Change in Plasticity of Copper under Weak Electrical Potentials

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Abstract. This paper examines the effect of weak electrical potentials on samples of commercially pure copper. Energy deposition was conducted in two ways. The first one involved alternating attachment of lead, titanium, chromium, aluminum, nickel and iron plates to copper samples. Within the second procedure a voltage from -3 to 3 V was applied to copper samples. The energy deposition lasted 30 min. When contacts and copper samples were disconnected, micro-hardness was measured and plasticity was calculated. As revealed, plasticity of copper drops in both cases. This value is 0.083 % for samples interacting with iron and nickel. The reaction of copper with chromium and aluminum resulted in 0.18 % and 0.10 % decrease of plasticity, respectively. The most significant change in plasticity was registered as a result of interaction between copper and lead or titanium – 0.21 %. It is found out that plasticity of copper samples drops sharply by 0.33 % as a result of connection with a source of power with a potential 0.2 to 1.5 V (in absolute value). The subsequent increase of voltage from 1.5 to 3.0 V hardly effects on plasticity, keeping it the same as at 1.5 V. A sign of an electrical potential is irrelevant for plasticity.

1. Introduction

Electrical contacts and various conductors are operated under external impacts like electrical and magnetic fields, electric potentials. Being insignificant, weak impacts aren’t taken into consideration, however, ignoring these factors might cause failures in electrical circuits. Therefore, it is necessary to carry out research into the influence of weak energy deposition on different properties of metals. It is established that micro-hardness of aluminum alloys can change by almost 30% due to static and pulse magnetic fields up to 1 T in different conditions of thermal treatment [1, 2]. Electrical potentials and electroplasticity effect also can changes on the properties of the surface [3-5]. Data from studies [6] suggests that micro-hardness of aluminum rises by up to 0.16 % when it reacts with selenium, copper and zirconium. The impact of an electrical potential ±1 V initiates the increase in creep rate of commercially pure aluminum [7]. Consequently, surficial properties of metals might be changed even as a result of weak external energy impacts. Therefore, it is necessary to conduct more experiments

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because a lot of interaction mechanisms lack for an explanation. So, this work aims at research into the influence of weak electrical potential on copper plasticity.

2. Materials and Methods
The study is carried out at the ambient temperature. For the purpose of research samples of preliminary recrystallized commercially pure copper were used, the sizes were 20x20x10 mm. The sequence of the study is similar to one described in [8] and presented in Fig. 1.

![Diagram of electric potential supply to the sample when measuring micro-hardness](image)

\( a \) – when connecting the metal; \( b \) – from the source of direct current

1 – sample, 2 – insulation layer, 3 – indenter, 4 – connected metal, P – load on the indenter,

I – source of direct current

**Figure 1.** Diagram of electric potential supply to the sample when measuring micro-hardness

Weak electrical potentials were generated in two ways. First, an electrical potential varying -3 to 3 V in increments of 0.2 V was supplied to copper samples from the source of stable voltage (Fig. 1, a). Within the second procedure different metals: lead, chromium, aluminum, titanium, nickel, and iron were connected with copper (Fig. 1, b). An electrical potential arose when a sample under consideration was connected with other metal with different work function. The experiment lasted 30 minutes. Work function for copper and other metals is selected from the data available [9, 10] and given in Table 1. Plasticity was studied indirectly: micro-hardness is related to plasticity as in [11]:

\[
\delta = 1 - 14.3(1 - \nu_1 - 2\nu_1^2) \frac{HV}{E} \tag{1}
\]

where \( \delta \) – plasticity, \( HV \) – Vickers hardness, \( \nu_1 \) – Poisson coefficient of the material, \( E \) is Young’s modulus;

Micro-hardness of metals \( HV \) was measured according to the Vickers method, using a micro-hardness measuring device HV-1000 with a load on indenter of 30 g, and deposition time of 18 seconds. Each sample was measured 30 times. The contact voltage difference was calculated according to the formula [12]:

\[
\Delta \varphi = \frac{A_{Me} - A}{e} \tag{2}
\]

where \( A_{Me} \) – function work of a metal, \( A \) – function work of copper Cu, \( e \) – electron charge;

The percentage change of plasticity was estimated according to the formula:
\[ Q = \frac{\overline{\delta}_E - \overline{\delta}_0}{\overline{\delta}_0} \cdot 100\% \]  

where \( \overline{\delta}_E \) and \( \overline{\delta}_0 \) - mean plasticity of copper samples when contacting with a metal and without the contact, respectively.

3. Results and Discussion

It is revealed that plasticity drops independently on the potential sign when connecting copper samples with different electrical potentials. The lowest plasticity was registered for a potential of 1.5 V, and the increase of electrical potential didn’t change it. Plasticity of copper vs. electrical potential is shown in Fig. 2.

![Figure 2. Copper plasticity vs. electric potential](image)

The change in copper plasticity in conditions of the second procedure is presented in Table 1. When connecting copper samples with metals with different work function it was established that plasticity is in reverse proportion to the contact potential in absolute value (the higher potential, the lower plasticity), e.g. plasticity of copper decreased by 0.22 % and 0.21 % when samples reacted with lead and titanium, respectively. As a result of copper and chromium interaction plasticity drops by 0.19 %. Aluminum, nickel and iron caused the decrease in plasticity by less than 0.1 %.

| Contact metal | \( A_{Me^+} \) [eV] | \( A_{Cu^+} \) [eV] | \( \Delta \varphi \), [V] | \( \overline{\delta}_0 \) | \( \overline{\delta}_E \) | \( Q \), % |
|-------------|----------------|----------------|--------------|-------------|-------------|------|
| Pb          | 4.25           | -0.40          |              | 0.97762     | -0.22       |
| Ti          | 4.33           | -0.45          |              | 0.97765     | -0.21       |
| Cr          | 4.5            | -0.18          |              | 0.97790     | -0.19       |
| Al          | 4.06           | -0.15          |              | 0.97871     | -0.10       |
| Ni          | 5.04           | 0.10           |              | 0.97887     | -0.09       |
| Fe          | 4.67           | -0.09          |              | 0.97891     | -0.08       |

Table 1. The change in plasticity as a consequence of the second experimental procedure

It is suggested that the results above are possible, since an electric contact of diverse metals, generating contact potential difference, causes overcharging of double surficial layers [13, 14]. As a
result, the density of surficial energy in the material under consideration changes, initiating the change in plasticity, respectively.

4. Conclusions
Experimental data suggest that electrical potential; generated both by the stable source of energy and due to contact potential difference of two metals, has an effect on mechanical properties of copper, e.g. on plasticity. A percentage drop of copper plasticity in comparison with the referential value is registered under contact electric potential. The maximal change was recorded when a sample under consideration was connected with lead and titanium contacts, the percentage plasticity was 0.22 % in this case. Exploring the influence of electrical potential on copper plasticity, it was determined that the sign of the supplied potential is irrelevant for plasticity, whereas its module is important. The decrease of plasticity by 0.3% was registered. The data obtained demonstrate that weak electrical potentials are important for mechanical properties of metals; this influence is to be considered when designing and modeling of complex systems and objects.

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