EXPERIMENTAL RESEARCH AND MODELING OF THE IMPACT OF PLASTIC DEFORMATION ON DIFFERENT MATERIAL CHARACTERISTICS

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Abstract. *Cold forming process in the plastic domain of deformation causes strain hardening in the formed material. Strain hardening can be used for practically all metals and alloys to increase most of mechanical characteristics, however ductility and some others are reduced. In the paper experimental researches of the influence of effective strain on change of main mechanical characteristics such as tensile strength, yield strength, impact toughness, and some other characteristics of cold formed material were carried out and analyzed.*
The results of the experiments are presented in the form of graphs. Special mathematical models for determination of different properties were obtained. These models are especially helpful for prediction of mechanical and other properties of a cold formed material. Knowing the material properties and their changes during the cold forming processes is very important for quality of the product and for planning the right technology of the forming processes.

Keywords: STRAIN HARDENING. MECHANICAL PROPERTIES, METAL FORMING, COPPER ALLOY, ELECTRICAL CONDUCTIVITY, REGRESSION ANALISYS,

1. Introduction

There is always an interest in development of copper alloys with a high electrical and thermal conductivity, good mechanical properties and microstructure stability up to high temperatures. A possible way to obtain this interesting combination of properties is to use a precipitation hardening system.

Detailed investigations of system Cu-Cr have shown that small additions of other alloying elements such as Zr, refine the microstructure and enhance the age hardenability of the binary alloy.

In the usual production process the mechanical properties of these ternary alloys are dependent mainly on the chemical composition and the thermo-mechanical treatment. But by cold forming the mechanical properties of alloy are changing because of strain hardening.

It is well known that any cold forming process in the plastic domain of deformation introduces strain hardening characteristics in mechanical response of the material treated [1-7]. Strain hardening can be used for practically all metals and alloys to increase hardness and tensile strength, however ductility is reduced [8, 9, 10, 11].

Knowing the mechanical properties of alloys and their changes during the cold forming is very important for economically production [12].

2. Experimental Work

The influence of cold forming on changing of tensile strength, yield strength, flow stress, electrical conductivity and impact toughness was examined in the experimental work.

For the testing material special copper alloy CuCrZr with 0, 71% Cr and 0, 05% Zr in copper matrix was used. This is a copper – chrome – zirconium alloy with high electrical and thermal conductivity and excellent mechanical and physical properties also at elevated temperatures. It is used as electrode material in spot, seam and butt resistance welding of low carbon steel sheets. Further it is used for manufacture of various components for resistance welding equipment. [15]

Mechanical properties of unformed material (before cold forming) were determined with tensile test, Brinell and Vickers micro-hardness were measured by measuring instrument WPM, electrical conductivity was measured by the Sigmatest instrument. Measured values for different mechanical properties for unformed material are presented below:

Tensile strength $R_m = 480$ N/mm^2
Yield strength $R_{p02} = 396$ N/mm^2
Impact toughness (ISO V-notch, 20 ^{0}C) W_i =169 J
Electrical conductivity a = 50, 1 m/Ωmm^2

For determination of the influence of effective strain on the change of hardness, electrical conductivity and flow stress, the cold upsetting was used.

The cylinders of CuCrZr with initial diameter of 10 mm and height of 14 mm were lubricated with teflon foil (near frictionless conditions) and then formed by the special experimental tool for upsetting. Many experiments were done to provide the right results. After each experiment effective strain, flow stress and electrical conductivity were measured.

3. Results

Table 1 represents the values for electrical conductivity measured at specimens which were formed at different effective strain. It is obviously that electrical conductivity is decreasing with higher values of the effective strain. From starting value of 49,8 m/Ωmm^2 electrical conductivity is down to only 44,6 m/Ωmm^2 at effective strain value of 1,1. The difference in electrical conductivity between unformed specimen and the specimen formed at ε_e =1, 1 is more than 10%.

Table 1. *Electrical conductivity measured at different rate of the effective strain.*

Effective strain ε_e	Electrical conductivity **a** [m/Ωmm^2]
0,05	49,8
0,2	49,1
0,4	47,8
0,6	46,2
0,8	45,5
1,0	44,9
1,1	44,6

Flow curve is one of the most important data for any forming process and provide us vital information about material behavior during forming process.

The measure of strain hardening must be incorporated in the consideration of more general processes. In this regard, it is assumed on the basis of sufficient agreement with experiments that the strain hardening for a particular material depends on the work per unit volume which has been expended. In our case there is an increase of nearly 50% between initial flow stress and flow stress of maximal deformed material (ε_e =1, 1). Flow stress diagram is shown on Fig. 1.

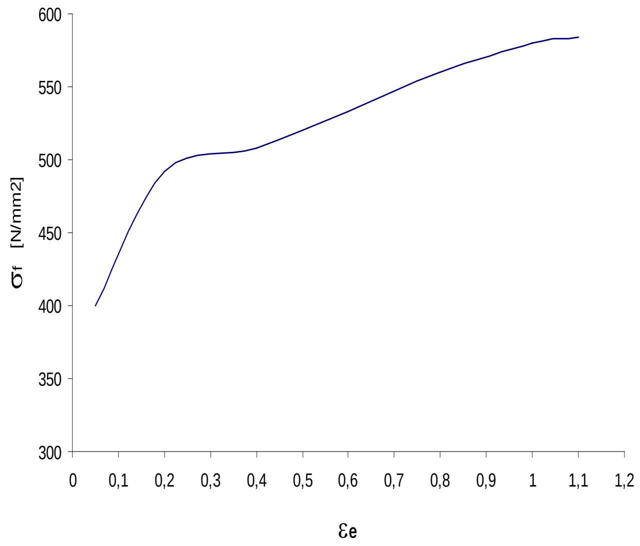

Fig. 1. *Change of flow stress (σ_f) as a function of effective strain ε_e*

The experimental results can also be presented in the mathematical way by using statistical methods especially regression analysis. For this reason the mathematical model for the regression analysis was chosen as written [12, 13]:

$$y = b_0 + b_1 x_1 + b_2 x_1^2 \quad (1)$$

b_0, b_1 and b_2 are free coefficients to be determined by regression analysis; y and x_1 are parameters. The equations, calculated by regression analysis, are:

$$\sigma_f = 406{,}4 - 375{,}33 \cdot \varepsilon_e - 191{,}36 \cdot \varepsilon_e^2 \quad (2)$$

$$a = 50{,}63 + 7{,}44 \cdot \varepsilon_e + 0{,}75 \cdot \varepsilon_e^2 \quad (3)$$

By using equations (2) and (3) values of flow stress (σ_f) and electrical conductivity (a) can be calculated for every value of effective strain in the experimental area (ε_e is between 0 and 1, 1).

For determination of tensile strength, yield strength and Charpy energy the copper alloy CuCrZr was deformed by cold drawing. The specimen bar with initial diameter of 20mm has been deformed by drawing on the drawing bench with drawing speed of 20 m/min and drawing die angle $2\alpha = 28^0$ at room temperature.

Bars of copper alloy were deformed by drawing to six different final diameters: 19 mm, 18mm, 17mm, 16mm, 15mm and 14mm. On this way we got six different cold formed specimens (deformed bars). From deformed bars test specimens were made for tensile test to investigate the influence of strain on mechanical properties.

The results of the tensile tests are shown as a diagram on Fig. 2 which presents the change of tensile strength R_m and yield strength R_{p02} as a function of effective strain ε_e.

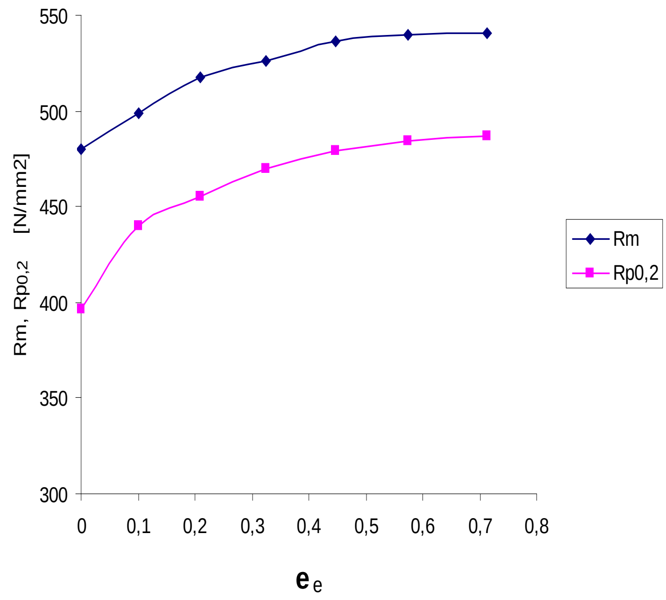

Fig. 2. *Tensile strength (R_m) and yield strength ($R_{p0,2}$) as a function of the effective strain ε_e*

The increase of tensile strength is very similar to that of yield strength. At the highest value of the effective strain (ε_e = 0, 71) the increase of tensile strength is 11% the increase of yield strength is 14% in comparing to initial values of unformed material (before drawing).

Fig. 3 presents impact toughness W_i as a function of the effective strain. Impact toughness of deformed bars was measured with Charpy test at the room temperature. The test specimens were standard ISO V-notch specimens (10mm x 10mm x 55mm and 2mm notch in the middle).

With increasing of the effective strain the impact toughness is decreasing. At the highest value of the effective strain (ε_e = 0, 71) the impact toughness is 12 % lower as it is before drawing. It is interesting that the decrease of impact toughness in our case is almost linear.

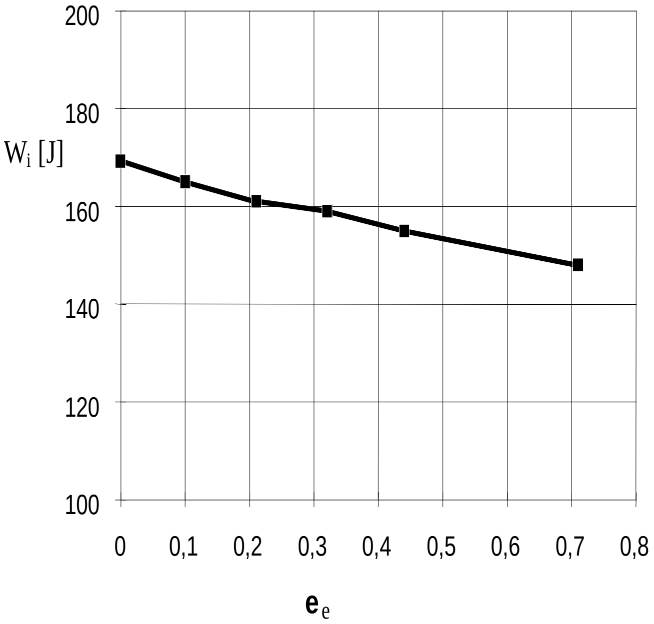

Fig. 3. *Impact toughness (W_i) as a function of the effective strain (ε_e)*

The experimental results can also be presented in the mathematical form by using regression analysis or any other suitable modeling methods [13] and mathematical model (1):

$$R_m = 482{,}46 - 165{,}27 \cdot \varepsilon_e + 134{,}43 \cdot \varepsilon_e^{\,2} \quad (4)$$

$$Rp_{0,2} = 410{,}54 - 236{,}1 \cdot \varepsilon_e + 186{,}34 \cdot \varepsilon_e^{\,2} \quad (5)$$

$$W_i = 168{,}87 - 35{,}39 \cdot \varepsilon_e + 9{,}37 \cdot \varepsilon_e^{\,2} \quad (6)$$

By using equations (4) to (6) tensile strength, yield strength, and impact toughness at any value of the effective strain inside the experimental area (from $\varepsilon_e = 0$ to $\varepsilon_e = 0{,}71$) can be calculated.

4. Conclusion

It is well known that any cold forming process in the plastic domain of deformation introduces strain hardening characteristics in mechanical response of the material treated. The strain hardening can also be used to get workpieces whose mechanical properties are higher than for the initial material. It is also interesting from an economical viewpoint, since cheaper materials can be cold formed to get the higher mechanical properties generally obtainable in higher-grade costlier materials.

The results of measurements which are presented in our paper have shown that knowing the mechanical properties of the material to be formed and the change of properties during and after forming process is very important to predict the quality of the workpieces and for planning the right technology of the forming processes. Special mathematical models which were obtained for each measured mechanical property are especially helpful for prediction of mechanical and other properties of a cold formed alloy. In the future research we will try to determine an influence of many other parameters (such as tool speed, lubrication, strain rate, etc.) on change of mechanical properties.

5. References

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