THE EFFECT OF ELECTRICITY ON THE MECHANICAL PROPERTIES OF WC - Co ALLOY

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ABSTRACT

The mechanical properties of WC based hard alloy ISO-K25 (90% WC, 8% Co, 1.8% TaC, 0.2% NbC) were investigated with and without current injection during testing. Currents with densities J=0-85 A/cm^2 d.c. were injected parallel to the long axis of the sample. Microhardness, macroscopic hardness and crack propagation with Vickers, Rockwell and Knoop indenters were studied.

It was found that with the passage of electric current, the microhardness of surface layers decreased from 17.1 to 15.6 GPa, especially in the range J=40-55 A/cm^2. The Vickers hardness of specimens decreased from 15.3 to 11.7 GPa with increasing currents up to J=40 A/cm^2 after which the hardness was constant. The average crack length, both parallel and perpendicular to the direction of the electric current, increased up to a maximum for the same range of J. However, the length of cracks parallel to the direction of electric current was a factor of ~1.3 greater than the perpendicular cracks. The maximum crack length and the minimum linear density of cracks with a Rockwell hemispherical indenter were also observed at J=40 A/cm^2. Knoop indentation did not produce cracks without the electric current or for with the long indenter diagonal perpendicular to the electric current, while cracks were obtained when the indenter was aligned parallel to the electric current.

1. INTRODUCTION

The effects of electric fields and current on atomic and dislocation mobility in metals are well known as electroplasticity /1,2. The passage of high-density (10^3-10^7 A/cm^2) electric current pulses (~100 μs duration) leads to decreasing the flow stress, increasing the elongation to fracture of metals. When the current direction coincides with the direction of sliding dislocations, the velocity of dislocations increases /3/. Electropulsing increases the fatigue life of polycrystalline copper – the number of cycles for crack initiation increases and the macrocrack growth rate decreases /4/. The electroplasticity effect has been applied to drawing steel wires /5/. While the effect of electric current on deformation and fracture of mild metals and alloys has been studied, the change of mechanical behavior of high-strength materials (e.g. cermets) has not been investigated. However, a change in plasticity and the rate of crack growth can significantly facilitate machining cermets, and can also affect the quality of surface machined.

Cemented carbides are extensively used as wear-resistant materials for cutting tools, drilling and mining equipment and valve components. Cemented carbides exhibit a unique combination of high hardness and moderate values of fracture toughness. Indentation fracture of WC-Co cermets is widely reported in the literature [e.g. /6/). Cracks generated by indentation are driven by a residual stress field associated with plastic deformation and remain radial or Palmqwist even at high indentation loads. The primary aim here was to determine the effect of low density ($<10^7$ A/cm^2) electric current on the mechanical properties (e.g. hardness, fracture toughness and crack propagation) of WC-CO cermet.

2. PROCEDURE

A WC based hard alloy ISO-K25 (90% WC, 8% Co, 1.8% TaC, 0.2 %NbC) was studied. The average carbide grain size and the approximate pore size range were 1.2 μm and 0.5-1 μm respectively. The 6.5 x 20 x 5 mm specimens were polished with 0.3 μm Al_2O_3 powder. The mechanical properties were investigated with and without current injection during testing The experimental set up is shown schematically in Fig 1. Currents with densities of 30, 40, 55, 70 and 85 A/cm^2 d.c. were injected along the long axis of the samples. The microhardness was measured under a load of 5 N. The hardness and crack propagation were studied with a Vickers diamond pyramid indenter under loads of 600, 1000 and 1500 N, and with a Rockwell standard hemispherical indenter with 1500 N. In some of the experiments a Knoop indenter was also applied with a load of 1000 N. Each point in the hardness evaluation is a mean value of 20 measurements. Experimental error in hardness measurements is given at 95 Pct

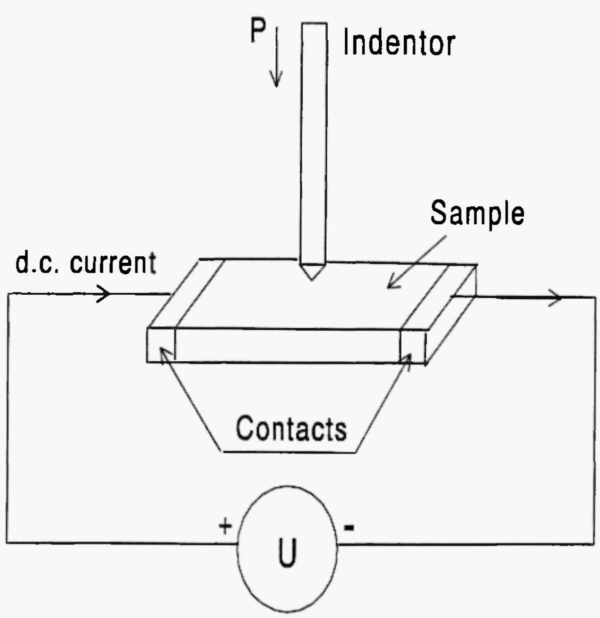


Fig. 1: Schematic diagram of the experimental set-up.

confidence level. The direction of indentation has been chosen so that one of the impression diagonals was parallel to the current passage. After indentation, the specimens were examined in optical and scanning microscopes to measure the crack propagation from the corners of the impressions.
A critical stress intensity factor /7/ K_{IC} was determined by:

$$K_{IC} = \frac{1}{3(1-\upsilon^2)(2^{1/2}\pi\tan\psi)^{1/3}} \frac{(HP)^{1/2}}{(4\bar{a})^{1/2}} \quad (1)$$

where: 2ψ = 136° for the standard Vickers indenter, Poisson's ratio ν=0.22 (typical of WC alloys), $\bar{a}$ is the mean radial crack length, H is the hardness and P is the load.

Because the fracture toughness is mainly determined by the crack length, K_{IC} was obtained in both perpendicular and parallel to the direction of the electric current.

To measure Ohmic heating a thermocouple was mounted on the specimen surface. In order to eliminate any possible temperature softening effect, the hardness was measured as a function of temperature up to 200°C. The specimens were heated in a furnace mounted on the table of the microhardness tester and then have loaded with P=5 N.

3. RESULTS

The effect of electric current on the values of microhardness and Vickers hardness is shown in Fig. 2. It is seen that with the passage of electric current the microhardness of the surface layers decreased from 17.1 to 15.6 GPa especially in the range between J=40 and 55 A/cm^2. Under high load the hardness decreased with increasing electric current up to J=40 A/cm^2, above which the hardness was approximately constant. The effect of electric current on crack length around the impressions is shown in Table 1. The average crack lengths, both parallel and perpendicular to the direction of the electric, current increased, reaching a maximum at the same J=40 A/cm^2. However, the length of cracks parallel to the electric current were larger than the perpendicular cracks, as may be seen in Fig. 3. For example, the average parallel and perpendicular crack lengths at J=40 A/cm^2 were 264 and 202 μm, respectively. It may be noted that the crack-opening near the corners of the impressions were also significantly higher in the direction parallel to electric current.

On the basis of equation 1, fracture toughness, K_{Ic}, was measured. K_{Ic} decreased more significantly in the direction parallel to the electric current, and remained constant for J>40 A/cm^2 (Fig. 4). Without of current passage the critical stress intensity is maximum, K_{Ic} = 14.4 MPam$^{1/2}$ and it is close to that calculated in work /7/, K_{Ic}=15 MPam$^{1/2}$.

The crack development around the Rockwell indentational impressions is shown in Fig. 5. The crack length increased with J while the linear density of cracks around the impressions decreased, as shown in Fig. 6. The maximum crack length and the minimum linear density of cracks also occurred at

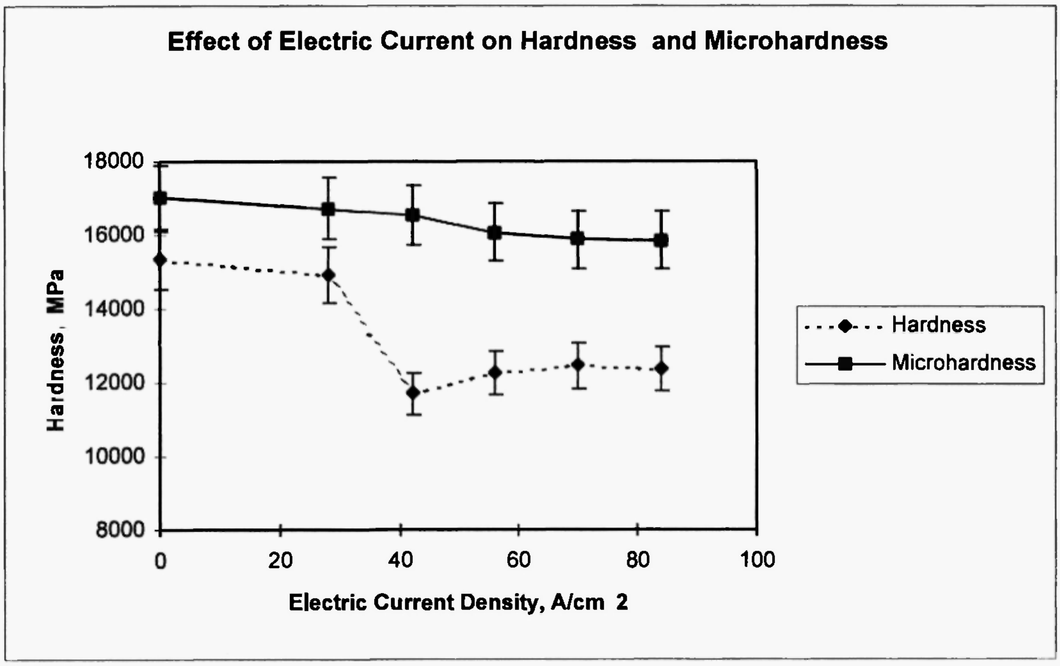


Fig. 2: Dependencies of the microhardness (P=5 N) and Vickers hardness (P=1000 N) on the transverse current density

Table 1

The effect of electric current on crack length around the impressions

Current density, A/cm^2	Length of cracks, ⊥ to current, μm	Length of cracks, ∥ to current, μm
0	140	144
30	155	184
40	202	264
55	199	230
70	177	245
85	179	269

J=40 A/cm^2. Under Knoop indentation (Fig. 7), no cracks were observed for J=0 and when the long diagonal was perpendicular to the current for J=40 A/cm^2, while cracks were observed when the long diagonal was parallel to the same current. These cracks emanated from the corners of the impressions, but were not collinear with the impression diagonals.

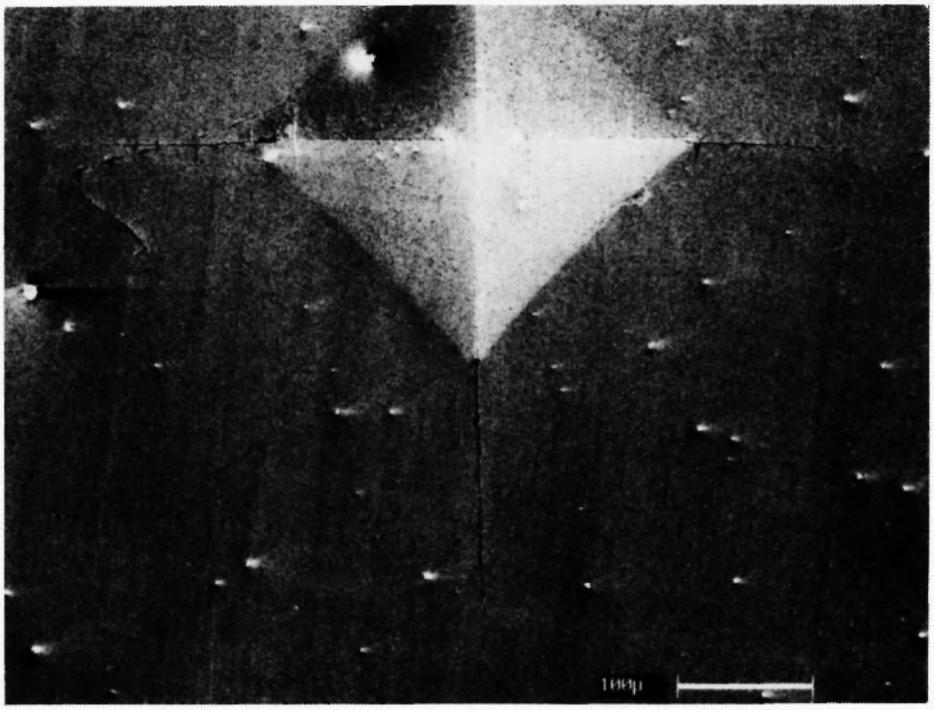


Fig. 3: The indentation impression on the surface of WC-Co alloys with application of electric current of J= 40 A/cm^2 and a load of P=1000 N.

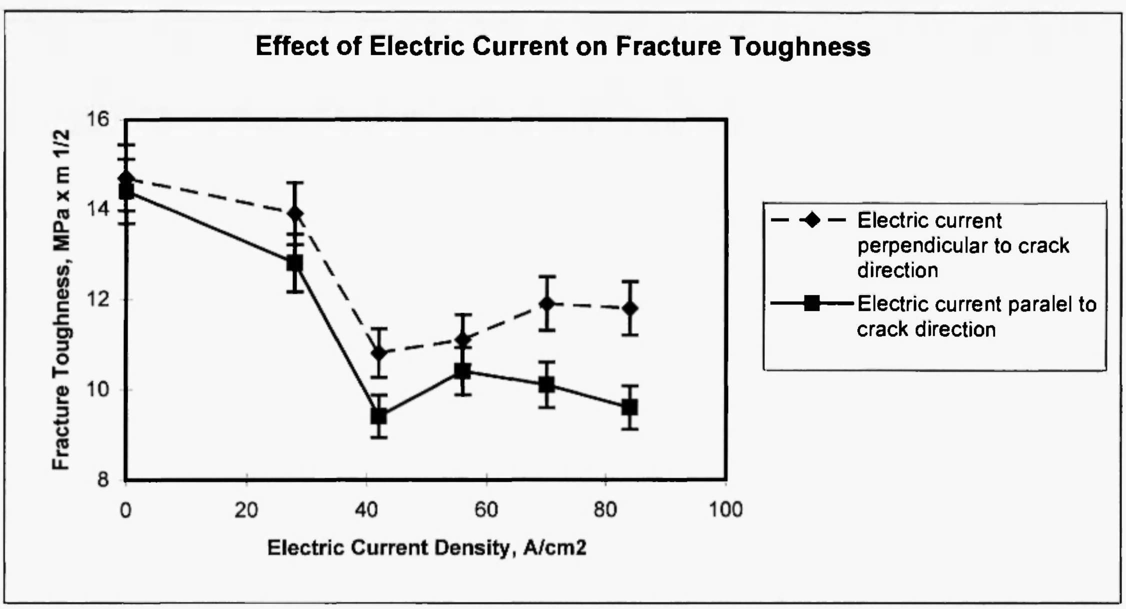
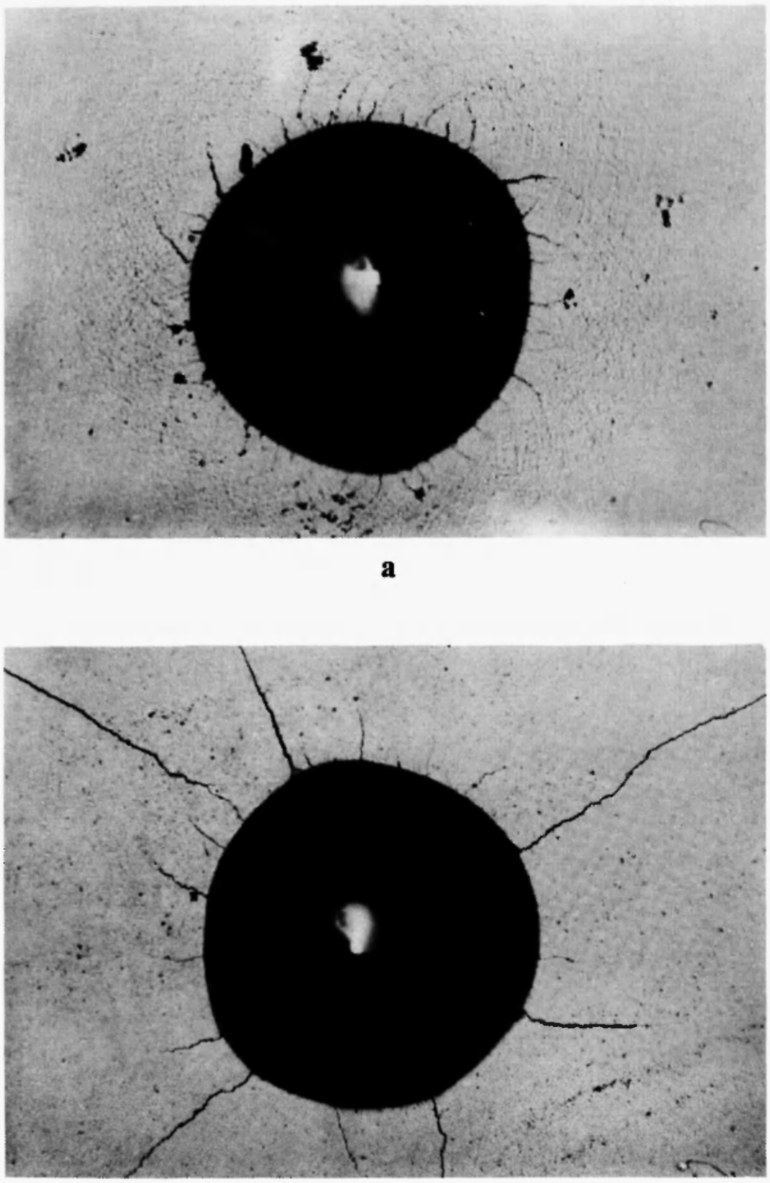


Fig. 4: Effect of the current injection on the fracture toughness, K_{IC}.



a

b

Fig. 5: Effect of the current injection on the crack development around Rockwell impressions. (a) – J = 0; (b) – J= 40 A/cm^2

The crack propagation from the corners of impression was predominantly the result of intergranular fracture, as may be seen in Fig. 8. Grain-localized "bridges" across crack interfaces were observed at large distances from the impressions. There were ligaments across the crack interfaces and the new cracks adjacent to the primary crack on distances no more than one or two grain diameters. No carbide microcracks are visible around the crack tip.

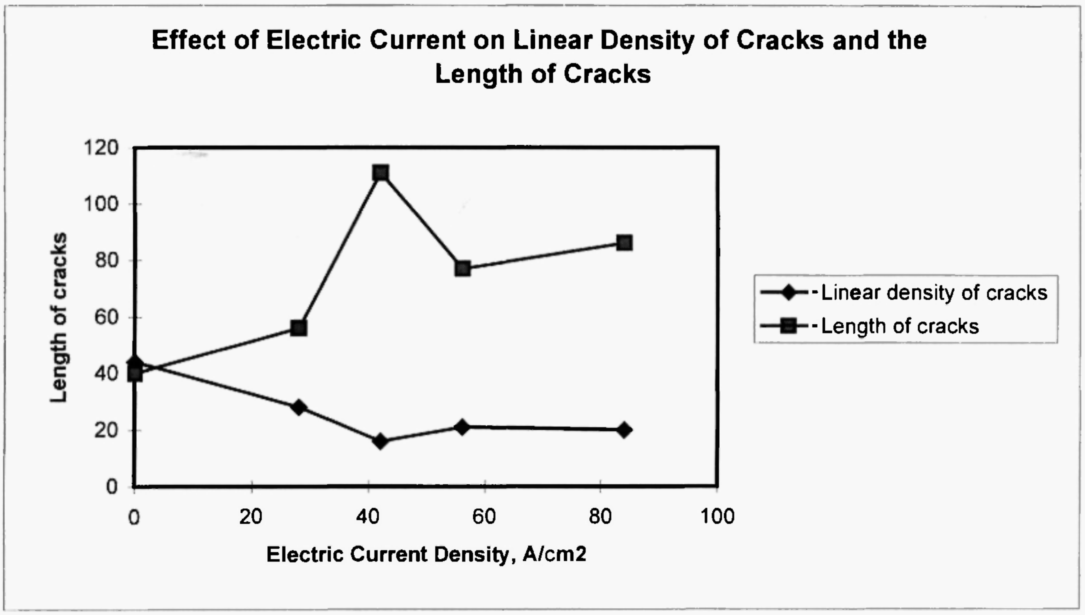


Fig. 6: Effect of the current injection on linear density of cracks and length of cracks around Rockwell impressions.

The average temperature of the specimen surface was raised with increasing J, up to T= 85°C at J= 85 A/cm^2. However, the microhardness of the surface layers was not affected by heating up to 200°C. The spread of the microhardness data increased with temperature, however. It should also be noted that the medium carbide grain size was small compared to the indentation contact diameter, especially under high loads.

4. DISCUSSION

The hardness measurements showed that the increase of the current density had a softening effect. This effect was greater for the Vickers hardness than for the microhardness. The difference in the softening curves under low and high loads is probably associated with the scale levels of deformation and fracture under indentation with low and high loads. In the microhardness test (P=5 N), the plastic deformation is localized in the microscale level (the medium impression diagonal was ~23 μm), i.e. comparable with the grain size. Moreover, in this case there were no cracks, so that all energy released went only into the plastic deformation of ductile binder phase. When the high loads were applied (P=1000 N), the plastic deformation and cracking were on the macroscale level. The medium impression diagonal was more than 350 μm, i.e. significantly larger than the grain size. The crack a

b

c

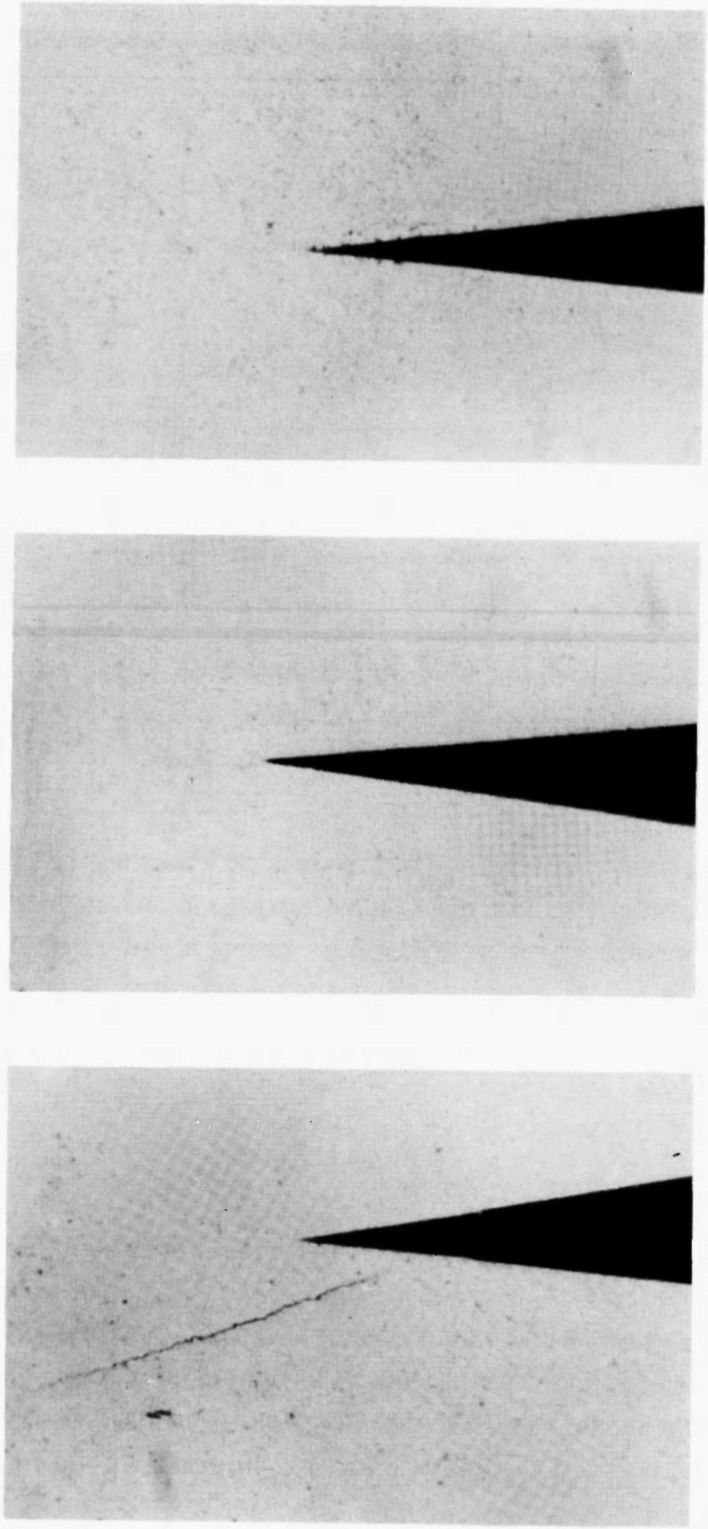


Fig. 7: Knoop impression on the surface of WC-Co alloys with (a) J=0 and (b, c) J=40 A/cm^2 when the long diagonal of impression is perpendicular to the current (b), and parallel (c).

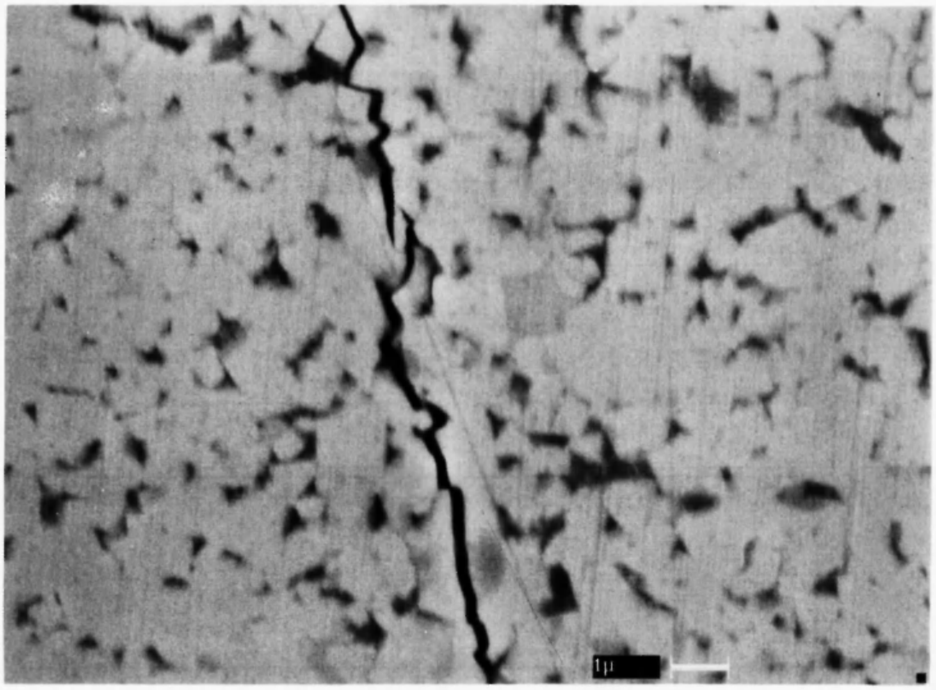


Fig. 8: Crack propagation with some bridging around a Vickers impression with load of P=1000 N.

propagation decreased the residual stress, facilitated the plastic deformation and thus the softening effect was greater than that obtained during microhardness testing (ΔH =3620 and 1132 MPa, respectively).

The product of linear density and the average length of the cracks depends on specific fracture surface energy. This parameter is constant for crack growth in WC-Co alloy /8/. Thus an increase in crack length around the impression was accompanied by a decrease in crack number.

Examination of the cracks in the impression corners shows that the crack length increased with the current, and thus the fracture toughness decreased.

It was shown that the increase of the average surface temperature (within the limited range experienced in this study) did not change the hardness. However, local temperature stress in the cracks tips or pores might effect dislocation motion and crack propagation. Measuring the local temperature, and then determining if this could affect the mechanical properties, will be challenging endeavors.

The application of electric current to plastic materials as, for example, polycrystalline copper leads usually as to plasticity effect and an increase in the number of cycles for crack initiation and a decrease in macrocrack growth rate under cyclic loading and thus increase the fatigue life /4/. The behavior of cermets is different in comparison with mild metals and alloys. The passage of electric current led to the plasticity effect (a decrease in the hardness) and simultaneously to the crack growth.

CONCLUSION

1. The passage of electric current through WC-Co alloy decreases the hardness and increases crack growth. The microhardness of surface layers and the Vickers hardness decreased from 17.1 to 15.6 GPa and from 15.3 to 11.7 GPa, respectively, with the injection of J=40 A/cm^2.
2. The electric current injection during Rockwell indentation leads to the opposite effects in the change of crack length and their linear density. The maximum crack length around the impression and the minimum linear density of cracks occurred at J=40 A/cm^2.
3. Knoop indentation showed that without the electric current and for impressions in the direction of long diagonal perpendicular to the electric current, no cracking occurred, while loading under with the long indenter axis parallel to the same electric current caused cracking.

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