniformity of the phases in composites and accepted compatibility between matrix and reinforcement. That's why selection of fabrication process and also reinforcement is indispensable task to get proper enhancement in the properties of MMCs. Powder metallurgy, liquid metallurgy techniques, in-situ techniques and chemical synthesis are the methods normally used for synthesis of MMCs [16]. Several opinions exist on which techniques are most preferable for fabrication of MMCs. For selection of reinforcement, ceramic particulates are popular as several literatures delineate the enhancement of mechanical and tribological properties due to incorporation of ceramic particulates in MMCs [1, 17-18]. SiC, TiC, ZrC, $TiB_2$, $ZrB_2$, AlN, $Al_2O_3$, $B_4C$, TiC are the ceramic particulates commonly used to intensify the characteristics of aluminum based metal matrix composites [1,19-20]. Thermodynamic stability in matrix phase, solubility in molten metal, grain boundary regime near to the metallic atoms are the characteristics of reinforcement responsible for determining the properties of MMCs.

$TiB_2$ particulate is chosen in this work as reinforcement in aluminum alloy based matrix due to properties like high Young's Modulus (345-409 GPa), low specific gravity (4.5), good hardness (3400HV), high melting point (3225 ˚C), good thermal stability and good thermal and electrical conductivity [21-22]. $TiB_2$ also enhances mechanical and tribological properties of aluminum matrix composites in a deterministic way [22-23]. $TiB_2$ does not react with aluminum which also helps not to lead to any interface product with detrimental effect on behavior [24]. SiC reinforced aluminum metal matrix composites are absorbing larger percentage of commercially available MMCs but in this case formation of aluminum carbide ($Al_4C_3$) reduces physical, mechanical and chemical properties of the composites [25]. $TiB_2$ reinforcement is free from this problem and $TiB_2$ acts also as a nucleating agent at the grain boundary of aluminum alloy and $TiB_2$ grains [2]. It is widely reported in various literatures that fabrication of Al- $TiB_2$ MMCs through in-situ methods are advantageous and popular due to several reasons [22-23,26]. But agglomeration behavior of $TiB_2$ particles segregates the grain boundary and weakens the inter-atomic force which is very much detrimental in functional output [27]. Some additives, e.g., CeO2, Mg, Zr are used within the matrix to solve out the problem of agglomeration [27-28]. In case of in-situ techniques, production of reinforcement happens by exothermic behavior which also can be negatively effective on the grain boundary regime of MMC [29]. To overcome these problems and also to make the fabrication processes more simple, flexible and economical for commercial purpose, stir casting method is introduced [30]. Stir-casting method is basically an ex-situ method where reinforcement particles are prepared externally and poured into the molten metal. Stir casting methods are also helpful to break the dendritic structures already present in the molten aluminum alloy which lead to better mechanical strength than original alloy excepting the effect of reinforcement. Some problems associated with this method like non-uniform distribution of particles and porosity can be addressed easily by controlling stirring process, lower particle size of $TiB_2$, preheating of the particles and molding techniques [7, 30]. Recent literatures on Al- $TiB_2$ composites reveal that stir casting method has been accepted widely as the mode of fabrication of MMCs including Al- $TiB_2$ MMC [7,10,31].

Al-$TiB_2$ MMC fabricated through stir casting method is the working material in this study. As tribological properties are one of the important considerations of Al- $TiB_2$ MMCs, miscellaneous works are found on this topic. Some works are also available considering mechanical behaviors of specified composites and comparison with others [12,13]. But most of the works are based on in-situ stir cast Al- $TiB_2$ composites. With increase of weight percentage of $TiB_2$ in in-situ composite, wear resistance increases in case of dry wear, sliding wear, abrasive wear, and erosive wear [22,26,32-33,]. Effect of grain refinement, surface roughness and in-situ reaction parameters on wear behavior of Al-$TiB_2$ composites are also studied [34]. How wear trend varies in elevated temperature is also reported [34]. Characterization of in-situ fabricated specific composites is also available in good numbers. But reports on characterization and tribological trends of stir cast Al- $TiB_2$ composites are really scanty [31]. All composites including Al- $TiB_2$ have been studied to find out the inclination of wear and coefficient of friction on applied load, and weight percentage mostly in dry condition. Characterization of composites and other new age materials, e.g., polymide composites, $Al_2O_{3f}/SiC_P/Al$ hybrid MMCs except Al- $TiB_2$ composites is also available in various lubricated conditions. But it is difficult to find an analysis of tribological trends of stir-cast Al- $TiB_2$ MMC in various lubricated conditions or a systematic approach to characterize tribological parameters in various lubricated conditions in comparison with dry condition.

There are many potential areas where Al- $TiB_2$ composites can be used for sliding and rolling applications. In that case lubricants also can be used for bringing the tribological parameters in favor. These tribological parameters are definitely influenced by the nature of the lubricant because most of the loads in contact surface of sliding are carried out by the pressure regime generated within lubricant film. So, it is needed to improve the understanding of the tribological behavior of Al- $TiB_2$ composites under lubricated contacts. It is reported that maximum percentage of lubricant is based on petroleum and they ended up in environment which leads to increment of toxicity in nature [35]. To overcome this issue of petroleum based lubricants on environment, vegetable oils based lubricants are becoming the alternative now a day's [36]. Triacyglycerol structure presents in natural oil which is an important aspect as lubricant because it contains long chains of polar fatty acids which adheres to metallic surfaces [37]. Length of carbon chain present in the fatty acids also can affect the friction nature of the contacting surfaces [37]. Many researchers have paid their attention to various bio-diesel based lubricants derived from vegetable oils, e.g., rapeseed oil, canola oil, soy oil, sunflower oil, rice bran oil [38]. As a part of the research on bio-diesel based lubricants and additives used on it, it is also concluded by some researchers that individual fatty acid esters are not so much effective as methyl esters derived from fatty acids are effective in reducing friction [39]. Works on bio-esters and their effects on engines as diesel and as lubricant are going on but some clear understandings are also needed on their behaviors in contact surfaces of newly developed materials to develop the potentiality of real time applications for both the materials and the bio-lubricants also [40]. Works on tribological behaviors under various types of bio-lubricants and on metal matrix composites are really scanty [1]. Some works are reported on aluminum matrix composites in air and water lubricated condition in direction to opt out detrimental effects of commercial lubricant on environment [41]. Some works are also reported on in-situ Al-$TiB_2$ composites in hydrocarbon based synthetic lubricated condition [42]. In case of many practical applications it is difficult to use water as lubricant. In this work, one commercial synthetic petroleum based lubricant, one commercial Chloro-fluro-Carbon free lubricant based on petroleum oil but blended with natural oil and one vegetable oil based bio-lubricant are used to understand the contact surface behavior and tribological parameters of stir cast Al- $TiB_2$ composites in lubricated condition. Contribution of various bio-diesel contaminated bio lubricants on contact surface are not well studied though a good number of works are carried out on characterization of bio-lubricants. Other than two commercially available lubricants, Rice bran oil based methyl ester is chosen for development and usage as bio-lubricant in this study due to some advantages as the wear resistant properties of rice bran oil is less in comparison with other vegetable oils because of the presence of natural anti oxidants like gamma oryzanol and tocopherols. Rice bran oil is thermally stable at high temperature i.e. 395 $^0$C without any mass degradation and also methyl esters are more effective for reduction of friction [43].

In this work, tribological tests on stir-cast Al-$TiB_2$ composites are performed in Multi-tribotester for various loads, speeds, and weight percentages of $TiB_2$ using three different lubricants. SEM images are taken after tribological tests to characterize the worn out surfaces in lubricated contact and to compare the tribological characteristics of Al-$TiB_2$ MMC under lubricated sliding from dry contact conditions.

## 2. EXPERIMENTAL PROCEDURE

### 2.1 Sample preparation

Stir casting process is used in this study for fabrication of Al-$TiB_2$ composites. Average particle size of $TiB_2$ varies from 5 μm to 40 μm.

Base alloy used as matrix phase is LM4. Chemical composition of LM4 alloy and $TiB_2$ particulates are given in Table 1 and Table 2.

**Table 1.** Chemical composition of LM4 alloy.

| Element | Cu | Si | Mg | Fe | Mn | Ni | Zn | Al |
|---|---|---|---|---|---|---|---|---|
| wt% | 3.2 | 6 | 0.05 | 0.6 | 0.4 | 0.2 | 0.15 | Rest |

**Table 2.** Chemical composition of $TiB_2$ powder.

| Element | Ti | B | C | O | N | Fe |
|---|---|---|---|---|---|---|
| wt% | 67-69 | 29-32 | 0.5 | 0.5 | 0.2 | 0.09 |

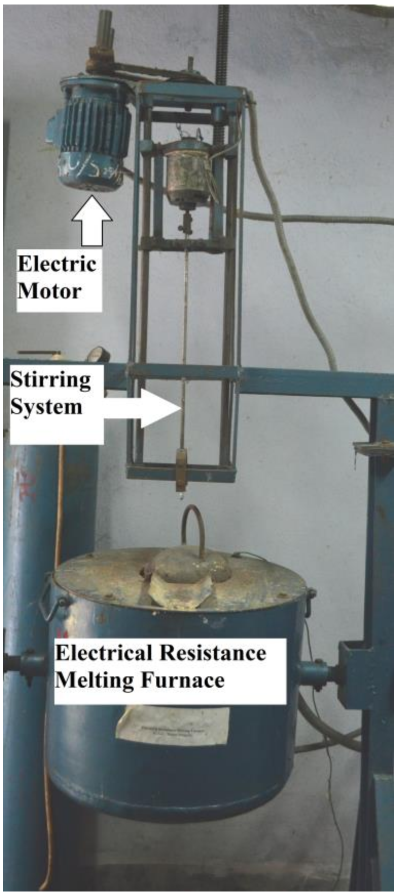



**Fig. 1.** Stir casting system used for fabrication.

To get proper homogeneous distribution of particles over the matrix phase, an electric stirrer controlled by speedometer is connected with Electric Resistance Arc Furnace. LM4 ingots are first placed in the furnace and got molten. $TiB_2$ particles preheated at 600° C are poured into the vortex of the molten LM4 alloy. String speed is kept fixed at 500 rpm for 15 minutes. Stirring of molten LM4 alloy helps to break dendritic structure if present inside and leads to better micro-structural unity in the end. Preheating of reinforcement is necessary because preheating helps to create an oxide layer over the particles [31]. Diagram of this total process is shown in Fig. 1. After ensuring overall equal distribution of particles, the mixture of molten metal and $TiB_2$ particulates poured into a fixed size metallic mould at fixed temperature 800 °C. Then it solidifies and with repetition of the same process four different weight percentages (1 %, 2.5 %, 4 %, and 5.5 %) of $TiB_2$ reinforced composites are prepared.

## 2.2 Lubricants used

Three different liquid lubricants are used in this study. Petroleum based commercial lubricant is SAE20W-40 procured from Indian Oil Corporation Limited. This commercial lubricant is based on high refined petroleum stocks with well balanced group of additives. Similar type lubricant is used previously by researchers to find out boundary lubricated tribology of an aluminum–silicon alloy sliding against steel [44].

Other commercial lubricant (Chain Lube Oil) is collected from a Germany based company (OKS). This liquid lubricant is based on refined petroleum oil but blended with some additives collected from natural mineral oil. This lubricant is free from chloro-fluro-carbon (CFC) which is healthy for environment in heated condition. Similar type of lubricant has been used previously to characterize Ni-P coatings [45]. Properties of SAE20W-40 and chain lube oil are listed in Table 3.

**Table 3.** Properties of SAE20W-40 and Chain lube oil.

| Lubricant | Viscosity | Density | Viscosity Index | Flash Point |
|---|---|---|---|---|
| SAE20W-40 | 13.5-15.5 cSt @100 °C (ASTM D445) | 0.8-0.9 g/ml | 132 | 200 °C |
| Chain lube oil | 300 cSt @40 °C (DIN 51 562-1) | 0.9 g/ml | 320 | 164 °C |

One bio-lubricant (Rice bran oil based TMP Ester) is formed in laboratory according to the standard process [43]. The crude rice bran oil is purchased from local industries in Kolkata. This crude oil is first heated to a temperature 110°C and then mixed with a methanolic solution which is also prepared by properly mixing methanol and KOH according to fixed molar ratio [40]. The mixing of processed crude oil and methanolic process is performed in a stirred condition with the help of an electric stirrer.

After keeping that mixture at 70 ˚C for 1 day, two distinct layers are formed of which upper one is ester. This process is called trans-esterification. Upper ester layer is separated out from that mixture and collected and used as bio lubricant for this study. Above steps are performed as replication of processes published in various research articles [38,43,46]. Properties of the fabricated rice bran oil based ester are tabulated in Table 4.

**Table 4.** Properties of Rice bran oil based TMP esters [43,47].

| Lubricant | Viscosity | Specific gravity | Flash Point |
|---|---|---|---|
| Rice bran oil based TMP ester | 4-5.5 cSt @40 $^0$C | 0.877 @30 $^0$C | 183 $^0$C |

### 2.3 Hardness measurement

Micro-hardness testing is done for various $TiB_2$ weight percentage composites using Vickers Micro Hardness Tester (Model-VMHT MOT, Sl. No. 1002001). Average load of 3 kgf is applied and a diamond indenter is used for indentation. Dwell time is retained at 15 s and speed of indentation is 50 µm/s. Tests are carried out at five different locations and the average is taken as the hardness of the sample.

### 2.4 SEM study

The surface morphologies of the fabricated composites are studied by scanning electron microscope (SEM, INSTRUMENT JSM-6360, Japan) to understand the basic mechanisms happening on the wear track. Same SEM machine is used to analyze wear track of the composites in dry condition [31]. Before scanning, samples are cut according to the size of the tray of the machine. Samples are also polished and etched using proper etchant.

### 2.5 Wear and friction measurement

Friction and wear tests are carried out on a computer controlled block-on-roller Multi-tribotester (DUCOM TR-25). Block specimen used in this study has the size 20 mm × 20 mm × 8 mm. Tests for measuring wear and friction are performed at ambient temperature (25 ˚C) under three different lubricated conditions. Time duration for each test is taken as 1800 seconds to get estimation for long run applications. In each experiment, specimen is held against the counter roller. Contact surface is flooded with lubricants at the time of experiment. For each experiment, a fixed flow rate of lubricant is maintained to get lubrication regime within contact surface. Pictorial diagram of test set-up is shown in Fig. 2.

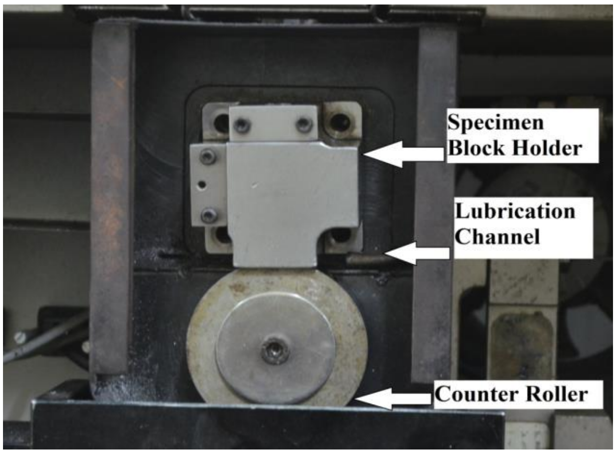



**Fig. 2.** Pictorial view of tribological test apparatus.

**Table 5.** Test parameters for measuring wear and friction.

| Parameters | Values |
|---|---|
| Constant normal load | 25 N, 50 N, 75 N |
| Constant sliding speed | 400 rpm, 500 rpm, 600 rpm |
| Weight percentage of $TiB_2$ in composites | 1 %, 2.5 %, 4 %, 5.5 % |
| Lubricants | SAE20W40, Chain Lube Oil, Rice bran oil based TMP Ester |

EN8 stainless steel is used as the roller material and the surface is ground with 600 grit abrasive paper before and after each wear tests. Material of the counter-face roller is important as it determines hardness ratio which is defined as ratio of the hardness of roller material to the hardness of block material and this hardness ratio determines also the wear rate of the contact regime [35]. Considering hardness of Al- $TiB_2$ composites from previous study, EN8 steel as roller material is perfect for testing wear and friction [31]. Wear is measured in terms of wear depth created at the surface in micrometer and friction is measured as friction loads in N using load cells for measurements. Coefficient of friction is calculated from the value of friction load. Normally effects of lubricants in contact surface exhibit their best functions in boundary lubrication regime. Pressure at contact interface is totally dependent on constant normal load applied at the time of tests which directs that normal loads are also responsible for creating boundary lubrication regime or mixed regime. That's why parameters for wear and friction measuring tests should be chosen in such a way so that optimal lubrication regime can be achieved in boundary or mixed regime. Parameters used for measuring friction and wear are tabulated in Table 5. After performing tests, results are analyzed and compared with the results obtained in dry condition for same materials under same load and speed conditions [31].

## 3. RESULTS AND DISCUSSIONS

### 3.1 Hardness

Change in micro-hardness of Al- $TiB_2$ composites with amount of $TiB_2$ particulates is shown in Fig. 3.

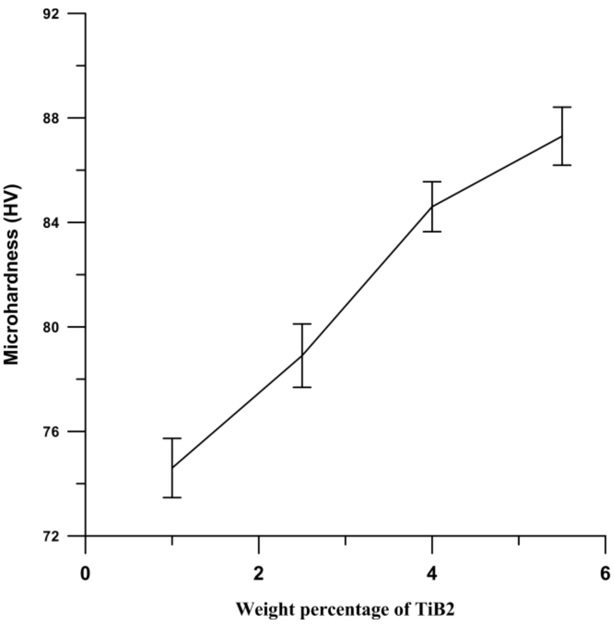
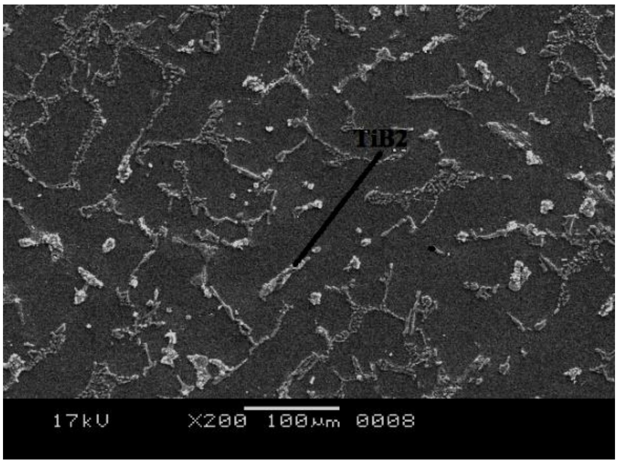



**Fig. 3.** Variation of hardness with wt% of $TiB_2$.

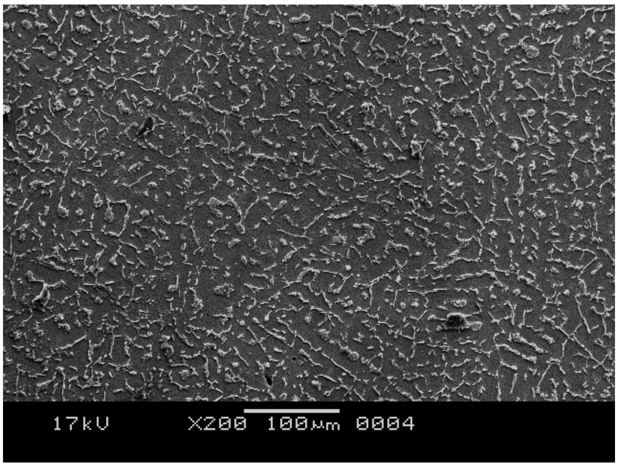
It is obvious from figure that with inclusion of $TiB_2$ particulates, hardness is affected due to fine particulate dispersion and higher hardness is achieved by higher weight percentage of $TiB_2$ in Al-$TiB_2$ composites. Similar observation is reported earlier [22,31].

### 3.2 SEM characterization

After fabrication of composites, surface morphology of each weight percentage composites is observed under SEM. Distribution of $TiB_2$ particulates over the surface is determined through this and also homogeneous nature in distribution is found out from SEM images. Detailed discussion on surface morphology of SEM images of various weight percentage fabricated composites is performed elsewhere [31].




(a)



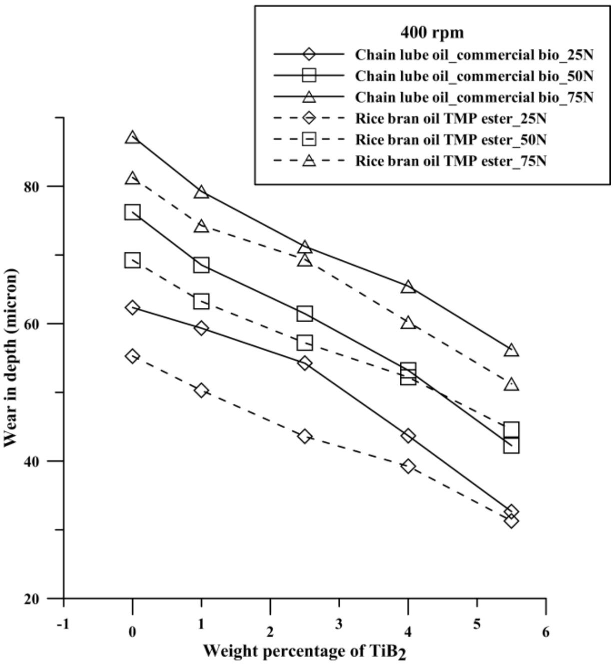

(b)

**Fig. 4.** SEM images of (a) 1 % $TiB_2$ composites and (b) 5.5 % $TiB_2$ composites.

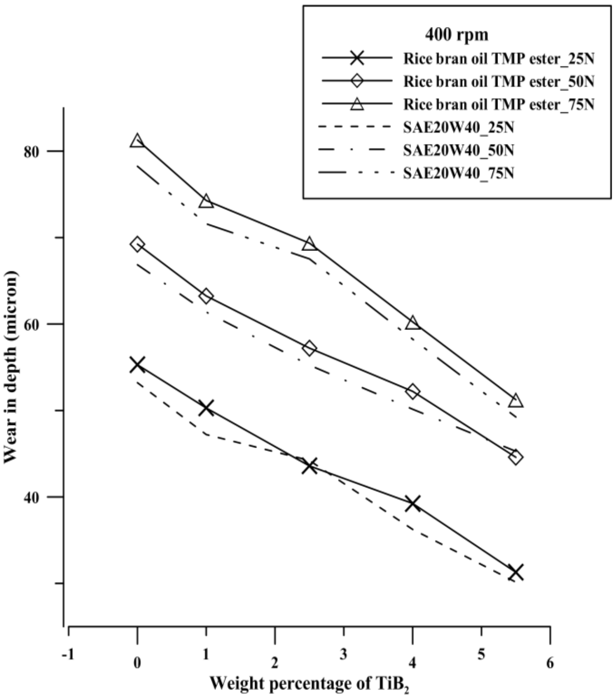
Figure 4 shows the SEM images for composites with highest weight percentage $TiB_2$ and lowest weight percentage $TiB_2$ as reinforcement. It is clearly noticed that nature of the distribution of particles is uniform and presence of $TiB_2$ particles in fabricated composites is confirmed.

### 3.3 Wear behavior in lubricated condition and comparison with dry condition

Figure 5 shows the wear test results of Al- $TiB_2$ composites using various lubricants at a particular speed of roller i.e. 400 rpm. Figure 5a presents the wear results for three different contact loads and for different weight percentage Al-$TiB_2$ composites including base alloy with two lubricants, one is CFC free commercial bio-lubricant with bio-additives [chain lube oil] and another one is bio-lubricant [rice bran oil TMP ester].




(a)




(b)

**Fig. 5.** Wear vs. weight percentages of $TiB_2$ for three different loads: (a) comparison of chain lube oil and rice bran oil, (b) comparison of rice bran oil and SAE20W-40.

With increase in normal loads, wear depth increases for all $TiB_2$ percentage composites irrespective of the nature of lubricants and this trend is in line with Archard's wear law. Wear depth decreases with increase in weight% of $TiB_2$ in composites. This is due to increase in hardness with higher amount of $TiB_2$ in the composites. At a particular load and speed combination, rice bran oil performs better than chain lube oil in terms of wear reduction. For same load i.e. 25 N, difference in wear depths for 5.5 % $TiB_2$ composite is almost 4.4 % and for base alloy it is almost 13 %. Similar trends are observed in Fig. 5b which depicts the wear results for different load and for different weight percentage composites but with rice bran oil TMP ester and commercial lubricant SAE20W-40. In terms of the value of wear depths, commercial SAE20W-40 is more effective as wear resistant followed by rice bran oil TMP ester and chain lube oil. This trend is followed in all the cases shown in Figs. 5a and 5b except a few. At 50 N loads and above 4 wt% of $TiB_2$ composites, wear is slightly more in presence of rice bran oil TMP ester than chain lube oil. At 25 N and 50N loads for 4 wt% and 5.5 wt% of $TiB_2$ composites, wear for rice bran oil TMP ester and for commercial SAE20W-40 are almost same. All of these tests are carried out at a fixed sliding speed, 400 rpm. At highest contact load i.e. 75 N and fixed sliding speed, comparison of wear in case of all three lubricants and all weight percentage composites is shown in figure 6a. At 75N loads, difference in wear values for 5.5 % $TiB_2$ composites between highest effective lubricant and lowest effective lubricant is almost 15 %. It is obvious from the figure that commercial SAE20W-40 is most effective wear resistant lubricant for composite -steel contact interface.

Figure 6b shows wear results for different sliding speeds with two commercial lubricants, one with bio-additives and one with petroleum base. Wear increases with sliding speeds and effects of the two lubricants remain same in nature in compliance with previous trends for all the roller speed conditions.

Comparison of wear in dry condition and in lubricated condition is drawn in Fig. 7. Dry condition results and parameters are based on previous report [31]. It is clearly seen that differences of wear depth reduces significantly in lubricated condition when compared to dry sliding conditions. It is important to observe here that inclination of graphs for wear depths with respect to weight percentages of $TiB_2$ in dry condition is much higher than in lubricated conditions. In dry condition, wear is mainly dependent on nature of contact surfaces and hardness ratios between two surfaces. But in lubricated condition, lubricant film and its interactions with surface layers play the main role and the contribution of weight percentage of $TiB_2$ particles (i.e. hardness of the composite) on tribological behavior becomes relatively insignificant.

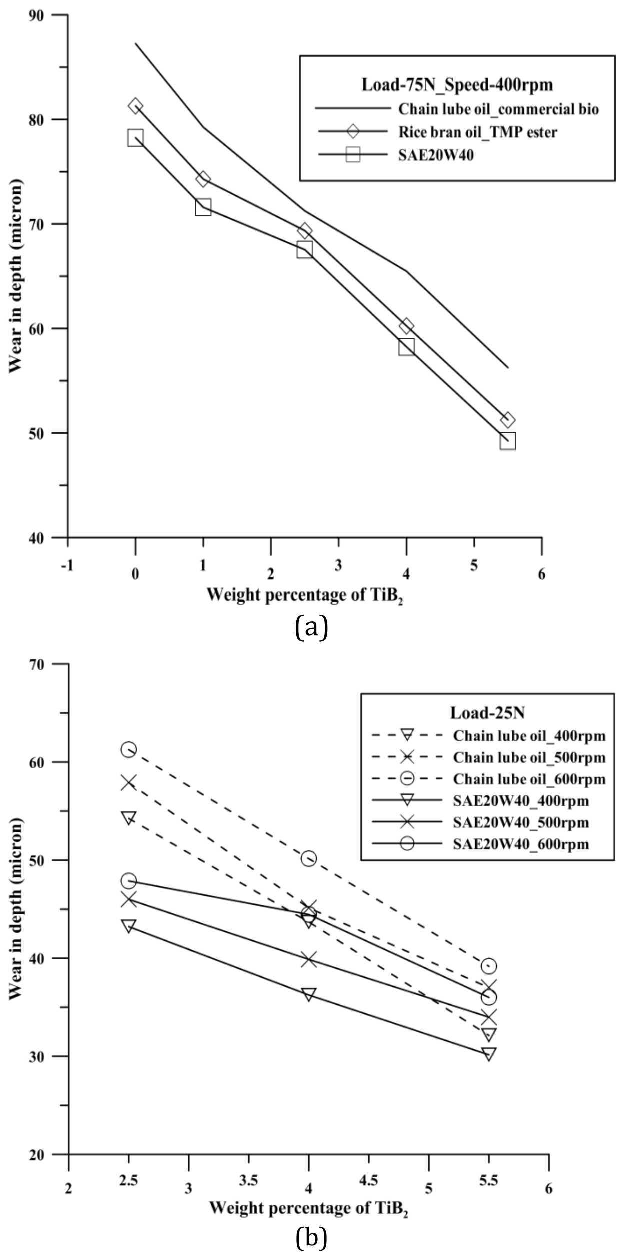



**Fig. 6.** Wear vs. weight percentages of $TiB_2$ (a) For three different lubricants at 75 N loads (b) For three different speeds for SAE20W-40 and chain lube oil.

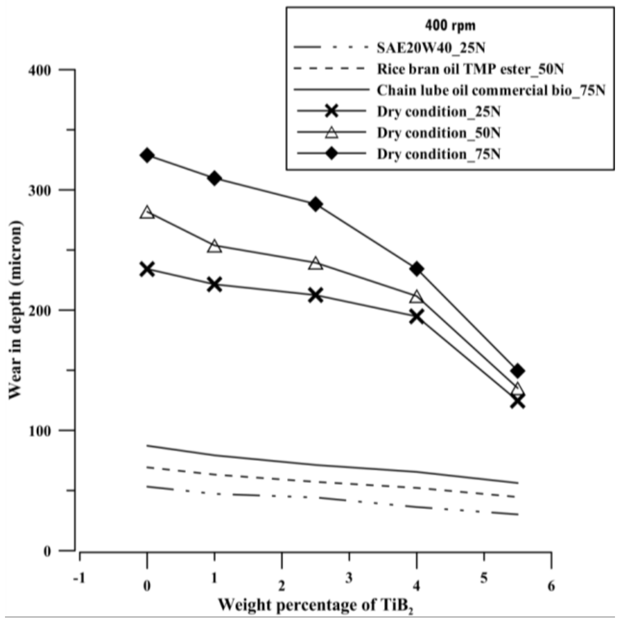
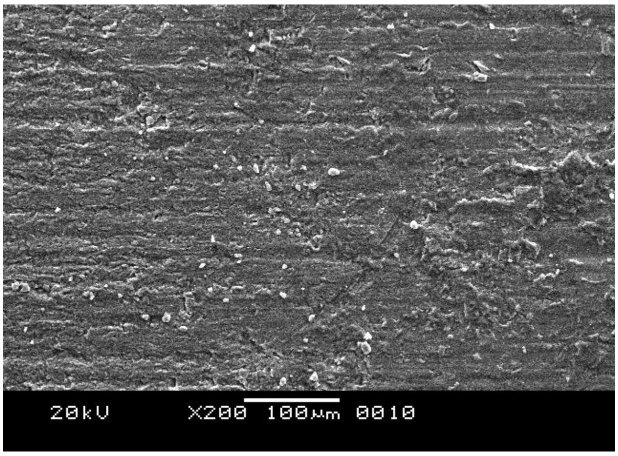


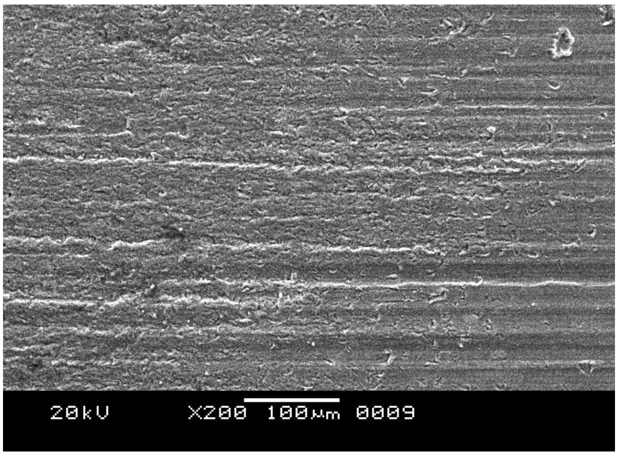

**Fig. 7.** Wear vs. weight percentages of $TiB_2$ under dry and lubricated conditions.

In lubricated contacts, wear is governed by the development of lubrication film in the contact interface between the composites and steel, and the interaction of the surfaces with the lubricant film. Generation of the lubrication film depends on the composition and the nature of the lubricant. Wear takes place due to breakage of junctions in apparent contact area of the mating surfaces or due to the deformation of asperities. In dry condition, dominating mechanism is abrasion and adhesion. In presence of lubricants, lubricant film reduces the number of junctions or number of asperities of the surfaces in contact. Beside this, absorption of lubricant by the surface helps to reduce adhesion force between two adjacent atoms of the mating surfaces, as a result of which mild abrasion occurs at the surface. Cooling effect of lubricant also helps to decrease surface temperature which leads to restrain the adhesion transference and plastic deformation [48]. Similar type of restraining in adhesion also occurs in Al- $TiB_2$ composite-steel interface in the presence of lubricants. These facts are responsible for reduction of wear in lubricated conditions. In lubricated condition, wear increases with normal loads also due to removal of the lubricant layer between contact surfaces and same reason is also applicable for the case of increased rotational speed. But in dry condition, more penetration of asperities in the contact surface occurs with higher load which yields more wear. But variation in wear with different lubricants occurs due to the variation in capability of the lubricant film to develop boundary lubrication or mixed lubrication or elasto-hydrodynamic lubrication condition [48]. In boundary lubrication regime, chemical interaction occurs between surface layers and lubricants that influences wear. In this aspect, SAE20W-40 and rice bran oil TMP ester is more effective as wear resistant lubricant. Esters present in the bio-lubricant helps to create effective boundary lubrication condition that influences wear in a large way though the film thickness may not be so thick [49]. SAE20W-40 is more effective by producing mixed regime mainly elasto-hydrodynamic lubrication [48] as the viscosity of this lubricant is higher compared to other two lubricants.

To observe the wear mechanisms in lubricated contact sliding, SEM micrographs of worn surfaces in SAE20W-40 lubricated contacts under 25 N and 400 rpm are shown in Fig. 8. As reported earlier [31], in dry condition, presence of longitude grooves, partial pits, micro-cutting and micro-ploughing indicates the contribution of adhesion and abrasion wear mechanism both.




(a)

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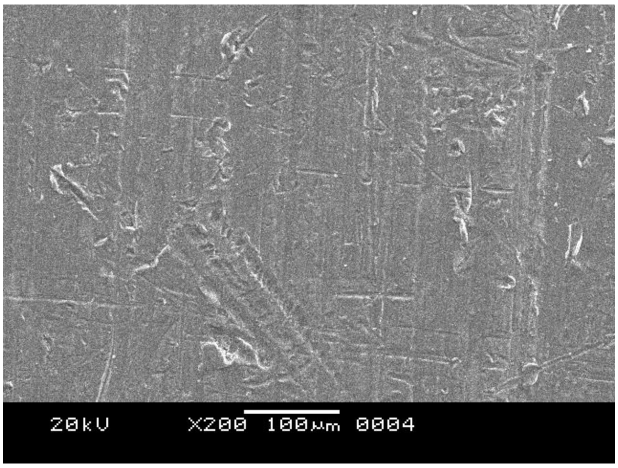


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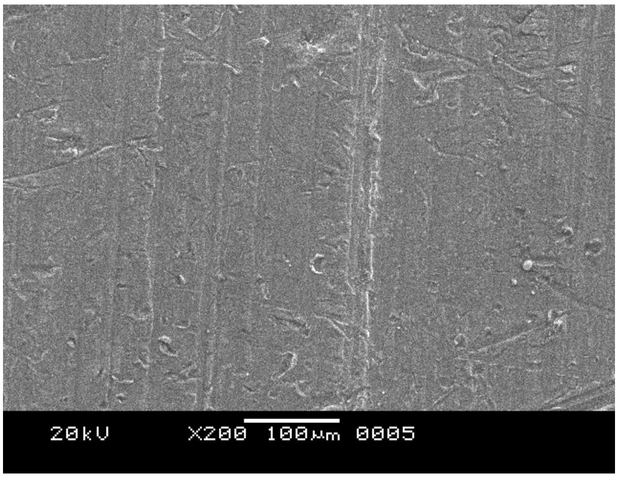



(d)

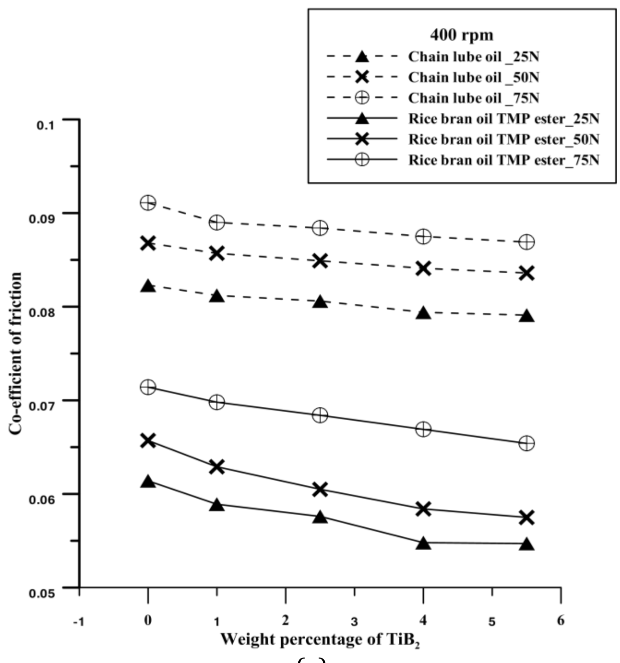
**Fig. 8.** SEM micrographs of worn surfaces of composites: (a) 1 % $TiB_2$, (b) 2.5 % $TiB_2$, (c) 4 % $TiB_2$ and (d) 5.5 % $TiB_2$.

But in lubricated condition, other than 1 % and 2.5 % $TiB_2$ composites, there is no sign of ploughing or cracking. No holes or pits are observed on the worn surfaces. Thus there is no effect from corrosiveness of lubricants. Elastic deformation of asperities is supposed to be an important mechanism for composite surface in lubricated condition. Wear due to elastic deformation creates no ploughing effects on the surface. With higher weight percentage, hardness of the composite increases which also increases the chance of abrasion of the surface at the time of sliding and this phenomena is observed in the dry condition but in lubricated condition higher weight percentage of $TiB_2$ increases the number of hard asperities at the mating surfaces resulting in lesser possibility of plastic deformation.

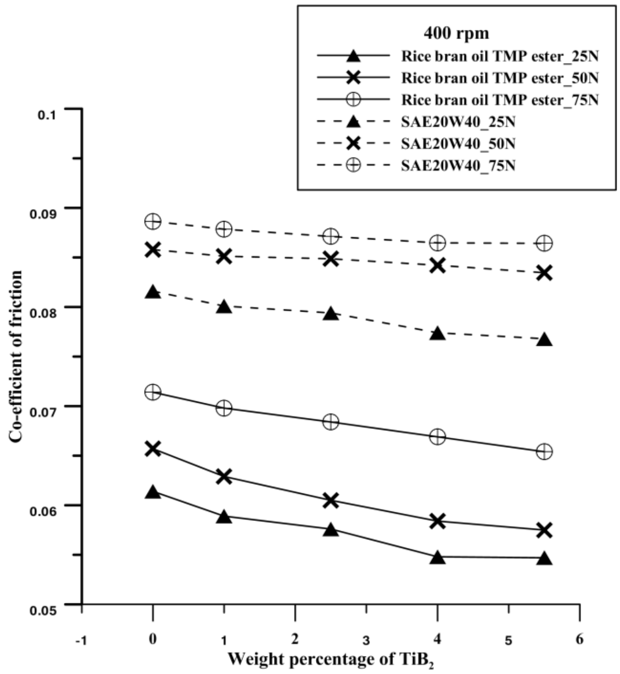
In dry condition, due to plastic deformation of asperities, hard particles are generated and laid in the surface but in lubricated condition only in case of lower weight percentage composites; there is small amount of plastic deformation yielding a comparatively rough surface. Lubricants also help to wipe out the tips which are procured at the time of sliding or rolling action and that is also an important reason behind getting smoother surfaces in lubricated conditions. Similar type of observations is reported elsewhere [42].

### 3.4 Friction behavior in lubricated condition and comparison with dry condition

Friction behavior of Al-$TiB_2$ composites under lubricated condition is shown in Fig. 9. The Figure 9a compares coefficient of friction vs. wt% of $TiB_2$ for rice bran oil based TMP ester and chain lube oil. Figure 9b compares coefficient of friction vs. wt% of $TiB_2$ for rice bran oil based TMP ester and SAE20W-40. It is observed that friction decreases with increase in wt% of $TiB_2$ and increases with normal load for all three lubricants. For TMP ester lubricant, friction coefficient values are in the range between0.054 and 0.062 for 25 N loads. Change in friction values for the same lubricant with change in loads from 25 N to 75 N for base alloy is about 17 % for base alloy and about 20 % for 5.5 % $TiB_2$ composite. Friction values for 5.5 % weight percentage composites lie in the range between 0.077 and 0.087 for different loads in SAE20W-40 lubricant and lie between 0.08 and 0.087 for different loads in Chain lube oil lubricant.



(a)



(b)

**Fig. 9.** Friction vs. weight percentages of $TiB_2$ for three different loads (a) comparison of chain lube oil and rice bran oil (b) comparison of rice bran oil and SAE20W-40.

From Figs. 9a and 9b, it is seen that with loads also, friction values vary more in case of ester lubricant than other two lubricants and friction values are more or less lie in the same range for other two commercial lubricants. For same load and same weight percentage of composites, friction values are lower for ester lubricants and comparatively these are much lower in case of higher load than in case of higher weight percentage. Ester type lubricant appears as the most effective lubricant on frictional behavior of Al-$TiB_2$ composites. Lowest value of friction obtained within these parametric conditions is 0.0547 which is significantly low from application point of view and the same is obtained in presence of ester lubricant.

Comparison of friction in dry condition and lubricated condition is shown in Fig. 10. Dry condition results and parameters are based on previous report [31]. It is clearly visible that the effect of weight percentages of $TiB_2$ on friction in dry condition is significant, while lines are almost parallel to axis under lubricated condition. It means effect of lubricant is much prominent than effect of weight percentage of $TiB_2$ on friction. In dry condition, friction values vary between 0.313 and 0.332 with varying loads for 5.5 % $TiB_2$

composites while these lie between 0.077 and 0.087 for commercial lubricant. Actually friction values are 5 times lower in lubricated condition compared to dry condition. It is apparent that for control of friction, lubricants play very vital role that can't be compensated by incorporating more $TiB_2$ particulates in weight percentages as reinforcement. Difference between friction values in dry condition and lubricated condition is also higher for ester lubricant.

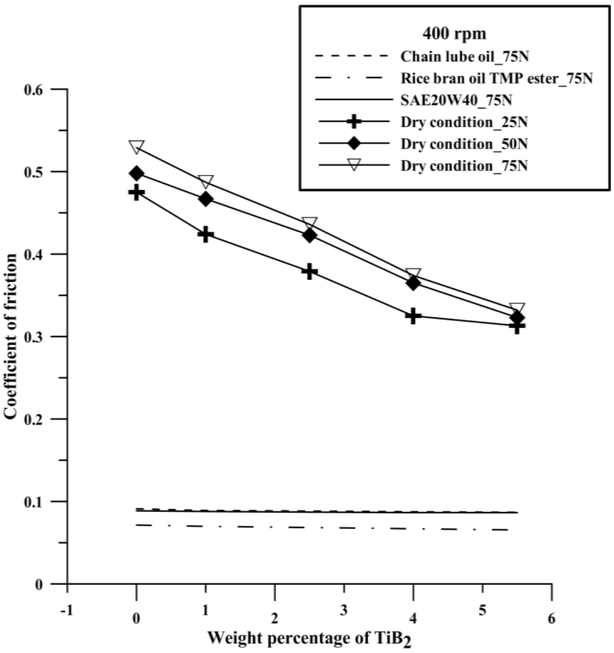



**Fig. 10.** Friction vs. weight percentages of $TiB_2$ under dry and lubricated conditions.

In lubricated conditions, frictional force develops due to generation of shear force within lubricant film and this shear force is dependent on characteristics of the lubricant itself. That's why lubricants having closed structure will be able to give similar frictional behavior [47]. This leads to almost same friction values of Al-$TiB_2$ composites under two commercial lubricants i.e. chain lube oil and SAE20W40 though these yield different wear values which is depicted in Fig. 5. Lubricants which are not absorbed by the surface show this type of effects but lubricants which can be absorbed by the metallic surface, form a metallic soap which resists the asperities to come near and thus they reduce the frictional values. This capability of reducing friction by forming metallic soap does not depend on the contact loads. The effect of metallic soap on surface is more than the developed shear force within certain parametric values. Thus frictional values are less in presence of methyl esters on contact surface as they can be absorbed to form metallic soap [49]. However, with higher load this condition may be destroyed and will be difficult to achieve in presence of methyl ester type of lubricant. In recent times, there has been growing interest in friction and wear study of metal matrix composites [50-54]. However, all these studies consider only dry contact situations. In this respect, the present study will help in widening the use of such composites in various lubricated conditions as well.

## 4. CONCLUSION

In the present study, Al-$TiB_2$ composites are developed through stir casting method and tribological tests are performed in a Multi-triobotester using three different lubricants are chosen in this study. In lubricated contact, mostly elastic deformation of asperities occurs during sliding against steel surface by higher weight percentage of $TiB_2$-composites. It leads to relatively smoother surface morphology of wear tracks which is confirmed by SEM images. In case of lower weight percentage of $TiB_2$-composites, little amount of ploughing and cracking is present on the surface due to mild wear by abrasion and less amount of plastic deformation of asperities. Petroleum based commercial lubricant is the most effective lubricant as wear resistant followed by methyl ester based lubricant and bio-additives based lubricant. In case of frictional characteristics, methyl ester based lubricants are the most effective one as they are capable to make metallic soap through absorption by surface up to a certain extent.

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