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Effect of ageing treatment on wear properties and electrical conductivity of Cu–Cr–Zr alloy

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Abstract. **In this study, the effect of ageing processes on the wear behaviour and electrical conductivity was investigated. Prior to solid solution heat treatment at 920°C and ageing at 470°C, 500°C and 530°C for 1 h, 2 h and 3 h, respectively, the prepared samples were homogenized at 920°C for 1 h. After the ageing processes, all samples were characterized in terms of electrical conductivity, scanning electron microscope (with energy dispersive X-ray spectrum (EDS)) and hardness (HV5). In wear tests, pin-on-disc type standard wearing unit was used. As a result, starting from 1 h aged specimens, orderly increase of electrical conductivity was defined. From EDS analyses it was observed that Cr rate increases as precipitates grow. With increase of Cr rate there was also a defined rise of electrical conductivity. From the wear tests, it was observed that the least wear loss was in Cu–Cr–Zr alloy aged at 500°C for 2 h and the most wear loss was in specimens aged at 530°C for 2 h. Furthermore, it was observed that the friction coefficient values resulting from wear rate were overlapped with hardness results and there is a decrease tendency of friction coefficient as wear distance increases.**

Keywords. **Cu–Cr–Zr; wear; ageing treatment; electrical conductivity.**

1. Introduction

Cu–Cr–Zr alloys are used in applications in many industrial areas, mostly in automotive sector, because of their high electrical and thermal conductivities (Durashevich *et al* 2002; Liu *et al* 2005; Li *et al* 2007). Along with electrical and thermal characteristics, it is also possible to improve mechanical characteristics of these alloys. However, it is difficult to improve the characteristics of these alloys with traditional heat treatment methods. Ageing treatment is one of the most important methods that increases mechanical characteristics of copper alloys without decreasing their conductivity characteristics (Liu *et al* 1999; Holzwarth *et al* 2000; Su *et al* 2007). Dispersion and size of second phase particulates that are formed by ageing in Cu–Cr–Zr alloys are the most important factors that increase the strength and hardness of the alloy (Nagarjuna *et al* 2001; Qi *et al* 2003). In some researches, it is emphasized that in over-saturated matrix, second phase particulates which are Cr-rich, compatible and thin-dispersed provide high resistance and particulates coarsened because of over-ageing in parallel with ageing temperature and time form a incoherent inter surface and affect resistance negatively (Fujii *et al* 2000; Tu *et al* 2002).

Cu alloys are ductile type alloys whose wear behaviour is similar to that of other ductile type materials like Al. As research results show that the second phase provided in the ageing conditions increase the materials resistance and improves wear characteristics (Rigney 2000; Yildiz *et al* 2007; Yaşar *et al* 2009). Damages occurred because of over-deformation on sample contact surface in Cu–Cr–Zr alloys at the time of wear tests can be explained with different wear mechanisms such as oxidative, abrasive and adhesive based on the applied load and sliding speed (Qi *et al* 2003; Straffelini *et al* 2005). In this study, to increase resistance and electrical conductivity of Cu–Cr–Zr alloys and to increase the optimum resistance/conductivity values, ageing heat proceeds have been applied. In experimental studies, determining the effect of particulates that are formed in the ageing on electrical conductivity and wear resistance was aimed.

2. Materials and methods

Cu–Cr–Zr alloy which is used in this study, and contains 0·65% Cr and 0·07% Zr was taken from De Le Bronze Industrial firm. Samples were fast-cooled after being taken for solution at 920°C for 1 h in argon atmosphere. Water quenched specimens were aged at 470°C, 500°C and 530°C for three different periods (1 h, 2 h and 3 h) and cooled in an electric resistance furnace at room temperature. Electrical conductivity was measured in

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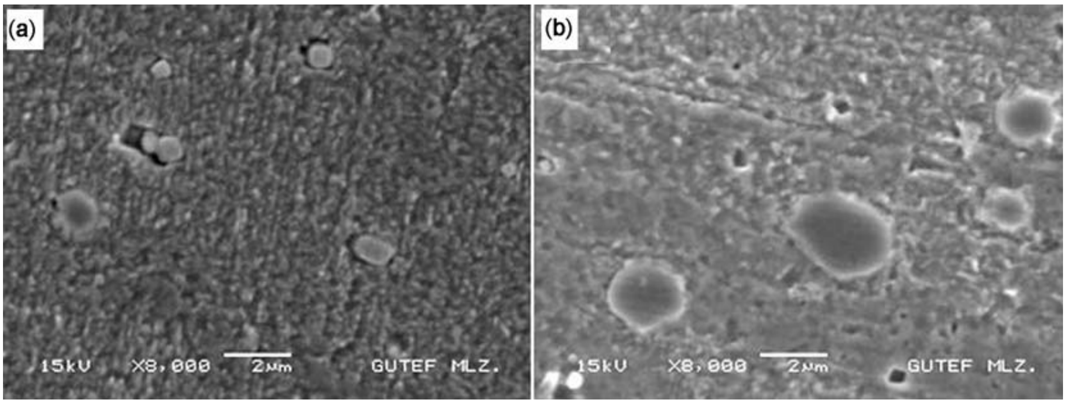

Figure 1. SEM images of non-aged (**a**) and aged at 500°C for 2 h (**b**) Cu–Cr–Zr alloy.

Solartron 1296 Elektrik interface, SI 1287 Elektrochemical interface. For microstructure analyses, samples were prepared with standard metalographic processes and etched for 30–60 sn with 50 ml ethanol, 1 ml HF, 8 ml HNO_3 and 4 ml HC1. Prepared specimens were examined with JEOL JSM-6060 scanning electron microscope (SEM). Hardness measurements were carried out in (HV5) AFFRI universal hardness measurement device. Wear tests were carried out in pin-on-disk type wear testing device. For wear tests parameters used were 45 N load, four different wear distances (250, 500, 750 and 1000 m) and 2 m/s sliding speed. A steel disc (AISI 4140) with 56 Rc hardness, ϕ 230 mm size and 20 mm thickness was used for the tests. The surfaces of all samples were smoothened with 1200 grid emery and were cleaned with acetone. Occurred material loss was defined by comparing specimen masses after wear tests with their original masses. Wear rate was defined by measuring mass loss of alloy at the end of every sliding distance. Wear surfaces of specimens were analysed with SEM.

3. Results and discussion

3.1 *Microstructure characterization*

Electrical conductivity and wear behaviour of Cu–Cr–Zr alloy at a larger rate depend on the ageing condition of alloy. Dimension of precipitate formed in microstructure by wear depends on wear temperature and period. Wear started forming Guiner–Preston (GP) parts at low temperatures, when at higher temperatures transforms into over-ageing with causes precipitate coarse. Figure 1 shows SEM images of non-aged (figure 1a) and aged (figure 1b) at 500°C for 2 h Cu–Cr–Zr alloy.

The SEM images (figures 1a, b) of Cu–Cr–Zr alloy show that in microstructures of both precipitate and specimens aged at 500°C for 2 h, there are precipitates and hexagon-shaped particulates formed with ageing. From EDS analysis carried out in SEM, Cr-rich parts formed inside the Cu matrix that grow by effect of ageing

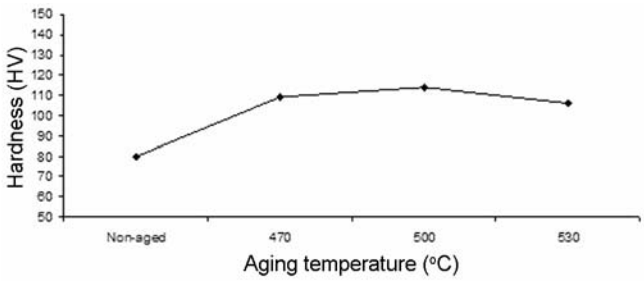

Figure 2. Hardness changes of aged Cu–Cr–Zr alloy at different temperatures and periods.

(Tu *et al* 2002). With an increase of ageing temperature, there is a decrease in hardness of alloy due to the effect of increase occurred in precipitates (figure 2).

In figure 2, effect of ageing temperature on Vickers hardness of alloy is seen. As hardness of Cu–Cr–Zr alloy which was 80 HV before the ageing treatment was compared with hardness value taken after thermal treatment, an increase of hardness in an evident form is appeared. In a study made earlier (Qi *et al* 2003), it was found that the reason for ageing endurance of Cu–Cr–Zr alloy was (Heusler phase) homogeneous dispersion of semi-stable and complex intermetallic precipitates occurred in the structure. GP parts and over-ageing are formed in the structure with ageing affecting the endurance and hardness of the alloy. Ageing at low temperatures, provides formation of GP parts and at high temperatures decreases endurance and hardness of material because of over-ageing. A study made by Su *et al* (2005) also supports these results. Hardness increase occurred in Cu matrix can be explained by Orowan mechanism.

$$\Delta\tau = kf^{1/2}R^{-1},$$

where $\Delta\tau$ is the increase in shear stress, k a constant, f the volume fraction of precipitates and R the diameter of precipitates (Su *et al* 2005). Volume fraction of precipitates with small diameter increase the value of $\Delta\tau$ and higher hardness values are obtained. Furthermore, this condition is also explained by dislocations formed in the structure with ageing and occurred through precipitates and resistance of dispersion obtained with precipitates formation. In another study made earlier, it was found that hardness value reached the highest point when ageing done at 500°C (Vinogradov 2002). EDS analysis shows that precipitates formed in microstructure with ageing thermal treatment are Cr-rich parts (57% Cu and 41% Cr). It was observed that Cr rate increases as the dimension of Cr-rich precipitate formed at 2 h ageing thermal treatment grows.

3.2 *Electrical conductivity*

Cu alloys are widely used at industrial fields because of their high electrical conductivity. Hence, in this study electrical conductivities of Cu–Cr–Zr alloy were measured before and after ageing. In table 1, changes of electrical conductivity measured on the basis of ageing temperature and period of Cu–Cr–Zr alloy are given.

As seen in table 1, the highest conductivity value was obtained in specimen aged at 530°C for 3 h. From figure 2, hardness results, it is observed that in materials included into over-ageing period a slight increase in conductivity continues when a decrease in hardness occurs. This is because hardness is growing parallel to ageing period and Cr-rich particulates in Cu matrix (Tu *et al* 2002). Ageing and second phase particles that occurred in the structure increases the strength in the crystal lattice. This increase in strength causes distortion and decreases the electric conductivity. However, due to the increase of Cr rate on the stages (the growth of precipitates), there will be an increase in the electric conductivity. Distortion that happens in the lattice because of second phase particles that are formed in the structure by ageing and two different mechanisms that compensate each other with the increase in the Cr rate during the growth of the precipitates will occur. Hence, there is an increase in both the growth of precipitates and electric conductivity. Precipitates in Cu matrix because of Cr-rich coarse phases and a decrease in electrons scattered on the surfaces provide a contribution to an increase in electrical conductivity. In a study done by Su *et al* (2005), it is emphasized that Cr-rich parts formed through the piece, border increase the hardness and electrical conductivity. Hence obtained hardness and electrical conductivity results in this study show similarity with the results of study made by Su *et al* (2005).

Table 1. Electrical conductivity (IACS %) values according to ageing temperature and period.

Ageing temperature (°C)	Ageing time (h)	Electrical conductivity (IACS %)
Non-aged	–	81·25
470	1	68·7
470	2	72
470	3	76·5
500	1	72·26
500	2	75·26
500	3	80·79
530	1	77·03
530	2	79·6
530	3	89

3.3 *Wear tests*

In figure 3, Cu–Cr–Zr alloy aged at different temperatures for 2 h and wear losses obtained in steel consisted tribo-system in 45 N load and various sliding distances are given. According to wear loss results (figure 3), effect of ageing temperature on wear endurance of alloy is seen.

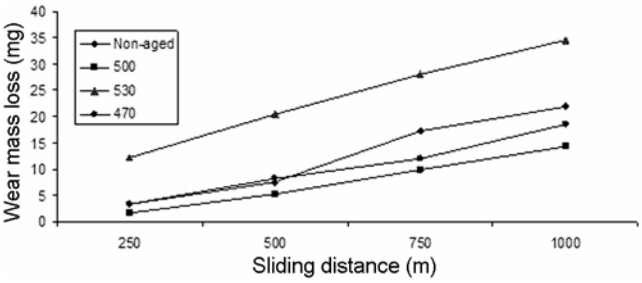

Figure 3. Wear losses occurred under 45 N load of Cu–Cr–Zr alloy aged at different temperatures for 2 h.

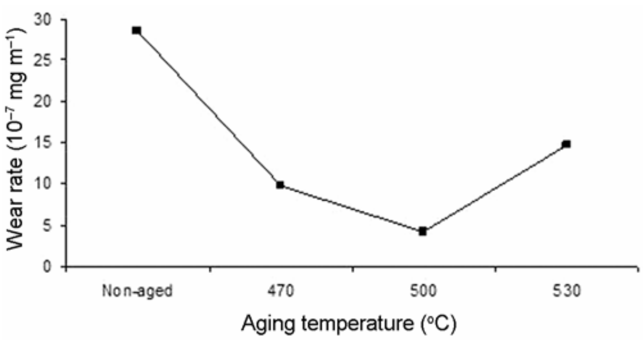

Figure 4. Effect of ageing temperature on wear rate.

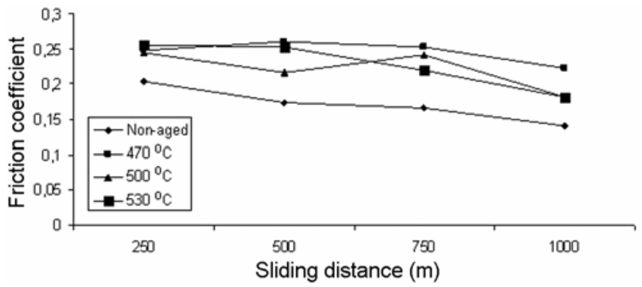

Figure 5. Depending on wear distance occurred changes in friction coefficient in Cu–Cr–Zr alloy aged at different temperatures.

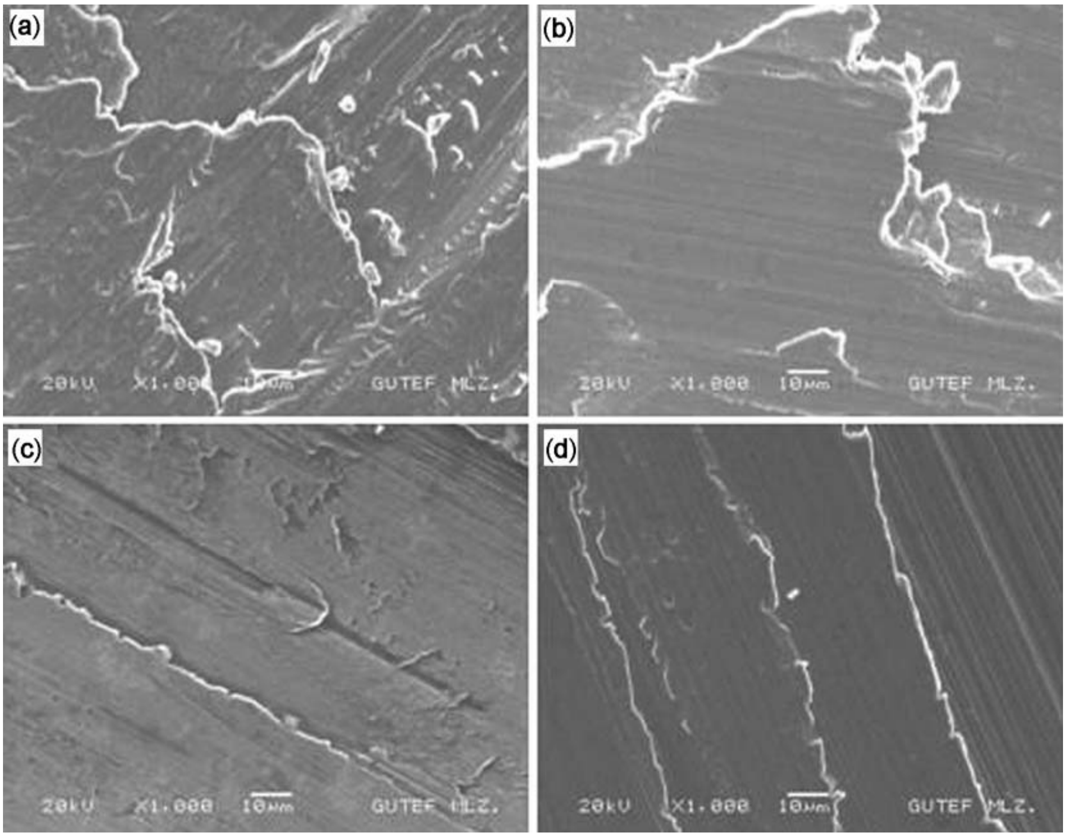

Figure 6. SEM images of wear surface of Cu–Cr–Zr alloy aged at different temperatures for 2 h and tested under 45 N load; (**a**) non-aged, (**b**) 470°C, (**c**) 500°C and (**d**) 530°C.

As the most wear loss was expected in non-aged specimen, its origination in specimens aged at 530°C was unexpected. This situation can be explained in two ways. Firstly, even there is a small possibility it may be the errors exist in the structure of Cu–Cr–Zr alloy. Secondly, it may be an increase of wear loss due to the effect of fractures occurred during the wear tests because of over growth of dimensions of precipitates formed in the structure with ageing. Second hypothesis is stronger because the hardness of alloy aged at 530°C is higher than non-aged alloy. Since the ductile Cu matrix is more easily deformed, it is easier to compensate the applied load. For this reason, fracture possibility of harder than non-aged specimens alloy aged at 530°C for 2 h occurring on contact surface increases. In figure 4, changes occurred due to ageing temperature in wear rates of Cu–Cr–Zr alloy is given.

Figure 4 shows that at the beginning wear rate decreases depending on the increase in ageing temperature, but there is an evident increase tendency in wear rate of alloy aged at 530°C. This condition derives from the microstructure of the material. Effect of hardness and microstructure of the alloy on determination of wear behaviour of Cu alloys is extended. Dimensions of second phase precipitates formed in the structure with ageing reach the most ideal dimensions at 500°C. This result is shown in figure 2. Precipitates formed in the structure with ageing of Cu–Cr–Zr alloy at 530°C are included into over-ageing period. By over-ageing coarse precipitates, hardness and endurance values decrease. Depending on this while the wear rate of aged Cu–Cr–Zr alloy increased the hardness of the materials decreased. In figure 5, depending on wear distance occurred changes in friction coefficient in Cu–Cr–Zr alloy aged at different temperatures are given.

As shown in figure 5, in 45 N load applied specimens as sliding distance increases, a decrease even in a very small measure occurs in friction coefficient. This is due to the effect of consistent temperature on contact surface of the specimen and the steel disc during the wear tests. With an increase in sliding distance, formation of oxide film layer occurs on the surface of the specimen during the friction. The most important factor which determines wear behaviour of Cu–Cr–Zr alloy and changes in friction coefficient in dry sliding conditions is the formation of oxide layer on the contact surface. The oxide layer protects the below metal surface when metal–metal contact occurs and acts as a solid lubricant. Adhesion between the specimen and the steel equivalent disc is higher than between the oxide layer and the steel disc.

Hence, the friction coefficient decreases. An increase of temperature occurred during the wear tests decreases the hardness of Cu–Cr–Zr alloy, because of this it can be said that an increase in sliding distance increases the ratio of wear rate. In figure 6, SEM images of wear surface of Cu–Cr–Zr alloy aged at different temperatures and periods and tested under 45 N load are given (Saglam 2006).

From the worn surface images shown in figure 6, depending on increase in sliding distance, plastic deformation occurs on specimen surfaces. Continual scratches occurred on worn surfaces and micro-cracks based on fatigue indicate adhesive wear mechanism. This wear mechanism is derived from high micro-shear tension occurred on specimen surface during the tests. In figure 7, material transfer occurred between specimen and steel disc sliding appear clearer in EDS analysis taken from the worn surface of Cu–Cr–Zr alloy.

According to EDS results shown in figure 7, it appears that Fe, Co and Ni are on the surface of aged Cu–Cr–Zr alloy. This condition shows material transfer between specimen and steel disc with effect of load also during the sliding. With an increase in sliding distance, high plastic deformation occurs on specimens' surfaces which causes the cracks in the beginning, then the growth of these cracks occur in advancing stages of wear and finally the material loss occurs. In a study made by Qi *et al* (2003), it is defined that formation of thin second phase precipitates formed in the structure with ageing, increases the endurance and because of the layer formed on the surface, at increasing speeds there is an intense abrasive wear. It is thought that as a result of Cu–Cr–Zr alloy ageing, with increase in the hardness of alloy second phase particulates formed in the structure pressure abrasive wear, counter to that adhesive wear mechanism gets more active state.

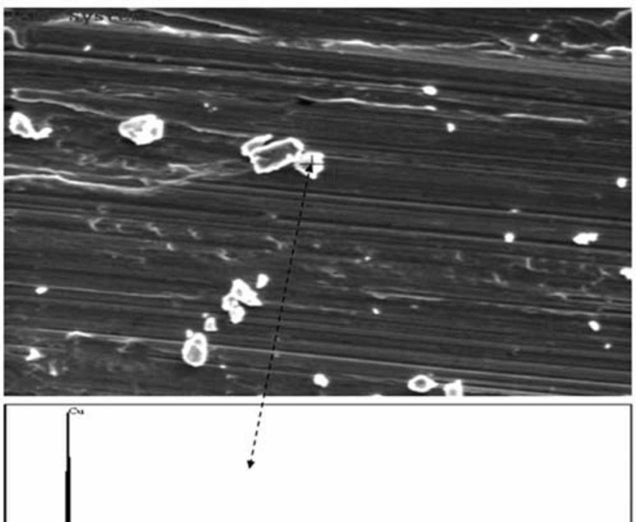

Figure 7. Wear surface SEM and EDS analyses results.

4. Conclusions

In this study, electrical conductivities were analysed by ageing Cu–Cr–Zr alloy which has high endurance and wear resistance (hence it is use in the automotive industry) and in the electrical flow conduction at 470°C, 500°C and 530°C temperatures for 1 h, 2 h and 3 h, respectively. Furthermore, in specimens aged for 2 h wear tests were carried out. Results obtained from the study are summarized below:

(I) High hardness values in Cu–Cr–Zr alloy were obtained by ageing thermal treatment. This is due to the dislocations formed in the structure with ageing, occurred through precipitates and the resistance of dispersion obtained with precipitates formation.

(II) When SEM images and EDS analysis of Cu–Cr–Zr alloys are analysed, after ageing thermal treatment, size of precipitate increases with increasing measure of chrome which is a second phase. It was observed that enlarged Cr-rich precipitates increase the electrical conductivity.

(III) In electrical conductivity tests of Cu–Cr–Zr alloys, the highest conductivity value was obtained by ageing at 530°C for 3 h. When the hardness results are considered, as in materials included into over-ageing period hardness decreases, there is an increase in conductivity. Hard precipitate formed in the structure with ageing thermal treatment decreases electrical conductivity (470°C). Due to this, by selecting appropriate ageing conditions in precipitate hardening, conductivity and endurance can be increased together (500°C).

(IV) After ageing thermal treatment, an increase in the hardness by second phase particulates in wear resistance occurs. Because of low hardness value of non-aged Cu–Cr–Zr alloy, the most wear measure was seen in this material.

(V) Second phase precipitates formed in the structure by ageing thermal treatment of Cu–Cr–Zr alloy at 530°C are included into the over growth (over-ageing) period and as a result of over-ageing growth, precipitates during the deformation are easily passed by dislocations and with this a decrease in wear resistance occurs.

(VI) It is defined that at the end of wear tests the least wear loss has Cu–Cr–Zr alloy aged at 500°C for 2 h. The most wear loss was registered in the specimens aged at 530°C for 2 h. As wear rates were analysed, it was defined that as wear distance of obtained values overlapped with hardness results increases, a decrease tendency occurs in friction coefficients.

References

Durashevich G, Cvetkovski V and Jovanovich V 2002 *Bull. Mater. Sci.* **25** 59

Fujii T, Nakazawa H, Kato M and Dahmen U 2000 *Acta Metall.* **48** 1033

Holzwarth U, Pisoni M, Scholz R, Stamm H and Volcan A 2000 *J. Nucl. Mater.* **279** 19

Li H, Xie S, Mi X and Wu P 2007 *J. Mater. Sci. Technol.* **23** 795

Liu P, Kang B X, Cao X G, Huang J L, Yen B and Gu H C 1999 *Mater. Sci. Eng.* **A265** 262

Liu P, Su J H, Dong Q and Li H, 2005 *J. Mater. Sci. Technol.* **21** 475

Nagarjuna S, Sharma K K, Sudhakar I and Sarma D S 2001 *Mater. Sci. Eng.* **A313** 251

Qi W X *et al* 2003 *Mater. Sci. Eng.* **A343** 89

Rigney D A 2001 *Wear* **245** 1

Saglam I 2006 *An investigation on wear behaviour electrical conductivity of Cu–Cr–Zr alloy*, M.Sc. thesis

Straffelini G, Maines L, Pellizzari M and Scardi P 2005 *Wear* **259** 506

Su J H, Dong Q M, Liu P, Li H J and Kang B X 2005 *Mater. Sci. Eng.* **A392** 422

Su J H, Li H J, Liu P, Dong Q M and Li A J 2007 *Comput. Mater. Sci.* **38** 697

Tu J P *et al* 2002 *Wear* **249** 1021

Vinogradov A 2002 *Acta Mater.* **50** 1639

Yaşar M and Altunpak Y 2009 *Mater. Design* **30** 878

Yildiz H B and Yaşar M 2007 *Metallofiz. Noveishie Tekhnol.* **29** 1659