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Synthesis and Tribological Characterization of Copper Based Composites Containing Carbide

Synthesis and Tribological Characterization of Copper Based Composites Containing Carbide

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Abstract: Keeping in view the importance of the Cu based composites in sliding electric contact applications, the aim of the study is synthesise copper-chromium alloy based composites containing different wt. % of TiC by using a cost effective stir casting technique and to compare their mechanical and tribological behaviour. The study also proposes to analyse the friction and wear behaviour of the formed composites under the sliding speed of 1m/s and load varied 5 N, 10 N, 15 N and 20 N. The hardness of the composite Cu-1wt%Cr-1wt%TiC and Cu-1wt%Cr-2wt%TiC has been found to increase slightly when compared with Cu-Cr alloy and as received Cu. The wear rate was found to show linear trend with increasing normal load following the Archard law. However, composites were found to show low wear as compared to that observed in pure copper. This might be due to high hardness of the composite, the compact transfer layer of wear debris and due to presence of hard TiC particles whicg results in a lower real area of contact which further causes lower wear. There was found no cracks in the composite. The addition of chromium was found to increase the wettability and mechanical properties. The composite hardness and strength was found to increase with addition of TiC and chromium element in the matrix phase up to certain content.

1. Introduction

Copper is used in many industrial applications because it possess very interesting features like excellent electrical and thermal conductivities, low price, cheaply available, easy to fabricate, and resistance towards corrosion. However, it possess low hardness, low tensile strength and low resistance towards wear. These features restrict its applications. To enhance the mechanical properties and resistance towards wear in the copper there are two ways either by an age hardening mechanism or to incorporate the hard phase in the matrix. In age hardening method, the low wt. % of chromium or zirconium in the copper matrix lead to the precipitation of a hard second phase which does not dissolve properly in the copper matrix mainly in low temperature regimes. In other alternative method to reinforce hard phase particles such as carbides, nitrides, oxides, borides into the copper base matrix to develop copper base metal matrix composites.

   Due to low harness, and high ductility copper has been found to show low resistance towards wear. Copper has been found to show severe adhesive wear and a large extent of wear debris comes out of the surface during sliding on a hard steel counterpart. It is desirable to enhance the wear resistance in the copper and to understand wear behaviour of Cu-base composites. Tjong and Lau [1] investigates the tribological behavior of Cu–SiCp (5–20%) composites under velocity of 1 m/s and loads varied from 15–55 N. From the study they showed that as the SiC particles added in the copper matrix they reduced the extent of strain localization in the sub-surface region leading to reduction in volume loss. Sharma

and co-workers [2] found that for Cu–SiCp composites as the load increases with speed the wear transform from mild to severe wear and then to seizure. The tribological behavior of copper–graphite (8–20%) composites by Moustafa and co-workers [3] shown that copper coated graphite composites shows wear resistance behavior in comparision to pure copper. Kennedy et al [4] examined the tribological behavior of Cu–Cu coated SiCp composites using pin on disk configuration under speed of 1 m/s and at a load of 27 N. They show the importance of interface bonding between the matrix and the reinforcing phase. They were use Co-B coating on the SiC particles which increses the interface bonding and thus helps in reduced pullout of the SiC particles from the copper matrix and thus makes the composite more wear resistance. Wan et al. [4] shows that copper coated and nickel coated alumina particle reinforced in Cu–alumina composites exhibited more wear resistance behavior as compared to uncoated ones. This was attributed to strong interfacial bonding between reinforce phase and the matrix.

Zhan and Zhang [2] found that reinforcement of graphite particles to Cu–SiCp composites, fabricated via powder metallurgy process, diminished the wear rates and lifted the transition from mild to severe to 723 K. The COF of copper hybrid composite was more stable and lower than that of SiCp/Cu. However, the wear test was done at 45 N load under 0.15 m/s speed. Gonzalez et al. [5] reported that modeling effort was required for SiCp reinforced composites to validate the results also. It was shown that testing temperature has a greater influence on wear rate of 8090 Al alloy reinforced with SiCp. Rice and Moslehy [6] showed an interface model to show the probable dynamic effects in dry sliding wear. Muller and Van [7] talked about the role of the fatigue and ductility in labeling the wear phenomenon. The Taguchi method was assumed by Sahin [8] to examine the influence of abrasive particle properties and testing conditionings on wear rate of 2014 aluminium alloy in which as a reinforcing phase was 10% and 20% SiCp. Axen et al. [9], formulate a friction model which was able to explain the discrepancies in the prediction of the COF multiphase materials by linear rule of mixture and COF was dominated by the COF of the most wear resistant phase.

In this present investigation, an attempt made to develop Cu-base composite using 2 wt. % TiC as reinforce into the Cu-Cr alloy. The titanium carbide is an exciting engineering material for the reinforce into copper matrix because it possess some exciting features like high melting point, high hardness and great extent of resistance towards wear. Optimal control of the reinforcement particles will give the best properties for sliding contact applications.

2. Experimental Procedure

2.1 Materials Selection
In this investigation pure copper (99.9%) used as matrix and reinforcing materials was pure chromium (99.8% and < 50 μm) which improve the wettability and finally titanium carbide added to prepare cast composites.

Stir Casting is composite material fabrication method in a molten state, in which a reinforcing phase (ceramic particles, short fibers) is mixed with the matrix material in molten state by means of mechanical stirring. It is very simple and straight forward process and also cheap method for the production of particulate matrix composites. To achieve better mechanical properties uniform dispersion of the reinforcement is very essential. Porosity has to be control with casting technique. The matrix material was heated by the furnace in a crucible. At the time of melting the reinforcing phase added with in the matrix and simultaneously the mechanical stirring done to disperse the material in all the direction. After stirring directional solidification takes place to obtain the desired product.

Furnace Setup and Stirrer: An electric muffle furnace of Kanthal wire as shown in Figure 1 was used to develop the cast composite. It has a PID controller which controls the temperature in the range of 0ºC to 1200ºC. The required temperature is set by changing temperature on digital display. Once the required temperature is reached it is maintained until furnace is turned off. Stirrer is made of long circular rod of stainless steel and blades welded at the end. A variable rpm motor is used for motion of stirrer.

Figure 1. Stir casting Furnace

2.2 Melting and Casting
The present work is aimed to investigate the mechanical properties along with tribological behaviour of cast Cu–1wt.%Cr–1wt.%TiC and Cu–1wt.%Cr–2wt.%TiC composite synthesized by alloying molten copper with Cr and dispersion of TiC particles. By stir casting route metal matrix composite was prepared. Pure copper of 2 kg was melted as a base matrix material in a muffle furnace. The melting process was commences in a graphite crucible. The temperature was raised up to 1200°C and after that it was allowed to stabilize the temperature then after 1wt.% of chromium was added to increase the wettability and then after 1wt% (and 2wt%) of titanium carbide was added in the metal matrix. When the temperature raises around 1215°C, pure TiC was mixed mechanically into melted Cu matrix alloyed with Cr. Chromium carbides—Cr–C, $Cr_{23}C_6$, Cr_3C_7 etc., were formed, through an exothermic reaction between TiC and Cr in the melt. Then the melt was stirred at a uniform rate with the help of a stainless steel turbine stirrer. The stirring was done at an impeller speed of 200 rpm. At the time of mixing the temperature was maintained 1200°C during addition of chromium and titanium carbide. The dispersion of all reinforced particles were achieved by the vortex method. The melted matrix with reinforcing phase were poured into the permanent metallic mold. The melt was allowed to solidify in the mold. After some period of time when temperature cools down to room temperature desired casting is obtained of the mold shape.

(a)   (b)

**Figure 2**. Casting of (a) Cu-1wt%Cr-1%TiC composite and (b) Cu-1wt%Cr-2wt%TiC composite

2.3 Friction and Wear Testing

Typical cylindrical wear testing specimens of 10 mm were produced from all the composites. There are number of testing machine available to evaluate wear but pin-on-disc type is most popular for tribological studies. Tribological test were conducted by sliding pins which are made of the composite material rubbing against a counter face which are made of steel disk made of SAE 4615 steel. The hardness of the steel was 174 BHN. The tests were conducted under a normal load of 5, 10, 15 and 20 N. The speed was 1 ms^{-1}. The flat surface of testing pin and steel disc were grounded of the order of 0.40 µm and these were thoroughly degreased, cleaned and dried before commencement of each test run. The cylindrical testing pin specimen was of 10 mm in diameter and 15 mm in height and the counter face disk was of 120 mm diameter and 10 mm thickness. Before conducting the test all the specimen of the composite material were ground with 4/0 grade emery paper, cleaned in solution of acetone to remove any particle which may stick on the surface. After testing, the weight loss of the specimens were measured, after covering the total sliding distance of 1800 m. The difference in weights of the pin before and after the experiment gave the weight loss from which volume of wear rate was calculated. Tests were conducted for various compositions for different combinations of loads and a fixed sliding speed. The total sliding distance covered in a test was 9000 m. Average value has been reported after conducting the wear test at least three times.

3. Results and discussions:

3.1 Metallographic Analysis:

The microstructure of the composites was examined under an optical microscope, Olympus, PME3, Tokyo, Japan. Figure 3 shows the optical microstructure of the as received copper, cast Cu-Cr alloy, Cu-1%Cr-1% TiC and Cu-1%Cr-2% TiC respectively. It is observed in Fig3 (a) that a fine tuned copper structure is occurs in the pure commercial copper, which is basic structure of the cooper. The Cu-Cr alloy as shown in Figure 3 (b) shows the presence of fine particles of chromium which imparts the characteristics of corrosion as well as wettability of the alloy. Figure 3 (c) and (d) shows the optical microstructure of Cu-1%Cr-1% TiC and Cu-1%Cr-2% TiC respectively, it is clearly observed the presence of reinforcing TiC and Cr particles. It is also observed that some formation of carbides resulting the reaction between Cu-Cr alloy and TiC and it increases as wt.% of TiC increases as depicted in the Figure 3 (c) and (d).
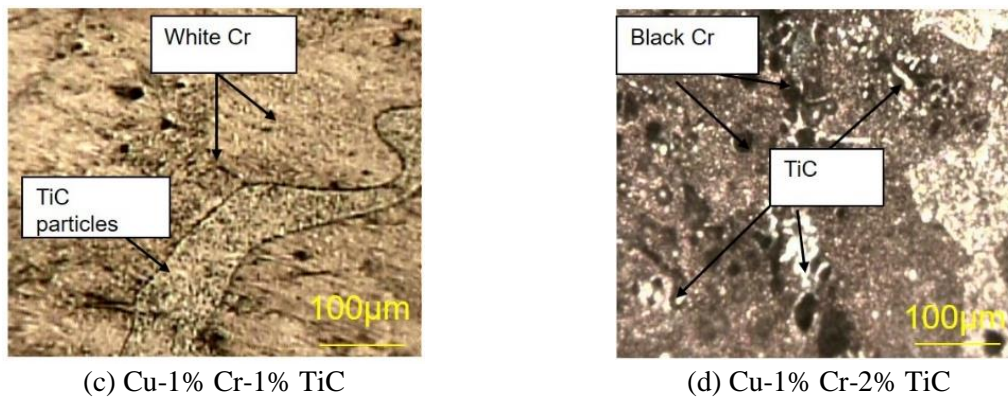

(a) As received copper

(b) Cu-Cr alloy

(c) Cu-1% Cr-1% TiC   (d) Cu-1% Cr-2% TiC
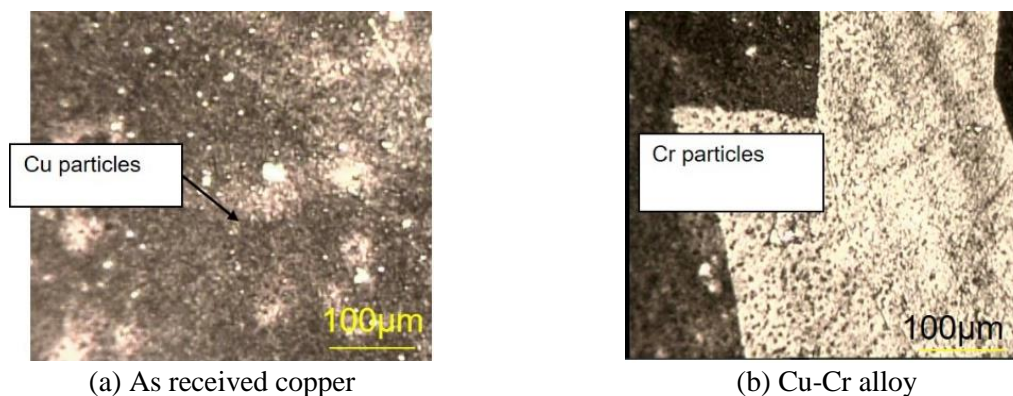
Figure 3. Optical Micrographs of the composites (a) pure Cu (b) Cu-Cr alloy (c)   Cu-1wt%Cr-1%TiC Composite (d) Cu-1wt%Cr-2%TiC Composite

3.2 Brinell hardness test

Hardness test was performed on the surface of the composites to check the hardness of the composites. Harness test was performed by applying 500 Kg load on the composites. Indentation size on the surface of the composites are given in the Table 1. As the TiC wt. % increases in the pure copper matrix the indentation size decreases as can be seen in Figure 4(a) and Figure 4(b). Indentation size directly reflect the hardness of the composites. Lower size of indentation is meaning of high resistance and high hardness.

Brinell hardness test was performed with the help of a Hardness Tester**.**

Brinell hardness number, BHN= $\dfrac{2P}{\pi D\sqrt{(D^2-d^2)}}$

P=load applied (in kg)
D=diameter of indenter (in mm) = 10 mm
d=diameter of indentation (in mm)

The hardness of the different materials used in the present investigation is listed in Table 1.

Table 1. Variation of Hardness with TiC content

Materials	Load applied (in kg)	Indentation (in mm)	Average Hardness (BHN)
Pure copper	500	5.2	35
Copper Chromium alloy	500	4.8	36.12
Cu-1wt%Cr-1wt%TiC Composite	500	4.0	38.12
Cu-1wt%Cr-2wt%TiC Composite	500	3.7	44.85

Figure 4(a). Hardness indentation of Cu-1wt%Cr-1%TiC Composite

Figure 4(b). Hardness indentation of Cu-1wt%Cr-2%TiC Composite

Table 2. Variation of Tensile Strength with TiC content

Material	% Elongation in gage length	% Reduction in area	Tensile Strength (MPa)
Pure Copper	55	59	220.15
Copper Chromium alloy	50	57	230.3
Cu-1wt%Cr-1wt %TiC Composite	47	55	249.82
Cu-1wt%Cr-2wt %TiC Composite	33	35	257.62

It could be observed from the table 2 that as the alloying addition increases the strength of Cu increases but that occurs at the expense of ductility, which is not surprising as the hard TiC particles induce some hardness reducing thereby the ductility.

The elongation in gauge length of Cu was observed to be 55% and its tensile strength was calculated as 220.15 MPa. For Cu-Cr alloy, elongation in gauge length was observed to be 50% and its tensile strength was calculated as 230.3 MPa. For Cu-1wt%Cr-1wt%TiC Composite, elongation in gauge length was observed to be 47% and also its tensile strength increases in comparison to copper and copper chromium alloy. In this specimen necking was observed before failure and elongation in gauge length was significant. For Cu-1wt%Cr-2wt%TiC composite, elongation was less than former specimen, showing increase in concentration of TiC decreases its ductility and improved tensile strength. In this specimen, fracture was expected to occur with necking. But it was observed to fail without necking. This may be because of some voids or surface cracks present or due to some other impurities

4. Wear and Friction Behaviour

4.1. Variation of cumulative volume loss with Normal Load
Figure 5 shows the effect of normal load on volume loss shows that volume loss increases continuously with load in a linear manner irrespective of sliding velocity. But in case of composites volume decreases with increase in TiC content in the present investigation.
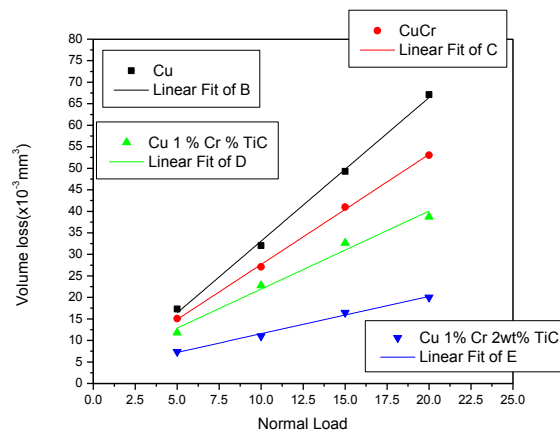
Figure 5. Variation of volume loss with normal load for cast copper, copper chromium alloy, Cu–1 %(by wt.)Cr–1 %(by wt.) TiC and Cu- 1 %(by wt.)Cr-2 %(by wt.) TiC composite at sliding speed of 1 m/s.

4.2. Variation of Cumulative Volume Loss with sliding distance at 5 N Load

The variation of cumulative volume loss with sliding distance was investigated at different loads of 5, 10, 15 and 20 N and at a constant sliding speed of 1 m/s and the same has been depicted in Figure 6-9 for different materials used in the study. All the data points have been fitted with linear least square fit line. It could be seen that the variation has a linearly varying relationship at all the loads following Archard's law and for all the specimens used in the study. It could also be observed that the at each load the composite containing 2 wt.% TiC shows the lowest volume loss whereas the pure Cu shows the highest indicating thus the beneficial effect of addition of TiC which raises the hardness of the Cu and improves its wear resistance.
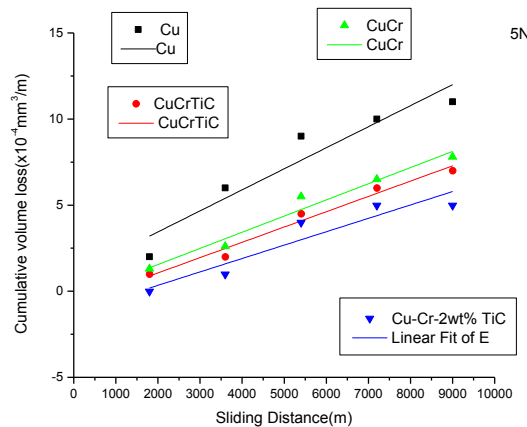

Figure 6. Cumulative volume loss with sliding distance at normal load of 5 N for cast copper, copper chromium alloy, Cu–1 %(by wt.)Cr–1 %(by wt.)TiC and Cu- 1 %(by wt.)Cr-2 %(by wt.) TiC composite at sliding speed of 1 m/s.

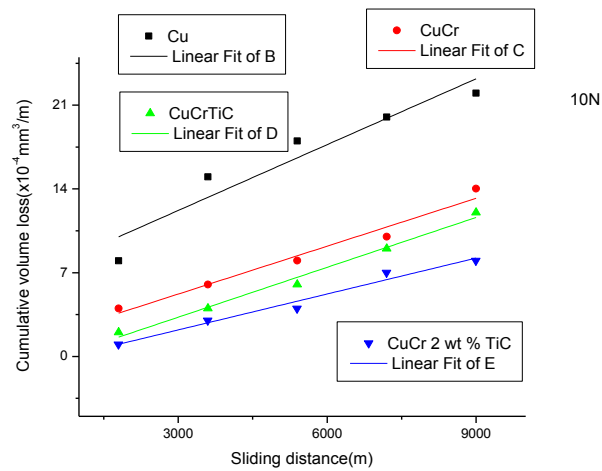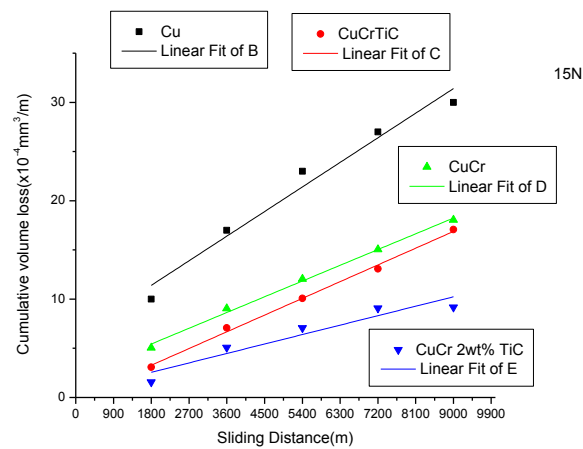### 4.3. Variation of Cumulative Volume Loss at 10 N Load

Figure 7. Cumulative volume loss with sliding distance at normal load of 10 N for cast copper, copper chromium alloy, Cu–1 %(by wt.) Cr–1 %(by wt.) TiC and Cu- 1 %(by wt.) Cr-2 %(by wt.) TiC composite at sliding speed of 1 m/s.

4.4. Variation of Cumulative Volume Loss at 15 N Load

Figure 8. Cumulative volume loss with sliding distance at normal load of 15 N for cast copper, copper chromium alloy, Cu–1 %(by wt.)Cr–1 %(by wt.)TiC and Cu- 1 %(by wt.)Cr-2 %(by wt.) TiC composite at sliding speed of 1 m/s.

4.5. Variation of Cumulative Volume Loss at 20 N Load
It could also be observed that the at each load the composite containing 2 wt.% TiC shows the lowest volume loss whereas the pure Cu shows the highest indicating thus the beneficial effect of addition of TiC which raises the hardness of the Cu and improves its wear resistance.
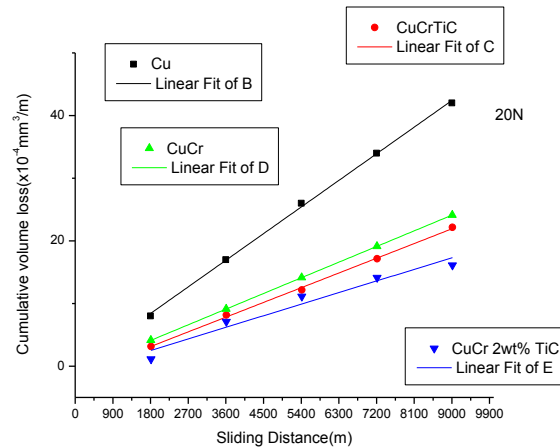
Figure 9. Cumulative volume loss with sliding distance at normal load of 20 N for cast copper, copper chromium alloy, Cu–1 %(by wt.)Cr–1 %(by wt.)TiC and Cu- 1 %(by wt.)Cr-2 %(by wt.) TiC composite at sliding speed of 1 m/s.

4.6. Variation of wear rate at Normal Load

The wear rate, i.e., volume loss per unit sliding distance has been estimated from the slope of the linear fit curves of variation of volume loss with sliding shown in Figure 6-9. Figure 10 shows the variation of wear rate with applied normal load for all the materials investigated in the present work. It can be observed that the wear rate increases linearly with normal load for all the materials. However, the composite containing 2 wt. % TiC shows the lowest wear rate and the Cu shows the highest wear rate. The wear rate decreases by a factor of 6 approximately at lowest load and 2 at the highest load by incorporation of 2 wt. % TiC.
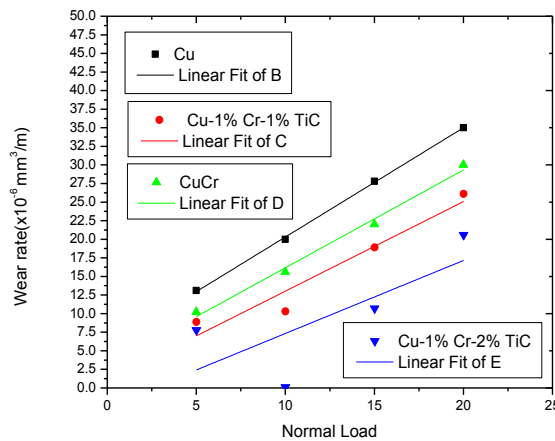

Figure 10. The variation of wear rate with normal load for as-received copper, cast copper, copper chromium alloy, Cu–1 %(by wt.)Cr–1 %(by wt.)TiC and Cu- 1 %(by wt.)Cr-2 %(by wt.) TiC composite at sliding speed of 1 m/s.

5. Friction Behavior

The friction force was constantly recorded on regular intervals which are displayed on the controller attached with the machine. Friction coefficient was obtained by dividing the friction force by normal load.

5.1. Variation of coefficient of friction with sliding distance at 5 N load

The variation of friction coefficient with sliding distance has been shown in Figure 11-14 at different loads of 5, 10, 15 and 20 N for all the specimens tested under the present study. All the variations show the fluctuating trend with respect to sliding distance. The value of COF for all the composites shows a decreasing trend as the applied load increases from 5 to 20N. The fluctuations in the COF may be not better contact in the early stage of testing then after sample and the counter face try to develop better surface conformity with each other.
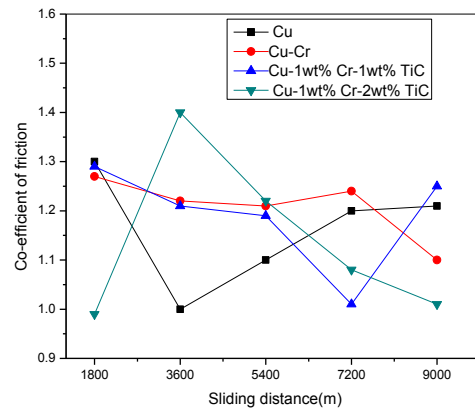

Figure 11. COF with sliding distance at normal load of 5 N at sliding speed of 1 m/s for cast copper, copper chromium alloy, Cu–1 %(by wt.)Cr–1 %(by wt.)TiC and Cu- 1 %(by wt.)Cr-2 %(by wt.) TiC composite at sliding speed of 1 m/s.

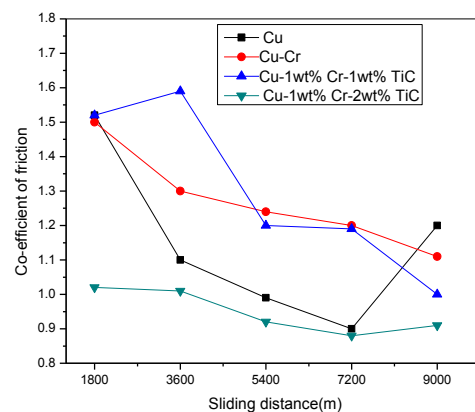### 5.2. Variation of COF with sliding distance at 10 N load

Figure 12. COF with sliding distance at normal load of 10 N at sliding speed for cast copper, copper chromium alloy, Cu–1 %(by wt.)Cr–1 %(by wt.)TiC and Cu- 1 %(by wt.)Cr-2 %(by wt.) TiC composite at sliding speed of 1 m/s.

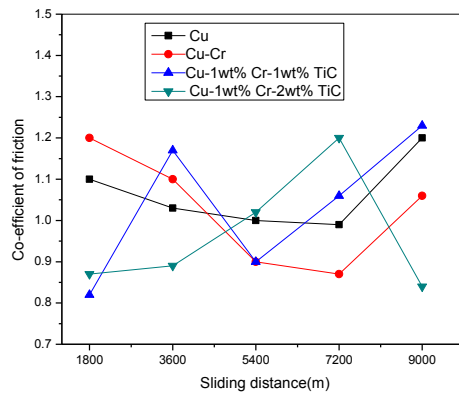*5.3. Variation of COF with sliding distance at 15 N load*

Figure 13. COF with sliding distance at normal load of 15 N at sliding speed for cast copper, copper chromium alloy, Cu–1 %(by wt.)Cr–1 %(by wt.)TiC and Cu- 1 %(by wt.)Cr-2 %(by wt.) TiC composite at sliding speed of 1 m/s.

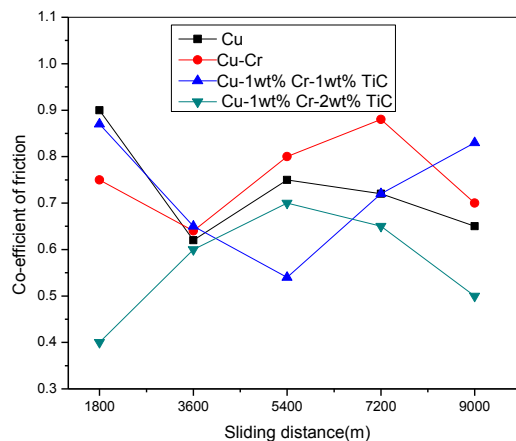*5.4. Variation of COF with sliding distance at 20 N load*

Figure 14. COF with sliding distance at normal load of 20 N at sliding speed for cast copper, copper chromium alloy, Cu–1 %(by wt.)Cr–1 %(by wt.)TiC and Cu- 1 %(by wt.)Cr-2 %(by wt.) TiC composite at sliding speed of 1 m/s.

5.5. Variation of average COF with normal load

The variation of average COF with normal load is shown in Figure 15. It can be seen that the COF decreases with increasing normal load and increasing content of TiC. The Cu-Cr-2 wt. % TiC composite shows the lowest COF whereas the copper shows the highest at all the loads used in the present study.
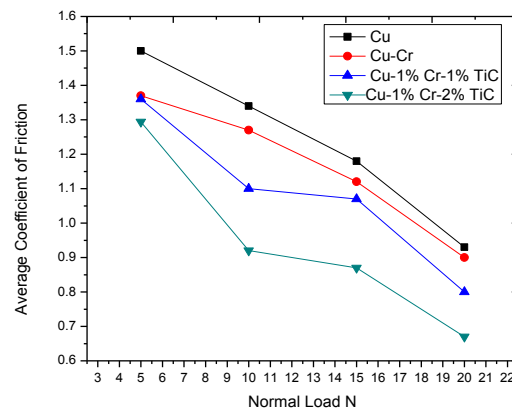
5.6. Variation of average COF with compositions

Figure 15. The variation of average COF with normal load at sliding speed of 1 m/s and sliding distance of 9000 m for cast copper, copper chromium alloy, Cu–1 %(by wt.)Cr–1 %(by wt.)TiC and Cu- 1 %(by wt.)Cr-2 %(by wt.) TiC composite.

Figure 16 shows the bar chart for the variation of average COF with the materials having different compositions. One could observe that the COF of Cu is more in comparison to other three and composite containing 2 wt. % TiC shows the lowest COF.
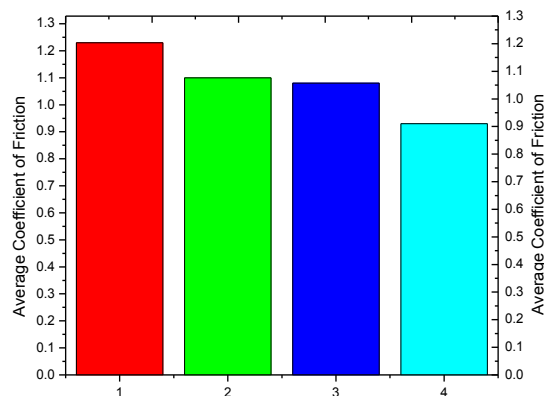

Figure 16. The variation of average COF with compositions at sliding speed of 1 m/s and sliding distance of 9000 m. (1) cast copper, (2) copper chromium alloy, (3) Cu–1 %(by wt.)Cr–1 %(by wt.)TiC composite (4) Cu- 1 %(by wt.)Cr-2 %(by wt.) TiC composite.

5.7. Examination of Worn Surfaces
The worn surfaces of the composites have been examined by SEM to explore the mechanism of wear and to correlate it with the observed friction and wear behavior in the materials. Figures 17 (a-d) shows the SEM micrographs of the materials tested at a load of 20 N and at a constant sliding speed of 1 m/s. All the specimens show the wear tracks and smooth surface covered with a layer of compacted wear debris which is called as transfer layer. However, the transfer layer appears to be fractured in case of Cu as shown in Figure 17 (a) whereas it well compacted in case of composites containing TiC as could be seen from Figure 17 (c ,d). Deeper groves could be observed in the micrograph shown in Figure 17 (b) which indicates a relatively larger loss of material from Cu-Cr alloy in comparison to composites containing TiC.

A relatively lower rate of wear observed for the composite containing 2 wt. % TiC as shown in Figure 17 could be attributed to the relatively higher hardness of the composite which lowers the real area of

contact and in turn lowers the wear volume loss and wear rate. The other contributing factor may be the cover of transfer layer over the sliding surface which reduces metal-metal contact resulting in reduced mass loss and wear rate. Figure 17 (a-d) shows the presence of the transfer layer over the worn surface but the extent of cover provided appears to be more in case of 2 wt. % composite in comparison to Pure Cu, Cu-Cr and 1 wt. % TiC composite. Hence it shows the lowest wear rate under the prevailing conditions of tribo-testing in the present work. The increase in wear arte with normal load is in consonance with the prediction by Archard's law so it not a surprising features. As the load increases the real area of contact also increase which results in more loss of material.

The reason behind relatively lower COF in the composites might be acknowledged to the lower real area of contact and the larger extent of cover of transfer layer. The other reason may the thickness of the transferred layer rather it has not been quantified in the present study. A harder substrate is able to hold a thicker layer of compacted wear debris which prevents the digging from the harder asperities of counter face inhibiting thus, metal-metal contact resulting in a lower coefficient of friction. Decreasing trend of COF was observed with increasing load might be due to better compaction of the wear debris of the transfer layer because some extra frictional heating also provided at the higher load.
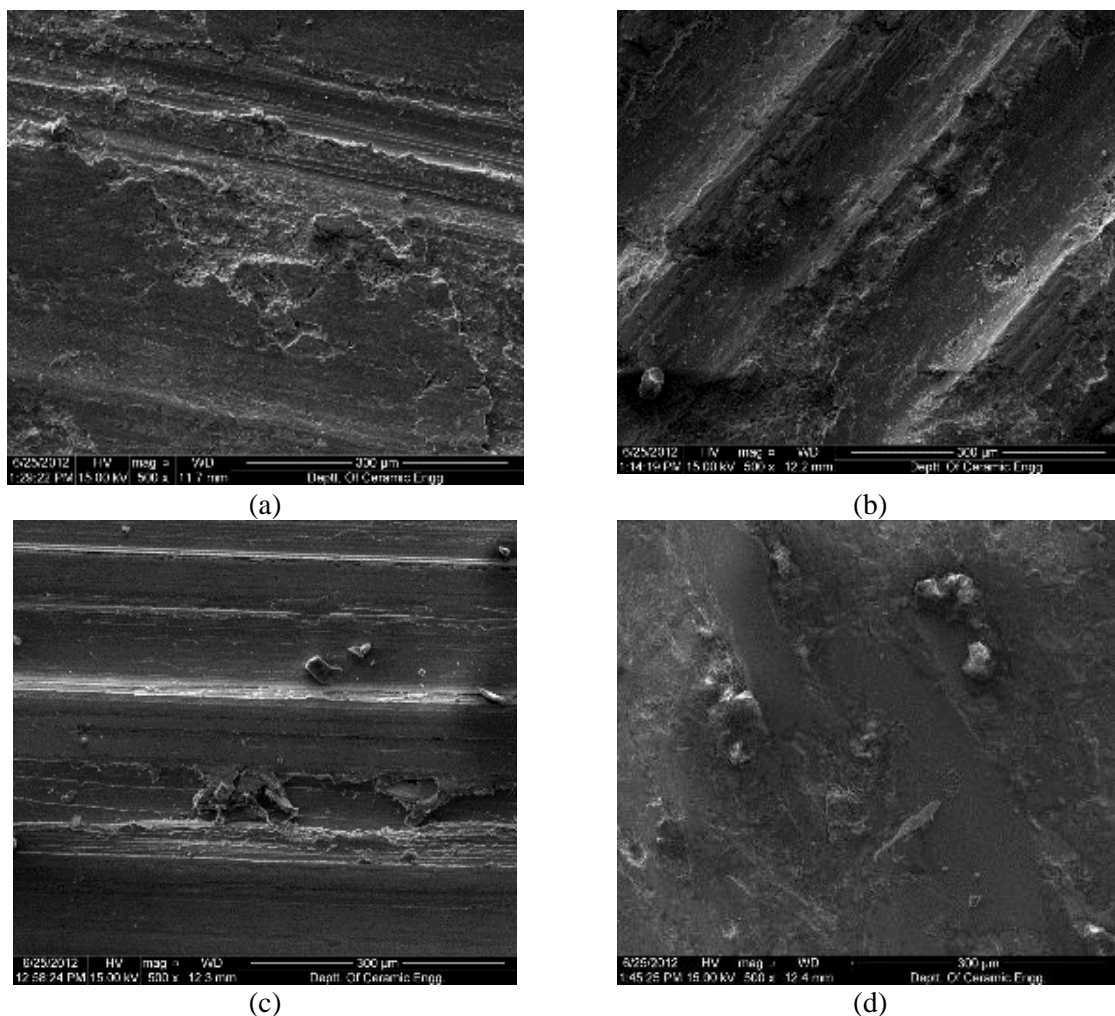

(a)   (b)

(c)   (d)

Figure 17. SEM micrographs of the worn suface under a normal load of 20 N (a) Cu (b) Cu-Cr (c) Cu-Cr-1 wt.% TiC and (d) Cu-Cr.2 wt.% TiC

6. Conclusions

- A cast Cu-Cr-TiC composite for the application of sliding contact and wear resistant was developed by using by cost effective stir casting method.
- Different type of intermetallic formation takes place which is seen by optical microscope.

- Addition of TiC in Cu matrix increased its hardness considerably due to which mechanical properties improves.
- For the given load, the cumulative wear volumes of composites, copper and copper chromium alloy increase linearly with sliding distance under dry sliding conditions.
- The wear rate follow the linear trend as the load increases. Composites were found better wear resistant materials.
- The average COF decreases with load in both pure copper and composites and copper chromium alloy. However composites show a lower COF than that observed in pure copper.

It may be finally concluded that Cu-Cr-TiC composite is a promising engineering materials for wear resistance applications.

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