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Synthesis and characterization of Cu – Cr Composite

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Copper composites reinforced with Chromium particles were fabricated by the Stir casting route. Copper (matrix) were melted (above $T_m = 1089^0C$) in a suitable furnace and after that Chromium powders were mixed mechanically with the help of stirrer. The copper- chromium composites were investigated using X-ray diffraction (XRD) and scanning electron microscope (SEM).A pin-on-disc wear testing machine was used to evaluate the wear rate, in which steel disc was used as the counter face. Loads of 10N, 20N and 30N and different RPM were employed.SEM analysis of the wear surfaces as well as the sub-surfaces are used to explain the observations made additionally, the results reveals that the maximum chromium incorporation was attained at 10% by weight. Actually, Cu with 10% chromium composite show better wear behaviors.

Keywords: XRD, SEM, RPM

1. Introduction

Cu-Cr composites are widely used to make electro contact materials. Due to Cu and Cr are immiscible, the Cr content of Cu-Cr composite for conventional melting and casting processes are usually not more than 25 mass%. Powder metallurgy (PM) is another conventional process for the production of Cu-Cr composites. Two processes are utilized to make contacts with PM methods: (i) By impregnation of chromium powders with copper or its alloy (ii) the sintering of a sample formed from a mechanical mixture of powders with present composition over a temperature range of solid phases or in the presence of a liquid-phase sintering (LPS).) In the present research we have made various sample with different composition like that 3% Cr 6% Cr, 10% Cr and rest are the % of Cu accordingly. Typically the sample of composite (Cu-Cr) are produced by Stir casting which involve number of steps like Mould preparation, melting and pouring and cooling. To finding Cu-Cr composite targets for applications requiring long-term stability and reliability, this work focused on synthesis and characterization of Cu-Cr composite and the effects of the microstructural features on the mechanical property were the main criteria also study about wear behaviour of that composite at different parameters. Also we have taken XRD and SEM of the samples. The XRD gives the idea about the planes of Cr and Cu which diffracted maximum light. The SEM gives images which provide what shape of Cr is dispersed into the Cu matrix. Moreover, the research carried out a series of experimental tests to explore the characteristics and effects of various advanced processes on the Cu-Cr composite's sample. Composite structures have shown universally a savings of at least 20% over metal counterparts and a lowest operational and maintenance cost .In this works it's shown that composite material is better than base metal in some places [1]. S.C.Sharma et al. [2] studied on an evaluation of the sliding wear behaviour of Sic particles reinforced copper alloy Composite materials. The composites are fabricated by liquid metallurgy technique. In this the SiC particles of size 50-100 p.m were used as the reinforcement. Phosphorbronze with chemical composition in weight % is given: Sn-18 to 20%, Pb-0.25%, Fe-0.25% and P-1.0%, rest of Cu was utilized as the base matrix alloy. It is found from the graphs that the wear rate of both the unreinforced alloy and the composite specimens increased with the applied load. The wear rate of each phosphor-bronze alloy/SiC reinforced composite reduced with increasing in the SiC content. S.Madhusudan et al. [3] studied on Fabrication and deformation studies on Cu-Al composite materials. The bath temperature is maintained at 720^0c. Kaczmar et al. [4] studied about Tribological properties of Cu based composite materials strengthened with AL_2O_3 particles. They had used Stir casting technique with of porous preform Al2O3 particles in copper matrix. Florin Stafanescu et al. [5] studied on the Practical Aspects Concerning the Solidification of Cast Metallic Composites. The graphite particles had introduced in the aluminium matrix to improve the wear properties of the matrix (friction coefficient losses by abrasion). Maksim antonovb et al. [6] studied on Comparison of the wear and frictional properties of Cu matrix Composites prepared by pulsed electric current sintering. The tribological properties had determined by dry reciprocating sliding ball-on-flat technique [7] usingUMT-2 versatile nano-micro tribometer operated at 1 N normal force at room temperature (25 °C) in air with a relative humidity of about 45%.

2. Experimental Details

2.1 Materials

Commercially pure copper (96.12%), chromium metal powder of 50 μm size were used for the preparation of Cu-

- Cr composites with different compositions.

2.2 Preparation of composite samples

Approximately1kg of Cu and Cr mix with different composition in the resistance furnace of stir casting setup. In my experiments I have prepared three sample which composition are given below Table 2.2.1

Table 2.2.1

Sample no	% of Cu	% of Cr
1	97	3
2	94	6
3	90	10

The following procedure are utilized for making samples. Which are given below

2.2.1 Expandable mould (sand mould).

2.2.2 Melting and Pouring.

2.2.3 Cooling and Solidification.

2.2.1Expandable mould (sand mould)

Sand casting is relatively cheap and sufficiently refractory even for steel foundry use. In addition the sand, a suitable bonding agent (usually clay) is mixed with the sand. Then mixture is mixed with water to to improving strength and plasticity of the clay. After preparing the green sand the mould cavity with the help suitable pattern are made by compacting the sand around pattern.

2.2.2Melting and Pouring

The equipment used for mixing and casting of composites is Stir casting set up. It is comprised of a cylindrical crucible of 150 mm diameter and 250 mm depth. The crucible was placed in a muffle furnace. The stirrer assembles containing of a graphite stirrer, which was connected to a variable speed vertical drilling machine (0 to 900 RPM) with the help of steel shaft. The stirrer included of three blades at angle of 120 degree apart. The melting of copper (matrix) is takes place in the crucible .when an appropriate temperature of melt is reached then pouring of chromium powder is takes place along with the sides of crucible with the help of hopper. Finally pouring of molten copper with chromium is takes place in the suitable prepared mould.

2.2.3 Cooling

The air cooling is takes place of a solidify copper – chromium composite material.

3. Characterization of the As-cast composite

3.1 Optical Microscopy investigation

The microstructures of sample were examined by optical microscope. In this experiment, three different sample of Cu-Cr composite was made from the Stir casting method by varying the Cr content from 3% Cr (by weight), 6 % Cr (by weight) and 10% Cr (by weight) and rest of the copper accordingly. The prepared samples were polished from 80C – 2000 grade emery paper and finally it was completed from cloth polishing with the help of diamond paste. The samples were etched by mixing of 100 ml of H_2O_2 (50 ml), NH_3 (25 ml) and distilled water (25 ml). The etched samples were immediately examined in optical microscopy.

3.2 SEM investigation

For morphological study, the metallogaphic specimens were prepared according to the standardtechnique and studied under SEM at the different magnification.

3.3 X-ray analysis

In Cu-Cr composite, the analysis of the different phase form from the solidification of the composite ingots was carried out from the XRD. X-Ray Diffractometer is an apparatus which use to measure diffraction angle 2θ with the position from rotated x-ray camera and diffracted beam gives the response of intensity. The intensity of diffracted beam versus diffracted angle is used for the calculating the of crystal structure of the sample by assuming the Bragg's law. The analyses were performed from the standard data given JCPDS (Joint committee on powder diffraction standards) file.

3.4 Wear testing

A pin-on-disc test apparatus was used to investigate the dry sliding wear characteristics of Cu-Cr composite with different content Cr as per ASTM G99-95 standards. The wear specimens (of cylindrical diameter 8mm and length 40mm) were machined form lathe machine and polished for metallographic examination. The tests were conducted for one hour at different loads: 20N, 25N and 30N at a sliding speed 2.0933m/s at room temperature. The initial weight of the specimen was measured in a single pan electronic weighing machine with a least count of 0.0001g. During the test the pin was pressed against the counterpart rotating against EN-32 steel disc by applying the load. A strain–gauged friction-detecting arm holds and loads the pin specimen vertically into a rotating hardened steel disc. The frictional traction experienced by the pin during sliding is measured continuously by PC-based data-logging system. After running through a fixed time period, the specimen were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. The difference in the weight measured before and after the test gives the wear of the specimen. The wear rates were determined using the weight loss method. The frictional forces are recorded by mechanical transducer/load cell. Although the frictional forces vary with sliding time, an average value for the analysis was considered. Each test was conducted for a constant load and speed for one hour and similar tests were carried out for different speeds and loads to investigate the tribological behaviour.

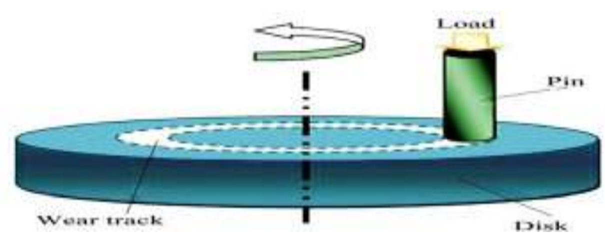


Fig. 3.5 Schematic diagram of abrasion wear test [8]

4. Result and discussion

4.1 Microstructure analysis

4.1.1 Optical micrographs

The maximum solubility of Cr in Cu matrix is approximately 0.89 wt. %. The microstructure of Cu-Cr alloy depends upon the percentage of Cr in the Cu matrix (phase diagram). According to the binary phase diagram of

Cu-Cr, the microstructure of as cast sample consist of bcc Cr-rich dendrites in an fcc Cu rich solid solution matrix with the content of Cr from 1.7 wt. % to 40 wt. %. The

The microstructures of the Cu-Cr composite with different Cr content are shown in Fig 4.1 (a) to (c). The white region represents a α-Cu solid solution and the gray regions represent a β-Cr in solid solution of Cu-Cr alloys. Chromium is located inside the copper matrix in the form of small discontinuous fibres. Their compositional data are shown in table 2.1

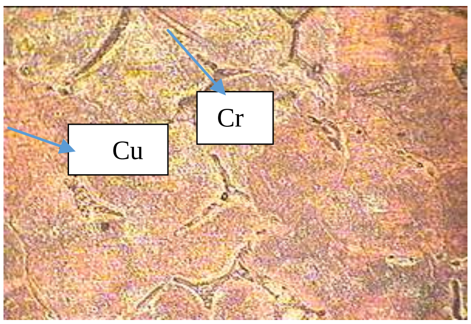
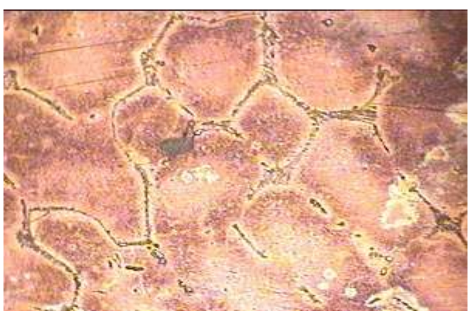


Fig 4.1 Microstructure of (a) Cu-3%Cr at 400X

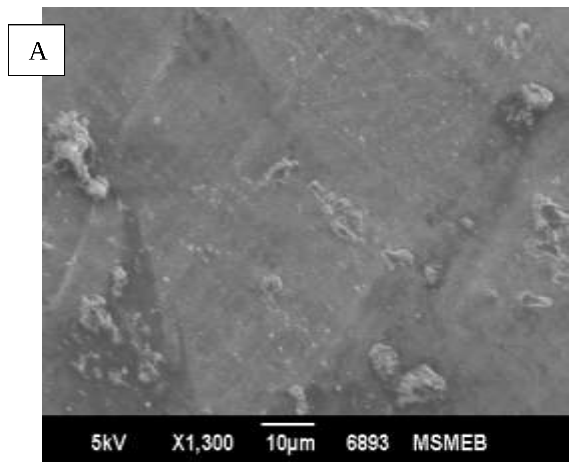


(b)Cu-6%Cr at 400 X

(c) Cu-10%Cr at 400 X

4.1. 2 SEM of composite sample

The SEM images of Cu-10% Cr sample at 400 X are shown in Fig 4.2 at different view angle. The dark region is α-Cu and white region shows β-Cr. The clear dendrites, grown in the direction of the solidification are seen in Figure 4.4 (A). The Cr phase in examined in Fig 4 (B) is seen in large patch form and segregated uniformly in the matrix. The shape of the granular of Cr-rich phase is changed by the addition of Cr in α-Cu matrix, as shown in Figure 4.3 and 4.4 at the different magnification.



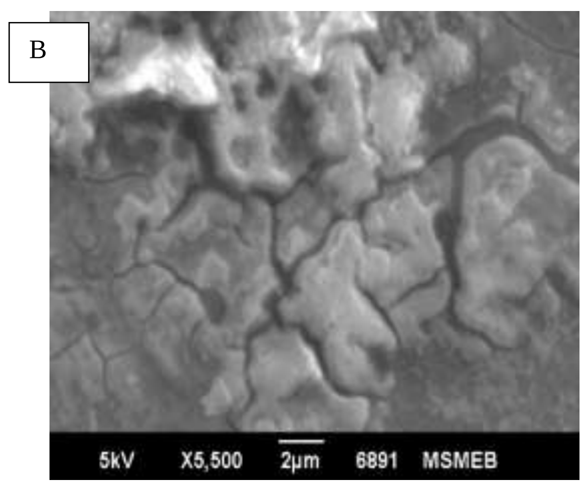


Fig 4.2 SEM images of Cu-10%Cr composite at 400X in different view angle

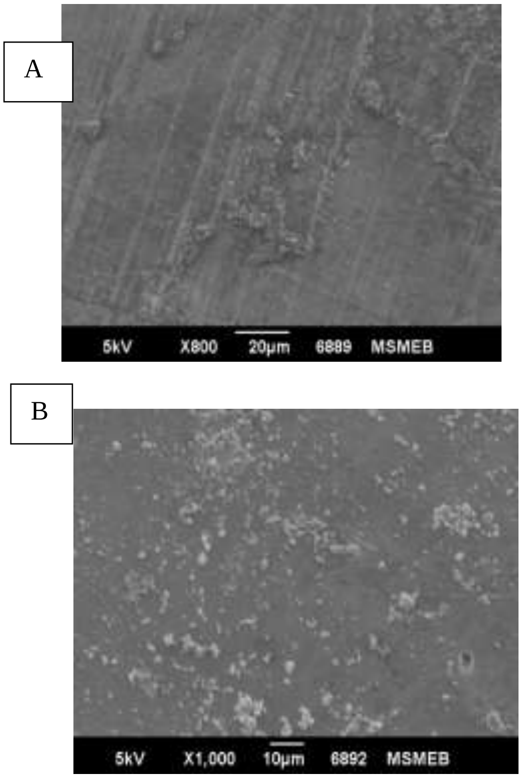


Fig 4.3 SEM images of Cu-6%Crcomposite at different magnification

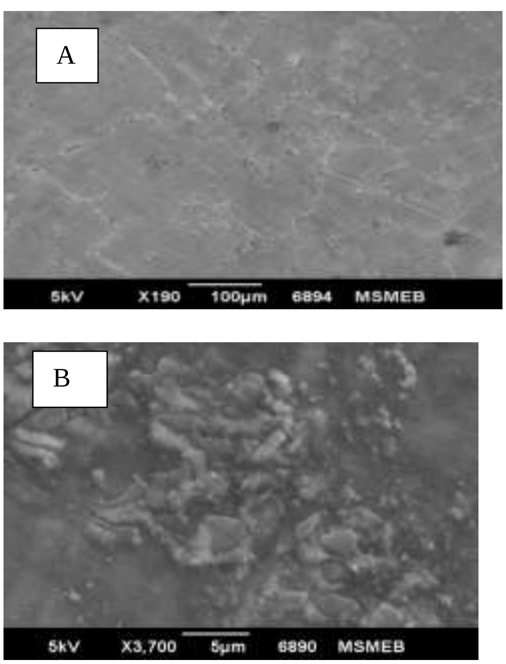


Fig 4.4 SEM images of Cu-3%Crcomposite at different magnification

4.1.3 XRD of samples

XRD analysis was conducted for the phase analysis of the cast composite samples. Fig 4.5, 4.6, fig 4.7 show the XRD micrograph of the cast composite samples with different composition like 3% Cr , 6% Cr , 10% Cr and rest of the Cu accordingly. In composite material samples, the different peaks of different planes are observed at the different diffraction angle. From the XRD analysis, the intensity of the peak increase with increase the Cr content matrix. In the shown figure, the major diffracted planes are appeared in the Cr (110), Cr (200) and Cu (111), Cu (200), Cu (220) respectively.

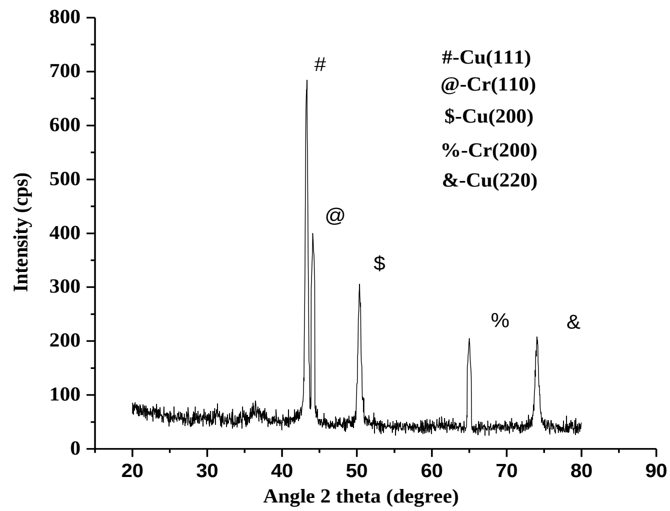


Fig 4.5 XRD pattern of Cu-3%Cr composite

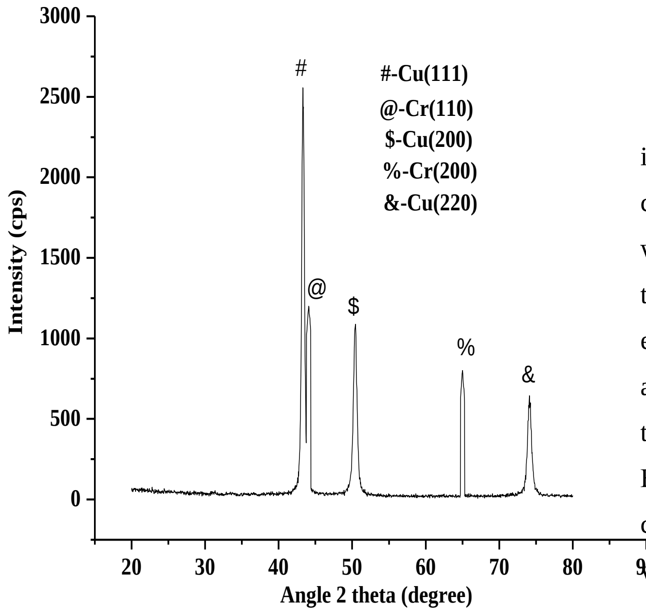


Fig 4.6 XRD pattern of Cu-6%Cr composite

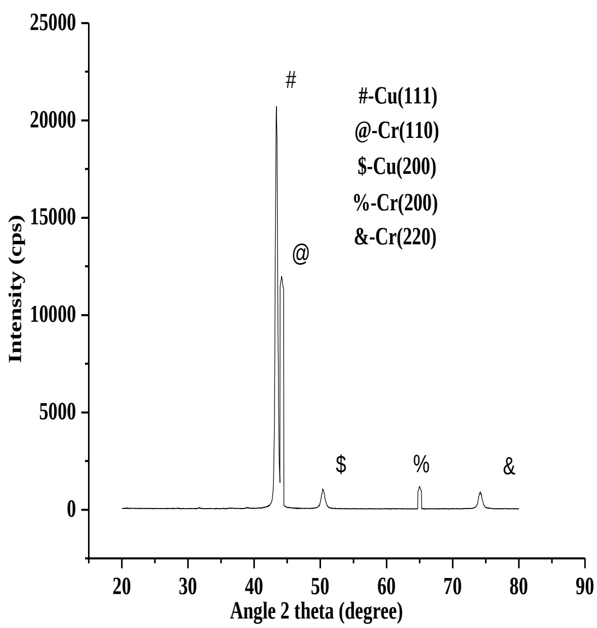
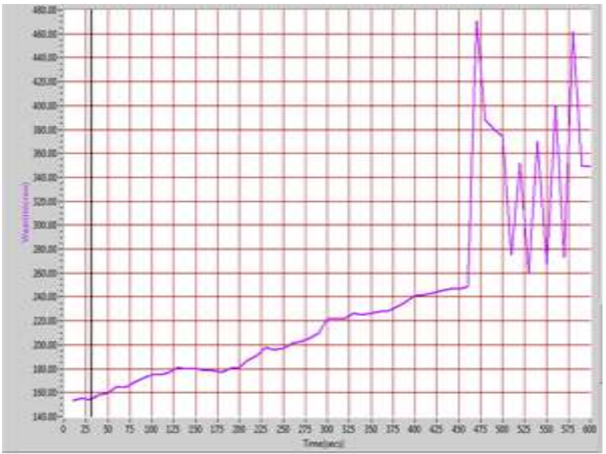


Fig 4.7 XRD pattern of Cu-10%Cr composite

5. Effect of Load and Sliding Speed on Wear Characteristic

5.1 Effect of sliding distance and load at constant RPM

The sliding wear of the composite is a complex process involving not only mechanical but also thermal and chemical interactions between two surfaces in contact. The wear resistance of composite materials is of characteristics that are very well applicable in automobile such as IC engines components, brake disc. The wear rate of as-cast and heat-treated hybrid composites had done on pin-on-disc technique to verify the wear resistance characteristics. Figure 5.1.2 (a) to (c) shows the wear rate of Cu−Cr composites with different volume fractions of Cr during wear test at an applied load of 10 -30 N. Figure 5.1.1 is the experimental curve found from the test investigation. The addition of reinforcement improves the critical transition values of applied load and wear resistance compared with the corresponding matrix alloy. The high wear resistance was attained in Cu-3 Cr whereas the least wear rate was found in Cu-10% Cr. This is due to formation of hard phase or transfer of load from the matrix to Cr-Particles accumulated at grain boundaries. However, the increase of volume fraction of Cr can also provoke clustering of the particles during the fabrication of the composite. The strength of particles/matrix interface is very important parameter since interfaces could be relatively weak due to interfacial reaction and poor wettability. The wear resistance of composite depends upon the strength of the reinforcement with the matrix, and it is continuously increasing with increasing the volume fraction of reinforcement.



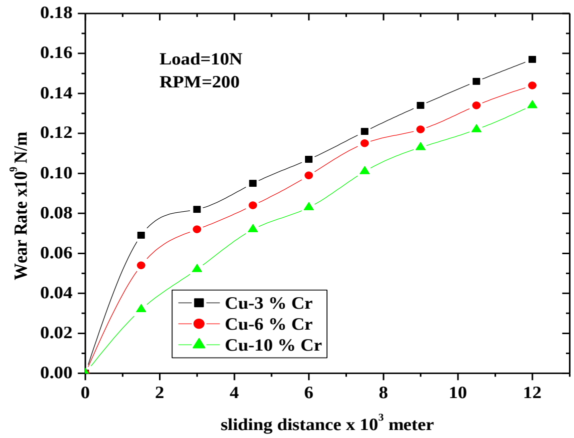
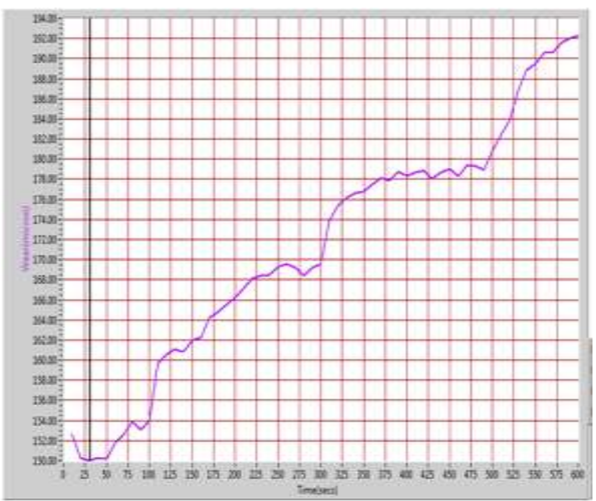
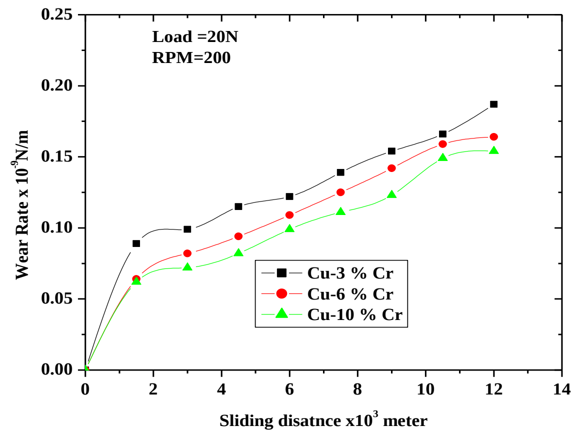
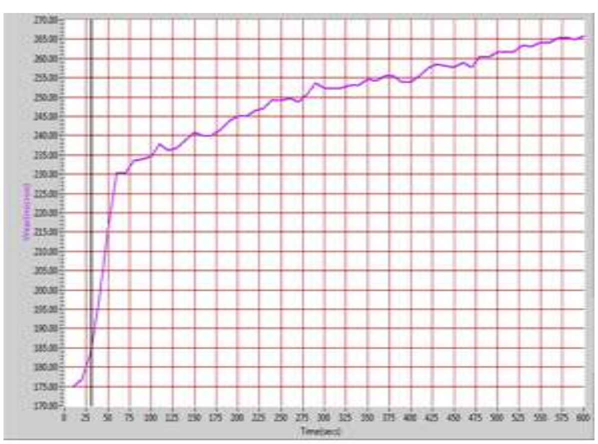


Fig 5.1.1 Wear (micron) Vs Time of (a) Cu-10% Cr

(b) Cu-6% Cr







(c) Cu- 3%Cr

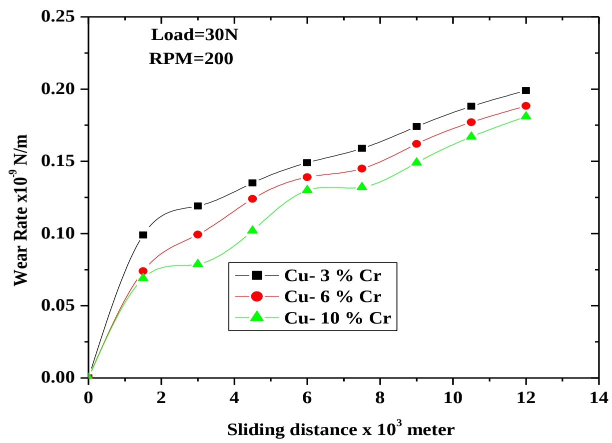


Fig. 5.1.2 Variation of wear rate with sliding distance

5.2 Effect of Load and Sliding Speed on wear characteristics

The effects of the sliding speed are also caused the deterioration of metal or alloy with the simultaneous effect of applied load. Their response is shown in Fig. 5.2.1 for Cu-10 % Cr. The effect of sliding velocity was discussed at 30 minute ribbing. The effect of sliding speed on the wear rate for all the composite are shown in Figure 5.2.2 (a) to (c) , in which the tests were conducted at constant load of 10N -30 N and sliding distance of 4500 m. The graph between specific wear rates Vs sliding velocity show that specific wear rate of composite increases with increase in the sliding velocity. From the figure 5.2.2 (a) to (c) it is clear that rate of increase of wear rate is initially high and decreases as the sliding distance increases. The specimen at Cu-3% Cr composite showed slight increase in wear, when compared with Cu-10% Cr specimen. It produced intense noise and seizing was observed during tests at sliding speed from 2.75 m/s to 3.23 m/s for as-cast material. But smooth running was observed with no seizing for higher percentage of Cr in the matrix. At lower sliding speed, the rate of formation of protective layer is fast on the pin surface because it properly reacts with oxygen. The analysis of wear derbies from XRD and EDAX analysis shows that the rubbing of the material is due to formation of the oxides layer on the surface. Initially the sliding speed increased, the quantity of fracture decreased due to formation of the protective layer are formed at the surface of the pin but this protective film is not stable at the higher sliding speed. The film starts to rupture because of the softening of the sample. The softening of the sample is due to continuously heating of the sample by continuously rubbing. As the percentage of reinforcement increases, it increases the area of fracture, which decreases the wear rate of the composites.

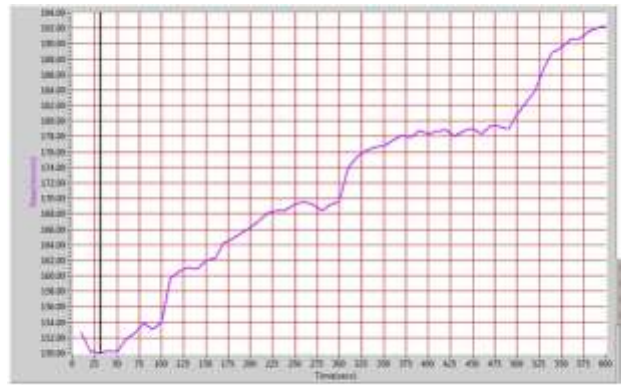
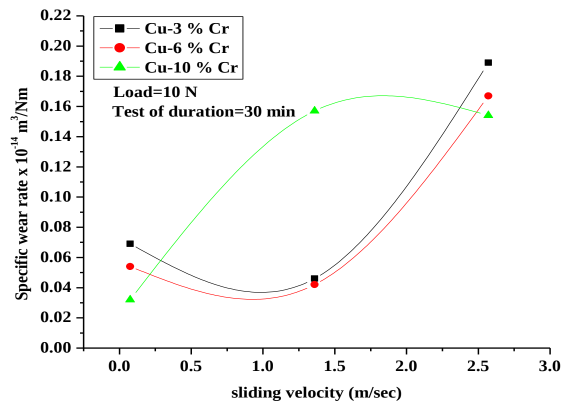
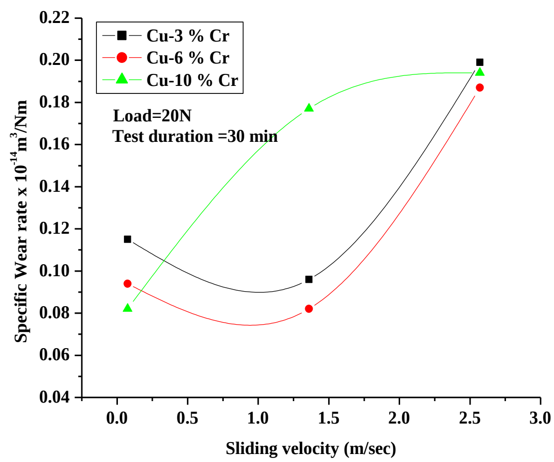


Fig.5.2.1 Wear (micron) Vs Time graph of Cu- 10%Cr





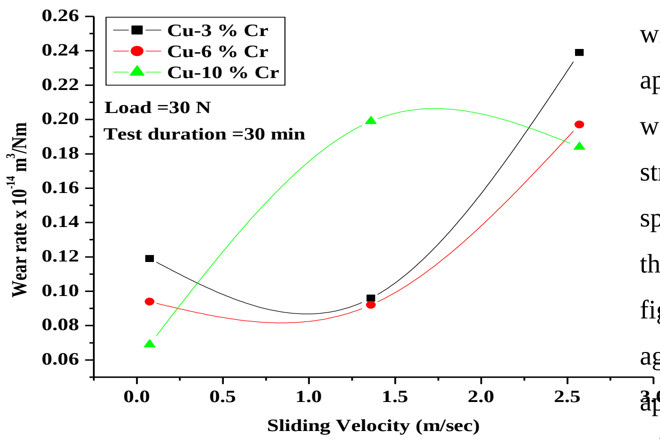


Fig.5.2.2 Variation of wear rate with sliding velocity

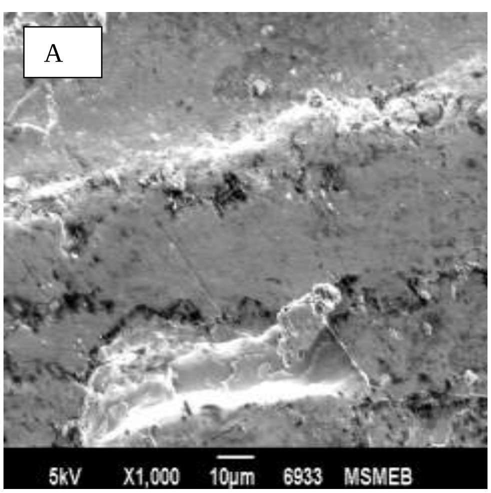
5.3 SEM images of worn surfaces

After the wear test performed on pin on disc apparatus the some selected specimens go for the Surface morphology of the composite at a SEM apparatus.Figure [5.3.1-5.3.3(a-c)] shows the surface morphology of composite which testing under the two different load and speed conditions. When the samples of Cu-10 % Cr is tested at slow speeds i.e. at sliding velocity of 300 rpm, in Fig. 5.3.1 (a), it shows that the cavities are formed in the composite matrix and also aligning parallel to the direction of sliding. Some particles also chipping off during sliding. With an increase in sliding velocity i.e. at 400 rpm, in Fig.5.3.1 (b), worn surface shows a different appearance because of delaminating of oxides from the test pin .In some regions there is aligning of substructures is taking place which parallel to the sliding direction. In some area, the smaller particulates have released from the composite matrix due to increment of the load from 10 N to 20 N. For the same composite, at same sliding speed of 400 rpm and with increasing applied load i.e. from 20 N to 30 N, cracks have appeared and are propagated in different direction. These are helped in chipping of hard particles i.e. red mud. In case of Cu-10% Cr composite samples tested under sliding velocity of 300 and 400 rpm, are shown in Fig.[5.3.2(a & b)]. From the figure it can be seen that with increasing the sliding velocity grooves have appeared [Fig. 5.3.3 (b)] where as at lower speeds, wave types structures is observed [Fig.5.3.1 (a)]. The structures of the worn surfaces are depended on the sliding speed and applied load conditions. The surface structures of the samples are shown in Fig. [5.3.3 (a-b)].Comparing these figures it can be observed that when the sample is rubbed against steel wheel, at low sliding speed and low applied load, the chipping off hard particles might be takes place and also the copper grains are grown into bigger sizes with increase in applied load i.e. from 10 N to 30 N, Fig. [5.3.1 (a-b)], the copper matrix polished along the direction of the sliding. Amount of cavitations also have increased. Some cavities appear to be formed around the hard particles (i.e. Cr- particulates). For the same composite the worn surfaces obtained at higher sliding velocity, (i.e.400 rpm), for two different applied load (i.e.10 N and 20 N) are shown in Fig. [5.3.2(a-b)]. The worn surfaces are relatively smoother than that of lower sliding speeds. It may be noted that cracks are formed parallel to the sliding direction. When the applied load is small, fragmentation of hard particles (i.e. red mud) occurs along the crack lines. With increase in applied load although the amount of cavitations appears to be low but deep cracks and grooves are clearly visible.

The wear mechanism involving plastic deformation, ripples layer, pulling out of particles at applied load has been seen and delimitation also progressed. At 30N composite surfaces exists more extensive grooving, this will be effect of plowing with harder asperity. During the sliding wear process, the Cu-matrix surrounding them was rapidly worn away and all the contact was essential between the Cr particles and the steel counterpart [9,10]. The sliding wear imposed a substantial tangential force on the Cr particles in contact with the counterpart and the resulting shear stress at the particle-matrix interface.

Generally increasing the contact pressure tends to increase the shear stress. At low loads, the shear stress was too small to debond or pull out the Cr particles from the Cu-matrix or deform the matrix plastically causing cracks. So the wear rate of composites was controlled by the wear rate of the more wear-resistant Cr phase. Thus the wear losses of the composites were mainly dependent on the level of the applied load and the weight percentage of Cr particles. This shows that the extent of the wear was reduced by the presence of Cr particles, because of the reduced driving force for the reaction between this Cr particles and the counter surface. The wear surface showed a predominantly adhesive wear at the lower load (small ripples with craters) and changes to a predominantly abrasive-adhesive wear at the higher loads (large smooth areas with long grooves.

Also there will be large plastics strains can be seen in the composite matrix which comes in direct contact with the steel counter face leads to subsurface crack propagation and subsurface delaminating. From the micrograph Fig. [5.3.3(a-b)], it can be seen that some cracks are formed at the grain boundaries of copper and its hard phase. This is due to strain hardening of copper during sliding with a applied load and because of pulling up of hard phase particles i.e. red mud from the copper grain boundaries. With increase in the applied load this effect is more visible. Reason behind this is due to embrittlement of hard particles during sliding



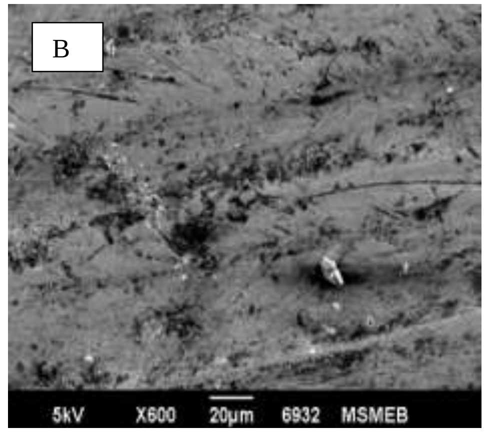
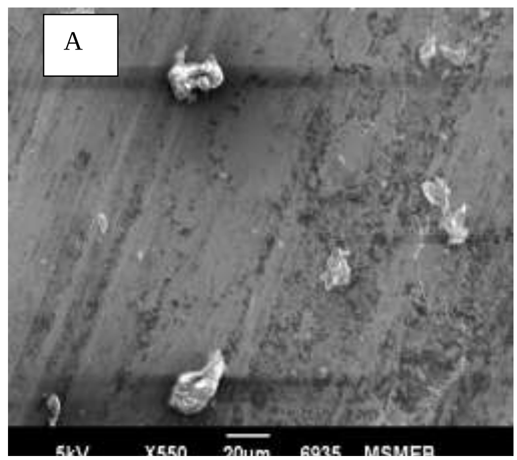


Fig. 5.3.1 SEM image of worn surfaces ofCu-3%Cr at 10N at (a) 300 rpm and (b) 400 rpm



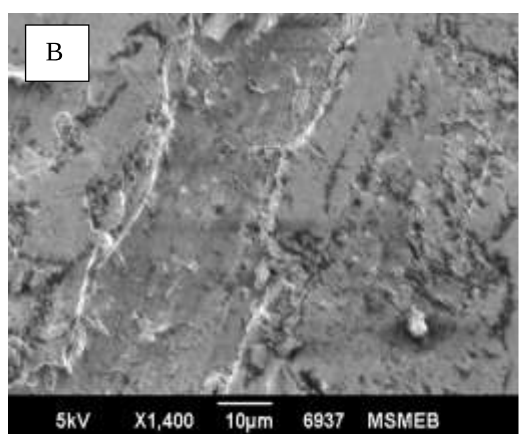


Fig.5.3.2 SEM image of worn surfaces of Cu-6%Cr at (a) 10 N and (b) 20N

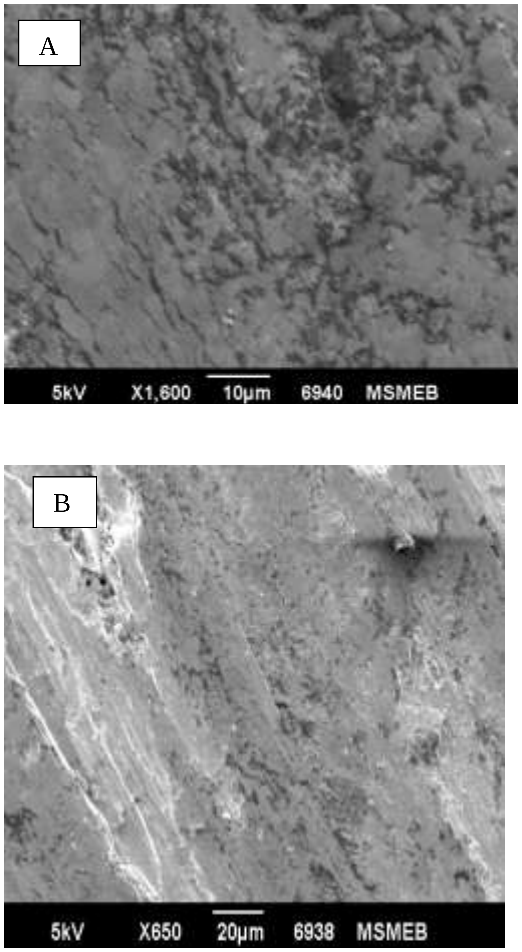


Fig. 5.3.1 SEM image of worn surfaces ofCu-10%Cr at 10N at (a) 300 rpm and (b) 400 rpm

4.7 Conclusions

1. Copper matrix composites have been successfully fabricated with uniformly distribution of Cr particles. Dispersion of Cr particles in Copper matrix improves the hardness and tensile strength of the matrix material and also the wear behaviour of the composite. The wear rate of the Cu-based hybrid composites is depending on the reinforcement and wear resistance was increased with the increase in the percentage of reinforcement.

2. From the microstructure analysis, it was observed that there is elimination of α-Cu and β-Cr phase. Also the dendrites of chromium phase are appeared by SEM images.

3. From the XRD analysis, it was observed that the intensity of peaks is increases with increasing chromium contents in the copper matrix.

5. The Cu- 10 wt. % Cr composites show good wear resistance, compared with 3 wt. % of Cr, 6 wt. % of Cr. Reason behind above statement is the increase in interfacial area between Copper matrix and Cr-particles leading to the increase in strength.

6. Alloy exhibits a sever wear rate by adhesion and in composites show no adhesion and abrasion wear was observed. At higher load and higher speed specific wear rate decreases with increases in Cr content. Wear coefficient tends to decrease with increasing particle volume content. It also indicates that red mud addition is beneficial in reducing wear of the Cu-Cr composite. Wear resistance of the composite increases due to addition of Cr- particles.

7. SEM analysis of the worn surfaces of the alloy which exhibits deep grooves cause more wear rate when compared with composites with finer grooves and surfaces appear to be smooth.

8. The reinforcements of hard Cr and smooth Cu matrix improve the tribological property of the material. However there exists an optimum filler volume friction which gives maximum wear resistance to the composite.

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