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Determination Of Wear Coefficient Of Deformed And Heat Treated Copper

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ABSTRACT

Since ages, copper and its alloys have found extensive applications in manufacture of bushes and bearings, heat transfer conductors, high conductivity electrical contactors and so on. However, currently, in all these applications, there is a significant enhancement in the service loads, wear resistance, conductivity thus forcing the material researchers to develop a newer class of copper based advanced materials. In this direction, researchers have focused their attention on improving the strength and the tribological properties copper.

This paper describes the results of dry sliding wear tests of copper subjected to different deformations and with different heat treatments, under constant applied pressures of 0.2 MPa and at constant sliding speed of 3.35 m/s and for a total sliding distance of 2000 meters. The wear behavior was studied using a pin-on-disc apparatus against heat-treated steel counter surface, giving emphasis on the parameter wear coefficient as a function of different deformations (20%-60%) and different heat treatments (below Rx, Rx & above Rx).Wear coefficient of the deformed copper at room temperature for both central normal plane and central rolling plane was noted to be significantly higher initially and then decreased with increase in degree of deformation but increases with increase in heat treatment temperature. Further, it is understood that, the wear coefficient values of central normal plane are slightly higher than that of central rolling plane, attributing that the central rolling plane has stronger wear resistance than central normal plane. It is also observed that the wear coefficient varies between 10^{-5} to 10^{-4}, signifying the entire wear process as mild wear, from which it can be concluded that the experimental values are in good agreement with the theoretically calculated value.

Key Words : Copper, Deformation, Heat treatment, Archard’s equation, Wear coefficient.

Introduction:

Pure copper has always attracted considerable interests in the Industrial applications because of its high electrical, thermal conductivities and good wear resistance. To understand the wear behavior of this copper, wear tests are often carried out with suitable mechanisms involved, for example, adhesive wear, is by far the most dominant form of material loss among sliding components in machinery [1]. The pin-on-disc test is a classical method commonly used for adhesive wear experiments. During the experiment, the sliding between the pin and disc may result in wear on both contact surfaces of the pair. To facilitate measurement, the pin is generally considered as it is the wearing member that has a lower hardness. Although weight loss and wear rate of specimens are to be considered, recent investigations [2,3] have found that wear coefficient is a better parameter to be used instead. This is because the wear coefficient has taken into account not only the wear rate (V/L), the applied load, but also the hardness of the wear pin or counter face which can affect the wear rate significantly. Although there are some concerns in using the wear coefficient as a wear parameter, as variations by an order of 10-1 were observed [4], such variations can be minimized if suitable precautions are taken.

An attempt has been made to deform the copper and subject it for different heat treatments to carry out the wear tests with a pin-on disc wear testing machine. The wear coefficient was calculated based on the Archard's equation for both the central normal plane as well as central rolling plane copper samples. The wear coefficient was noted to decrease with increasing degree of deformation and increases with increasing heat treatment and also found to be in the order of 10- 4 to 10-5 which can be concluded from the theory that the deformed and heat treated copper has underwent a mild oxidational wear only.

2. METHOD OF TESTING

50 mm dia. pure copper samples with aspect ratio 1.5 were subjected to 20%,40% ,50% and 60% deformations using a computer controlled servo hydraulic 300T (FIE-UTE Model) universal compression testing machine operated at a constant crosshead speed of 0.25 mm/sec. Care was taken in lubricating the end faces and also to keep the samples at the centre of the compression test.

All the deformed samples were cut into four quarters manually with a hacksaw. The first quarter was kept as it is. The other three quarters were subjected to heat treatments at 2000 C (below Rx), 2700 C (Rx) and 3500 C (above Rx) for about 2 hours.

2.1 EXPERIMENTAL PROCEDURE FOR DRY SLIDING WEAR STUDIES

Samples were machined from the central normal plane and central rolling plane areas of the quarter portions of the copper specimens that were subjected to different deformations and different heat treatments. Sliding wear tests were conducted on a pin-on-disc wear testing apparatus (model: TR20-LE, Ducom Make, Bangalore, India). The cylindrical copper pin samples (12 mm in diameter and 30 mm in length) were held against a heat treated EN 31 steel disc (confirming to AISI 52100) of hardness 62 HRc with surface roughness 1.6 Ra. During sliding, the load is applied on the specimen through cantilever mechanism and the specimens were brought into intimate contact with the rotating disc at a track radius of 100 mm .All the pins were subjected to running-in-wear under a constant applied load of 10 N, up to a sliding distance of 2000 m against the EN 31 steel disc at a fixed sliding speed of 3.35 m/s. In order to ensure effective contact of fresh surface with the steel disc, the fresh samples were subjected to sliding on emery paper of 240 grit size fixed on the steel disc. The samples were cleaned with acetone, dried and weighed (up to an accuracy of 0.001 gm using a DONA microbalance) prior to and after each test. The wear rate was calculated from the weight loss measurement and expressed in terms of volume loss per unit sliding distance.

Hardness has some influence on the wear behavior on any material. Hardness of the worn surfaces of the deformed as well as heat treated copper samples was measured using Rockwell hardness tester. In each sample, 4 indentations were taken and the average hardness value along with standard deviations reported. During hardness measurement precaution was taken to get the indentation at a distance of at least twice the diameter of the previous indentation.

Wear co-efficient was calculated with Archard equation. The wear damage on the specimens was evaluated via wear rate (micro metres) calculated. A complete wear micro structural characterization was carried out via scanning electron microscopy (JEOL JSM 5600). The wear tracks on the copper specimens were also investigated with optical microscopy.

3. Wear coefficient

Wear volume of a material as a function of hardness and applied pressure is expressed by Archard's wear equation [5]

$$Q = KW / H$$

where Q = volume removed from the surface by wear per unit sliding distance, H = indentation hardness of the softer surface, W= normal pressure applied between the surface, K = Archard's wear coefficient is dimensionless always less than unity. The value of K provides valuable means of comparing severity of different wear processes. For sliding wear of metals typical values of K for the mild wear of metals are 10 - 4 to 10- 6 while K becomes

10 - 3 to 10 -2 for severe wear.

4. Results and discussions:

4.1. Wear coefficient of copper - central normal plane

The wear coefficient of pure copper at different deformations and at different heat treatments as a function of deformation is shown in Fig. 1a. It is noted that the wear coefficient decreases with increasing degree of deformation. It is further noted that the order of wear coefficient varies between 10-5 and 10-4. In the copper subjected to different deformations (20%,40%, 50% & 60%) at room temperature, wear coefficient is found to be in the order as 7.495 x 10-5, 5.655 x 10-5, 5.113 x 10-5 & 4.648 x 10-5. Similarly when the same copper subjected to 20% deformation and heat treated at below recrystallization, recrystallization, and above recrystallization, the wear coefficient is found to be in the order of 9.09 x10-5, 1.349 x 10-4 & 1.516 x 10-4.

Similarly for 40% deformed copper subjected to below recrystallization, recrystallization, and above recrystallization, the wear coefficient is found to be in the order of 8.881 x 10-5, 1.205 x 10-4 & 1.45 x 10-4. Further for 50% deformed copper, subjected to below recrystallization, recrystallization, and above recrystallization, the wear coefficient is found to vary from 8.367 x 10-5, to 1.108 x 10-4 & 1.30 x 10-4. The copper subjected to 60% deformation and heat treatments at below recrystallization, recrystallization, and above recrystallization, the wear coefficient is found to vary from 7.059 x 10-5, 9.18 x 10-5 & 1.103 x 10-4.

It is to be noted from the above discussion, that the wear coefficient obtained for the copper for different deformations and heat treatments is varying between 10-5 to 10-4 and hence the wear mechanism can be attributed as mild or oxidational wear. Thus as per the consideration of earlier researchers, the copper is subjected to mild/oxidational wear even at higher deformations and higher heat treatment temperatures, as the tests are carried out at low loads. However, it is not physically meaningful to consider, mild wear at higher deformation and higher heat treatment temperatures, as was observed in the present study.

4.2. Wear coefficient of copper - central rolling plane

The wear coefficient of deformed and heat treated copper (below recrystallization, recrystallization and above recrystallization temperatures.) as a function of deformation at constant applied pressure and at constant sliding velocities is shown in the Fig. 2 b. It is evident from the figure that the wear coefficient decreases with increasing degree of deformation, but increases with increase in heat treatment.

In the copper subjected to different deformations (20%,40%, 50% & 60%) at room temperature, wear coefficient is found to be in the order as 6.711 x 10-5, 5.171 x 10-5, 4.764 x 10-5 & 4.39 x 10-5. It is interesting to note from the above that, when the copper is deformed at room temperature, the wear coefficient is found to be less and in the order of 10-5 .

When the copper is subjected to 20% deformation and heat treated at below recrystallization, recrystallization and above recrystallization temperatures, the wear coefficient is found to be in the order of 8.715 x 10-5, 1.04 x 10-4 & 1.203 x 10-4. Similarly when the copper is subjected to 40% deformation and heat treated at below recrystallization, recrystallization and above recrystallization temperatures, the wear coefficient is found to be in the order of 7.522 x 10-5, 8.715 x 10-5 & 1.012 x 10-4. When the copper is subjected to 50% deformation and heat treated at below recrystallization, recrystallization and above recrystallization temperatures, the wear coefficient is found to be in the order of 6.798 x 10-5, 8.358 x 10-4 & 1.004 x 10-4. When the copper is subjected to 60% deformation and heat treated at below recrystallization, recrystallization and above recrystallization temperatures, the wear coefficient is found to be in the order of 5.371 x 10-5, 7.408 x 10-4 & 8.993 x 10-5.

Considering the recommendation of earlier researchers, the order of magnitude of wear coefficient obtained in the present study signifies that mild or oxidational wear is operating on the copper subjected to different deformations and different heat treatments.

Comparison of Fig. 1a and 1b, states that the order of magnitude of wear coefficient of copper for the central normal plane and central rolling plane is noted to be same (10-4 to10-5). But the copper subjected to different deformations at room temperature exhibited higher values of wear coefficient than copper heat treated at above recrystallization temperatures. The comparison between the central normal plane and central rolling plane, demonstrates that the deformed copper as well as heat treated ones follow similar behavior. But it is understood that, the wear coefficient values of central normal plane are slightly higher than that of central rolling plane, attributing that the central rolling plane has stronger wear resistance than central normal plane.

Wear phenomena and transitions in wear mechanism over wide ranges of load and sliding speed was first adopted [6] in studies of the sliding wear of mild steel. It has been proposed by these investigators [7–9] that the ranges of normalized wear rate or wear coefficient [10,11] are for different wear mechanisms for mild and severe wear are 10-4 to10-6 and 10-3 to 10-2, respectively. In the present study normalized wear rate for the investigated material under different deformations and at different heat treatment temperatures were calculated and it is found to decrease with increasing degree of deformation and the wear coefficients [10] were also getting to be in the range of 10-4 to 10_5. However, it was found that within the constant applied load and constant sliding speed, the normalized pressure _F of the investigated materials comes to be almost 1, which is a good agreement with the theoretical value of _F. Thus there is a possibility of transition of different wear mechanism from one to the others within the constant applied load and constant sliding speed. In the present study the wear coefficient of the order of and 10-4 to10-5 is considered as mild wear, taking strong support from worn surfaces observation of SEM analysis. The wear rate as a function of applied pressure in case of sliding wear is expressed by Archard [12] law of wear equation, which states that the wear rate increases linearly with increasing sliding distance. This is primarily due to the fact that with increase in sliding distance, the penetration of hard asperities of the counter surface to the softer pin surface increases and also the deformation and fracture of asperities of the softer surface increases. Again, on the other hand more amount of softer material from the pin surface get accumulated at the valleys between the asperities of counter surface resulting in decrease in asperity height of the counter surface.

4. Conclusions

From the experimental results, the following conclusions can be drawn:

(1) Wear coefficient decreases with increasing degree of deformation (20% to 60%) and increases with increase in heat treatment temperature (below recrystallization to above recrystallization).

(2) Wear coefficient values of central normal plane are higher than that of central rolling plane, attributing that the central rolling plane has better wear resistance, a similar phenomenon that was observed with wear rate.

(3) The wear coefficient varies between 10-5 to 10-4, irrespective of the deformation and heat treatment, which can be considered as mild oxidational wear by taking also the strong support from the worn surfaces of copper pins.

(4) The surface hardness values of the deformed as well as heat treated copper samples from the central normal plane are lower than that of central rolling plane, attributing that the central rolling plane has high wear resistance.

(5) From the SEM observations it is inferred that at lower deformation (20%), the wear surface is characterized by the formation of deep continuous grooves, cracking along the transverse and longitudinal direction and also formation of equiaxed debris and mixed wear debris. But it is observed that at higher deformation (60%), formation of continuous grooves and some damaged regions were observed only on worn surfaces.

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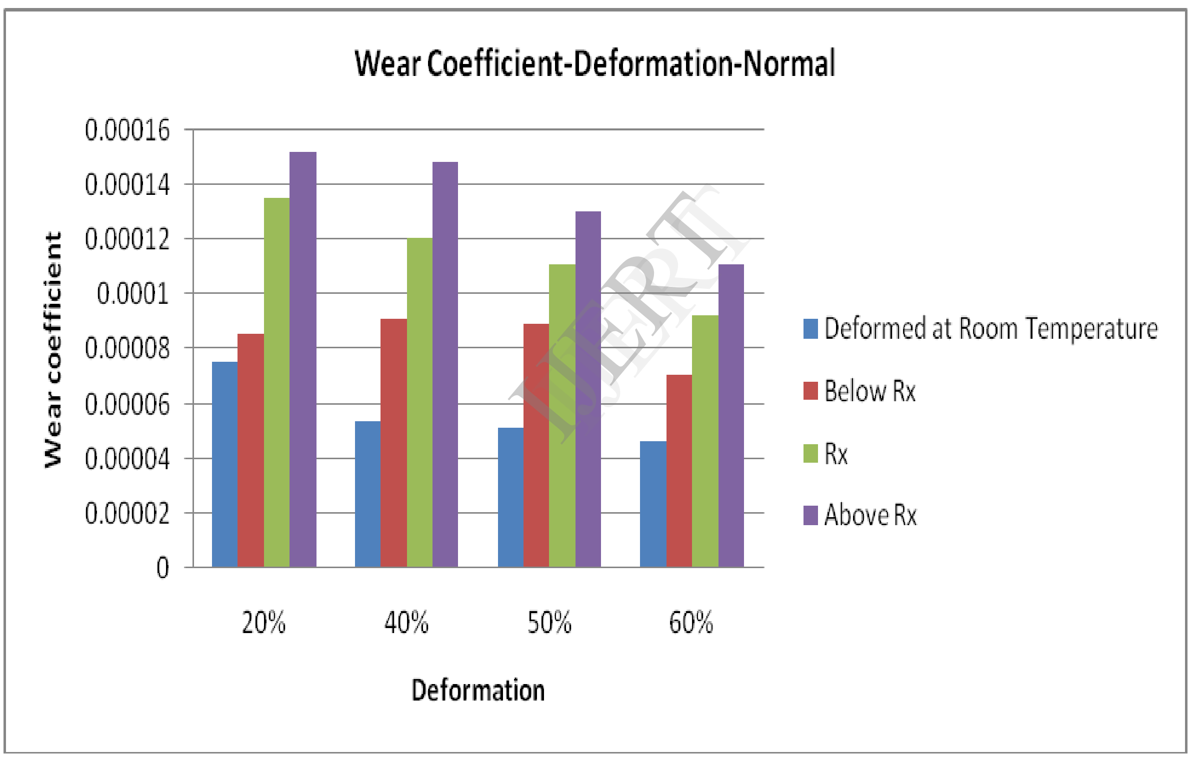


Fig. 1 a shows variation of wear coefficient of central normal plane with deformation

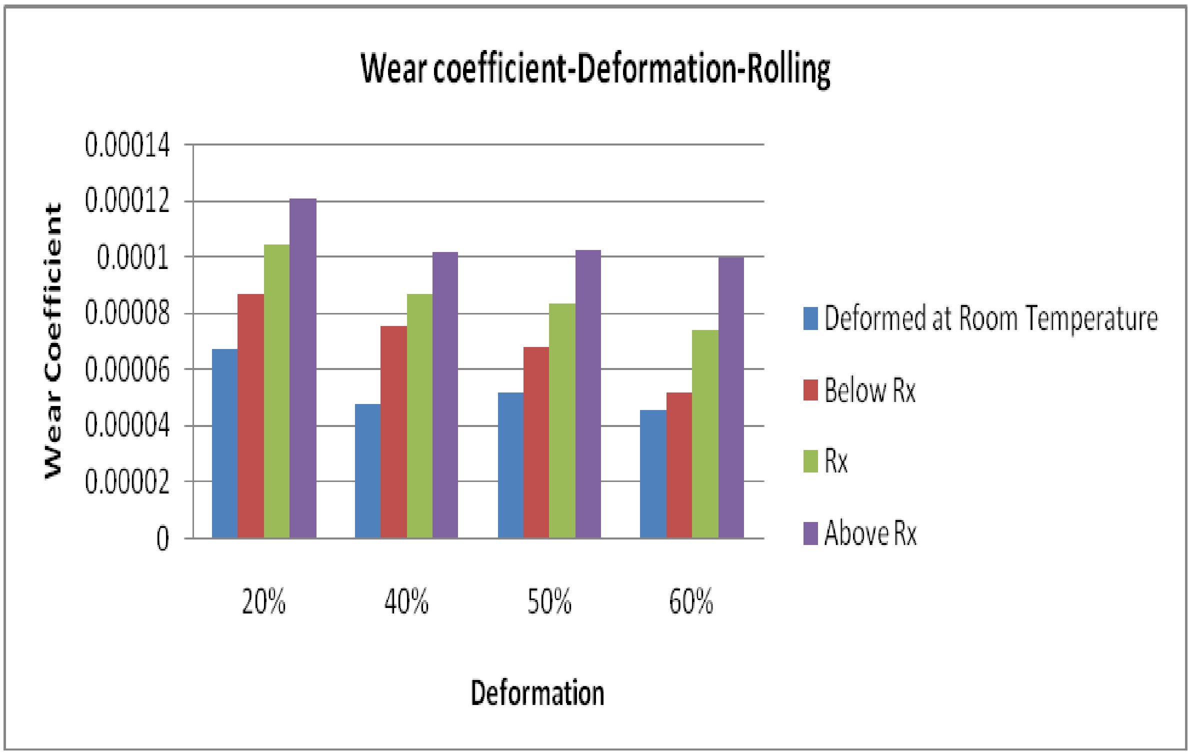


Fig. 1 b shows variation of wear coefficient of central rolling plane with deformation

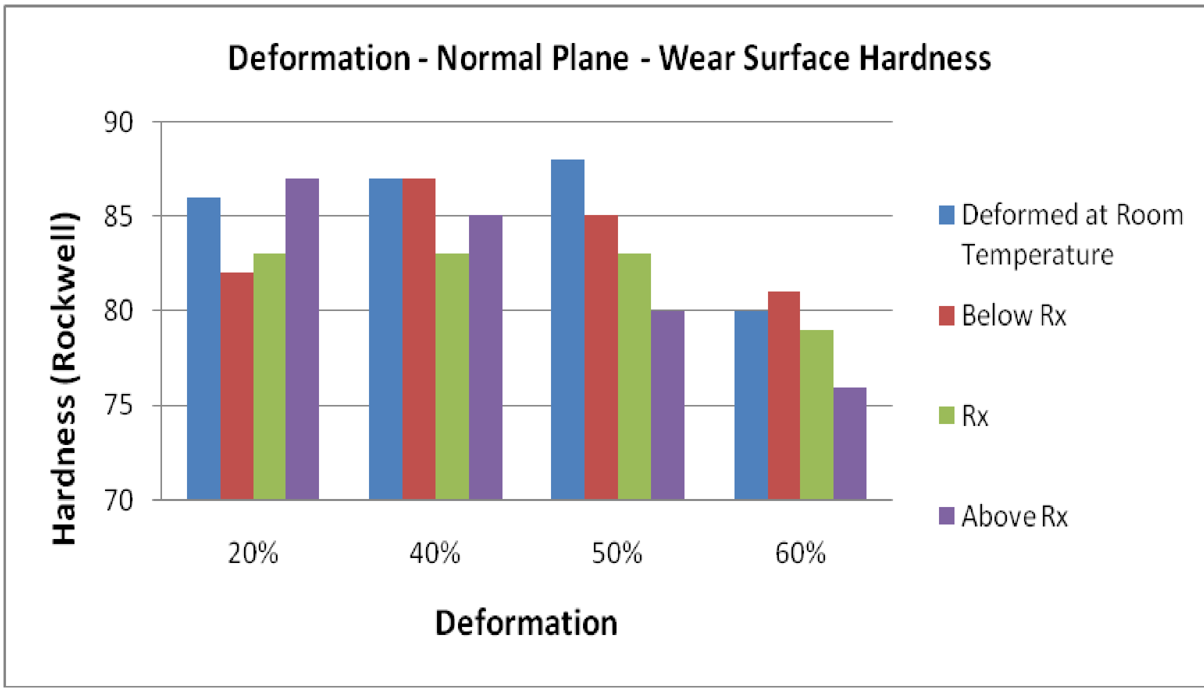


Fig. 2 a shows variation of Hardness of central normal plane with deformation

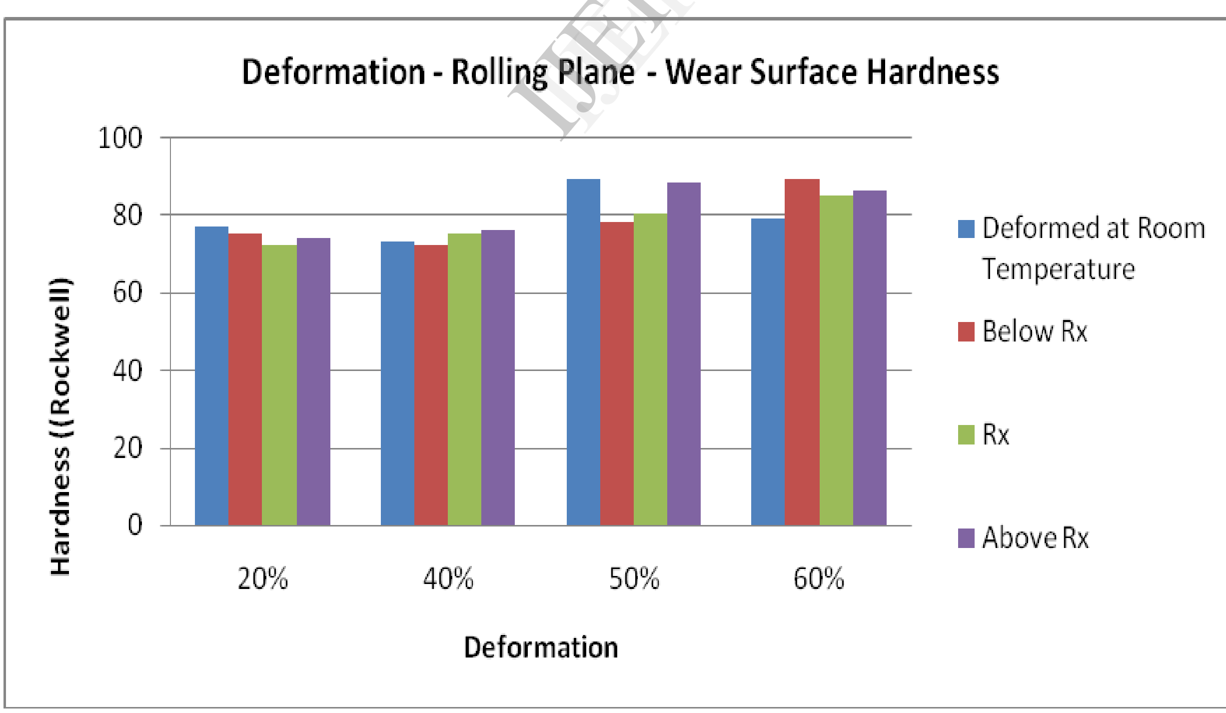
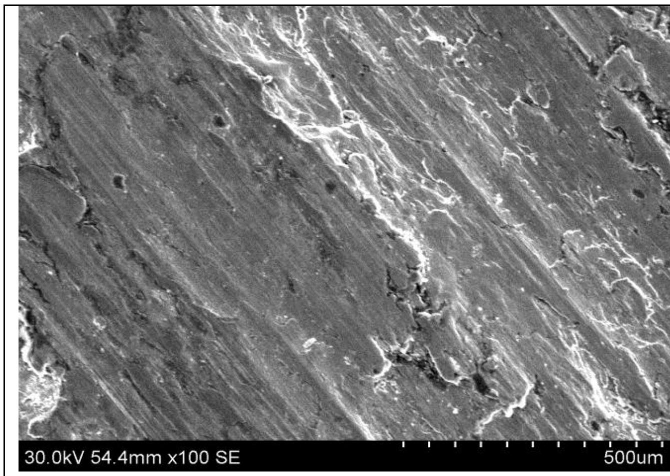
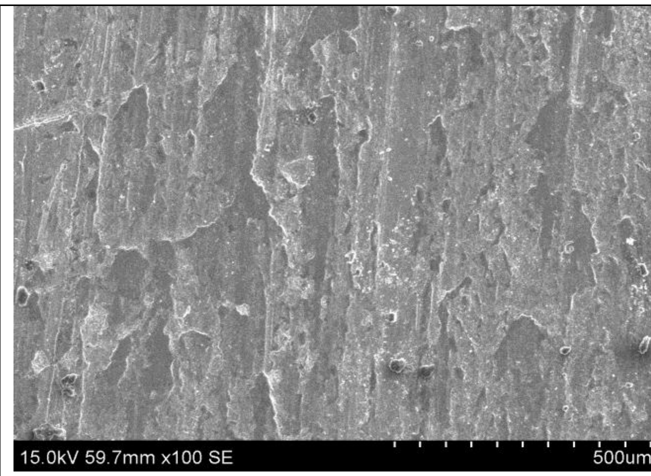


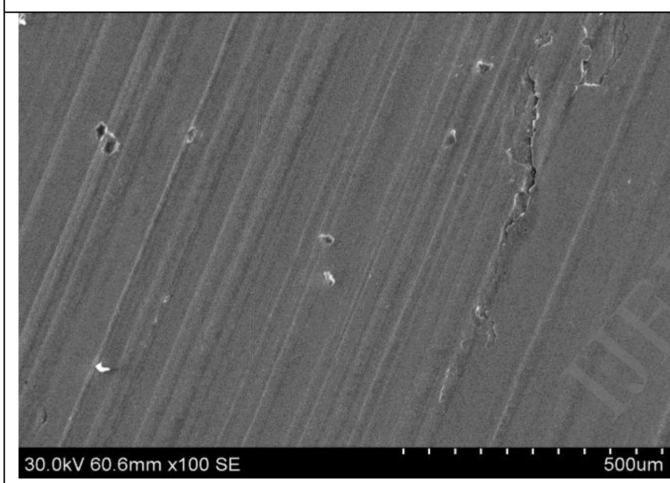
Fig. 2 b shows variation of Hardness of central rolling plane with deformation



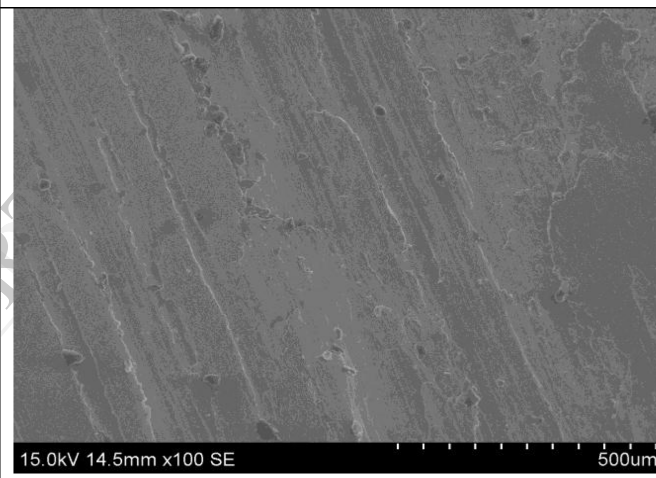
Normal Plane - Copper-20% Deformed at room temperature



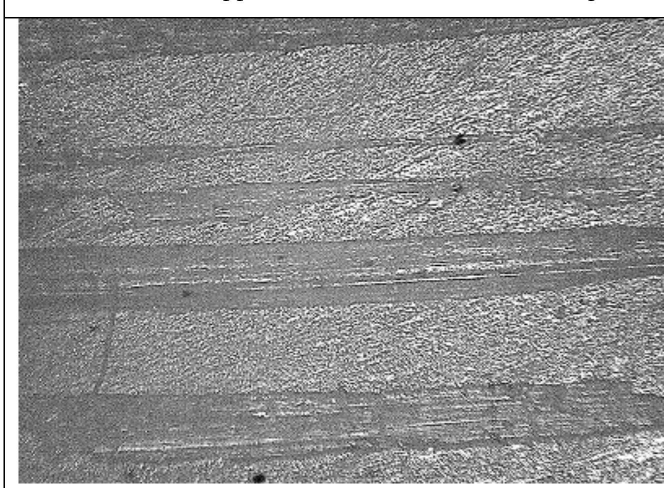
Normal Plane - Copper-40% Deformed at room temperature



Normal Plane - Copper-50% Deformed at room temperature



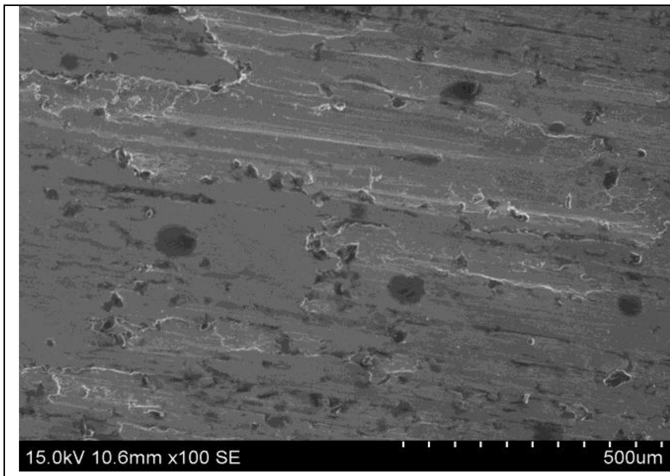
Normal Plane - Copper-60% Deformed at room temperature



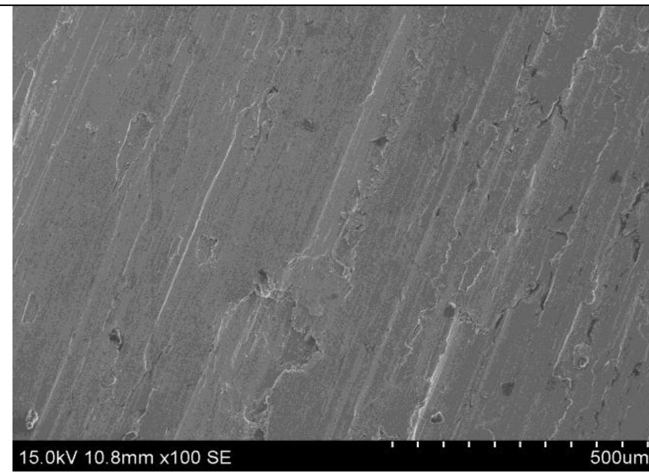
Wear track of En 31 steel disc – Micro Photo graph

Wear track of En 31 steel disc – Micro Photo graph

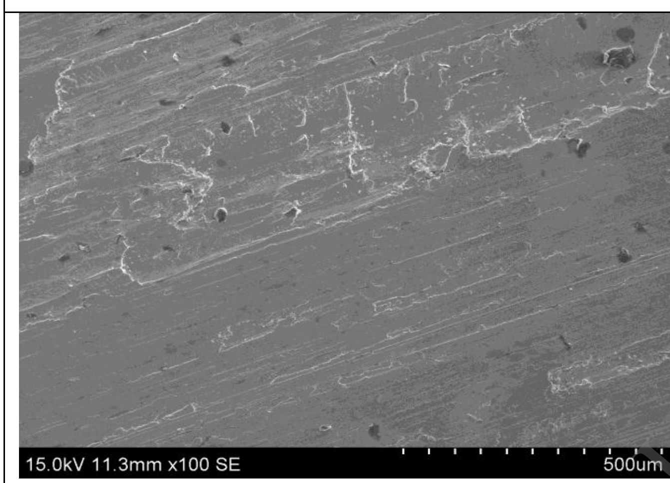
Worn surface SEM and micro photo graphs of copper pins from central normal plane



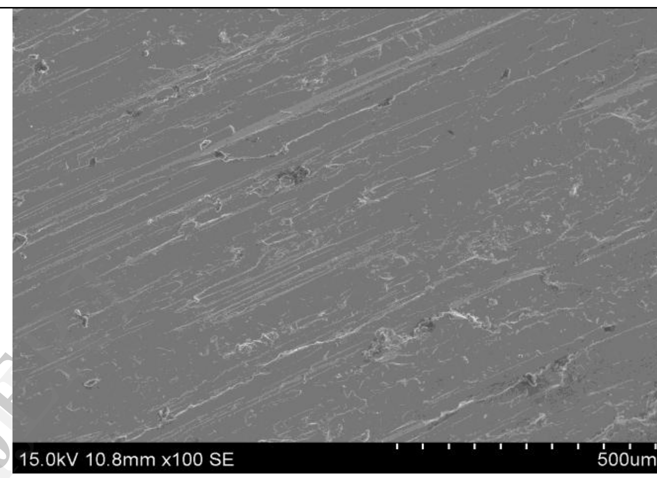
Rolling Plane - Copper-20% Deformed at room temperature



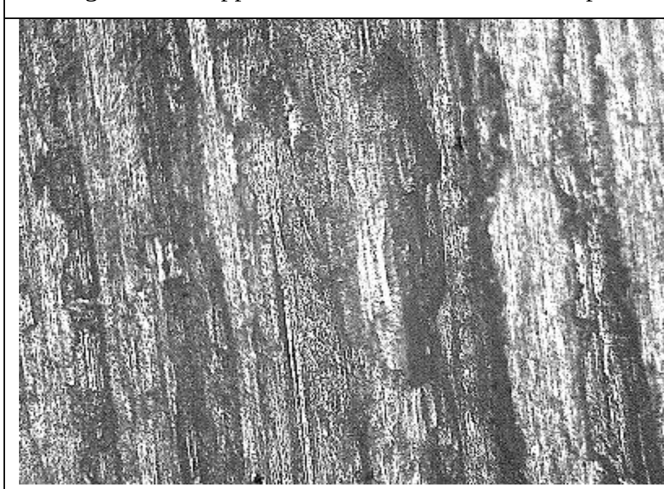
Rolling Plane - Copper-40% Deformed at room temperature



Rolling Plane - Copper-50% Deformed at room temperature



Rolling Plane - Copper-60% Deformed at room temperature



Wear track of En 31 steel disc-Micro photograph

Wear track of En 31 steel disc- Micro photograph.

Worn surface SEM and micro photo graphs of copper pins from central rolling plane