Investigation of ECAP on Microstructure and Mechanical Properties of Bronze at Different Temperatures

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Abstract: Tin bronzes are widely used as structural materials in parts of friction units for critical applications operating in harsh operating conditions. In this work, the study of the influence of equal channel angular pressing on microstructure and mechanical properties of single-phase tin bronze is carried out. According to the analysis of the results of the study, it was revealed that the size of the grain is consistently refining with each new cycle of deformation. Moreover, analysis of the influence of deformation's beginning temperature on the evolution of microstructure and mechanical properties of single-phase tin bronze was conducted.
Keywords: equal channel angular pressing; microstructure; mechanical properties; bronze.

1. Introduction

Currently one of the structural materials used for parts of friction units for critical applications operating in harsh conditions are tin bronzes which have a unique combination of high strength and elastic properties, and they have excellent corrosion resistance, good anti-frictional properties and high wear resistance. It is possible to improve the mechanical properties of this alloy by obtaining ultrafine-grained structure through severe shear deformation. Severe shear deformation shows a good prospect in the creation of new high-strength materials with a unique complex of physical and mechanical properties [1].

The most promising method of implementation of severe shear deformation throughout the volume of the deformable billet is the method of equal channel angular pressing (ECAP). On the department "Processing of metals by pressure" of Karaganda state industrial university, a number of experiments were conducted to determine the impact of multi-cycle equal channel angular pressing on microstructure of various ferrous and non-ferrous metals and alloys and the change of their mechanical properties, including the implementation of combined processes [2-4].

As the issues regarding the influence of chemical composition and heat treatment on structure, mechanical and corrosion properties of tin bronzes have previously been investigated in sufficient detail [5–6], and the structural aspects of large shear deformation in modern literature are considered insufficiently. Based on the foregoing, the aim of this study is to investigate the effect of ECAP on the structure and mechanical properties of single-phase tin bronze.

2. Research methodology

Single-phase tin bronze BrTZn4–3 was chosen as a research material. To align the chemical composition in a single phase bronze and convert two-phase structure with solid δ-phase inclusions to single-phase α-phase (therefore increasing plasticity), bronze was subjected to homogenization at 700-750°C followed by rapid cooling. The experiment conducted on the billets with square cross-section and sizes 12×12×55 mm. This size of the original billets selected to ensure the possibility of conducting mechanical tests after the pressing process.

Pressing temperature should be below the temperature of beginning of recrystallization $(0.5\div0.6)T_{melt}$. If for pure metals remains a valid relationship of A. A. Bochvar $T_{recr}/T_{melt}\approx0.4$, for single-phase solid solutions, at the expense of rational doping this ratio may be increased to 0,6 [7]. Increasing the temperature of beginning of deformation enhances the probability of occurring during hot deformation of dynamic recrystallization, which leads to an undesirable enlargement of the grain. Therefore, the choice of a temperature mode is based on the fact that in the process of hot deformation the primary recrystallization took place completely, and the collective was suppressed. One of the features of nano - and microcrystalline materials obtained by severe plastic deformation is a significant instability of their structure during heating. In particular, the temperature of recrystallization of nano- and microcrystalline materials is significantly lower than usual recrystallization temperature of pure metals and equals to $T_1=0,275\div0,35T_{melt}$ [8]. Considering studied data, deformation of billets conducted at the following temperatures: 25°C, 320°C and 520°C.

During ECAP process, velocity of metal flow across the section of billet isn't equal – lower layers advance uppers. This leads to distortion of the initial shape of the billet – sharpening on the ends. During multi-cycle pressing this effect is undesirable, because there is a need for additional leveling of the billet between passes. In order to reduce this negative impact to a minimum, it is rational to use so-called B_c route, at which billet after each cycle tilting (rotated) around the longitudinal axis by 90°. Furthermore, this tilting provides alternating deformation and helps to refine the grain in the pressing process [9].

The analysis of foreign and domestic literature shows that in most cases growth of accumulated strain during ECAP after 6-8 passes do not lead to further refinement of the structure. Therefore, it could be assumed that increasing of accumulated strain inter-crystalline shifts do not lead to the formation of new dislocation walls, and accordingly, fragments, i.e. deformation occurs mainly due to accommodative inter-fragmental shifts and this deformation mechanism becomes predominant [10]. Also with increase of the degree of shear deformation properties of deformable metal improved, however, the accumulation of a certain degree of deformation can lead to the destruction of the sample, which is unacceptable. In this regard, the number of cycles of deformation for tin bronze was equal to 8.

Mixture of graphite and oil was selected as lubrication during pressing because such lubricant forms a film on the metal.

Preparation of thin sections for metallographic studies extrusion carried before and after according to standard methods, and an optical microscope Leica equipped with micro udometer was used in this research.

To determine the mechanical characteristics of the alloy before and after ECAP, a torsion-testing machine MI40KU was used. For testing, standard samples of cylindrical shape were used, and the tensile velocity was 0.5 mm/min. This value corresponds to a strain rate equal to 0.56×10^{-3} s^{-1}.

3. Results and discussion

In the initial state single-phase tin bronze has a coarse structure with a large number of twins, since the samples were obtained from rod.

To assess the effectiveness of ECAP, it is necessary to compare the microstructure of bronze before and after deformation. The microstructure of tin bronzes obtained after pressing at different temperatures is presented in figure 1.

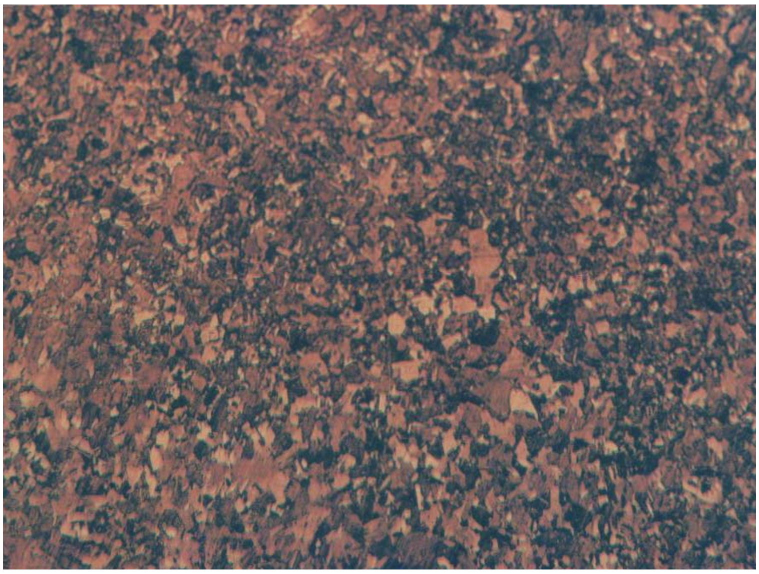
The analysis of the microstructure of single-phase tin bronze brand BrTZn4-3 after ECAP showed that intensive grain refinement is observed after each cycle of deformation. After the first passes, the structure is non-equal granular with a large difference of grain sizes, but at 7-8 passes the structure becomes homogeneous with the presence of a large number of borders.

a)

b)

c)

d)



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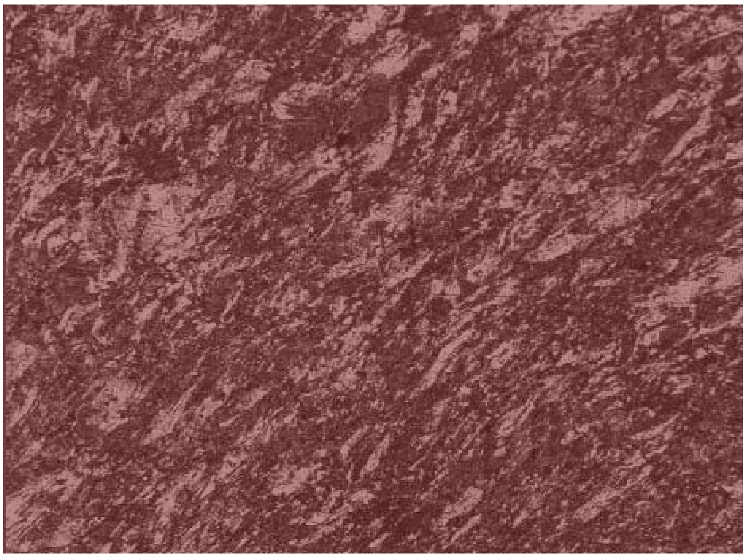


f)

a – at temperature 25°C, mean grain diameter 0,5 microns; b - at temperature 25°C, (longitudinal direction), mean grain diameter 0,6 microns; c – at temperature 320°C, mean grain diameter 0,7 microns; d - at temperature 320°C, (longitudinal direction), mean grain diameter 0,9 microns; e – at temperature 520°C, mean grain diameter 2,1 microns; f - at temperature 520°C, (longitudinal direction)

Fig. 1 - Microstructure of the BrTZn4-3 alloy after 8 pressing cycles, x1000

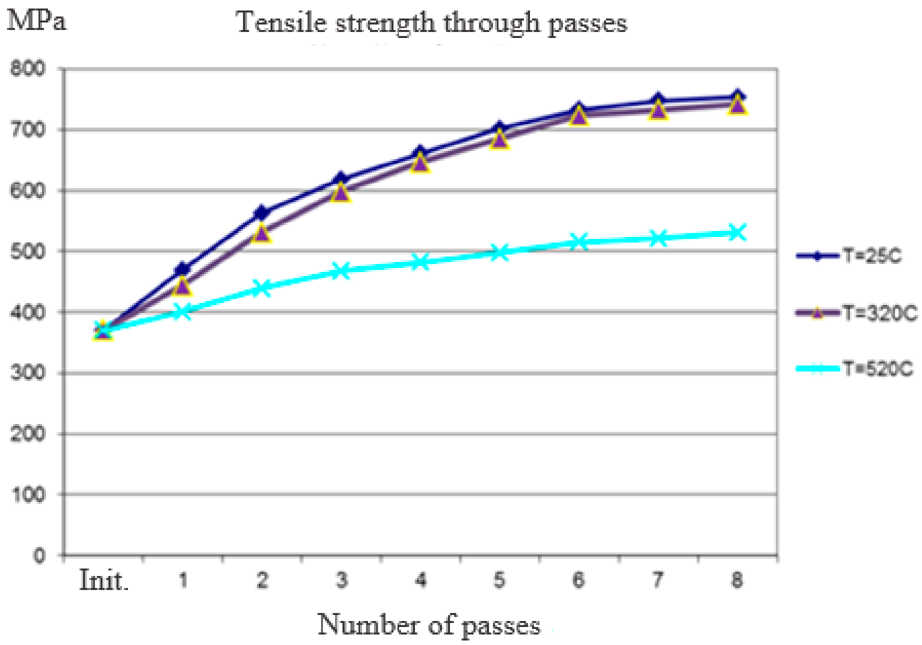
In the study of the microstructure after each pressing cycle, lag of evolution of grain structure was observed in the longitudinal direction. Microstructure often had a marked deformation texture. It was also found that the structure in the transverse direction refines more intensively, however, after 4-5 cycles of pressing refinement of the structure practically uniform in all directions of the sample.

The minimum grain size obtained during pressing of the alloy in equal-channel step die at room temperature equals to 0.5 microns. The resulting structure is homogeneous with a large number of borders. However, at this temperature there were a large number of billets destructions.

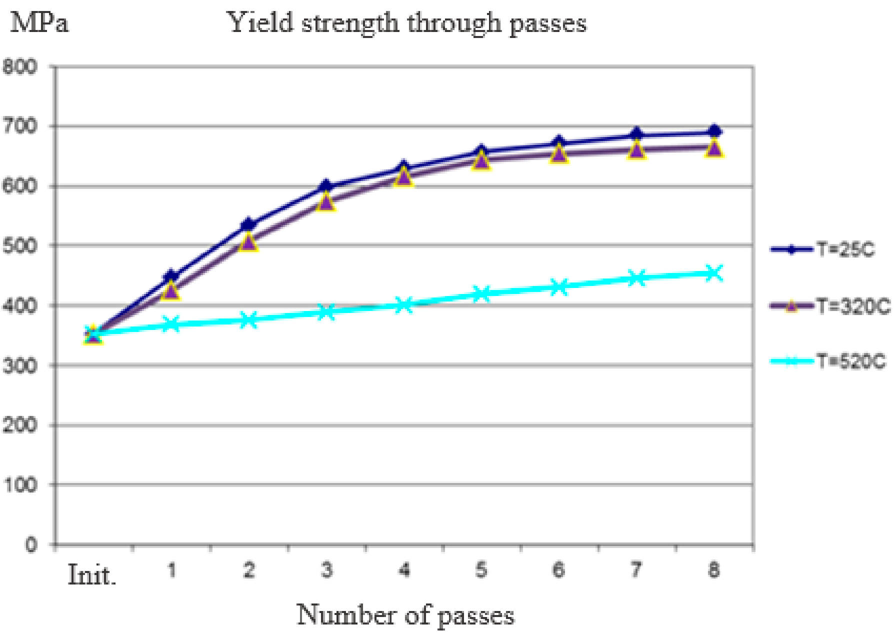
The analysis of the microstructure of single-phase tin bronze after pressing at a temperature of 320°C showed that this pressing temperature accounts for the temperature range of the return, which is characterized by a gradual decrease of the dislocation density, reduction of the concentration of excess defects, the redistribution of dislocations leading to a decrease in the level of micro distortions. The structure in the transverse and longitudinal direction after 8 passes almost homogeneous throughout the billet.

Increasing the heating temperature of the billet before pressing up to 520°C significantly reduces the pressing force and deformation resistance, but increases the unevenness of the metal flow, which grows with increasing of temperature difference between the billet and the container. This leads to an uneven distribution of deformation resistance at the cross section of the billet. Cooling of peripheral layers leads to a faster flow of the inner layers of the billet. As a result, the structure becomes non-equal granular with marked deformation texture. In addition, there is a large discrepancy between the structure in longitudinal and transverse direction.

The results of the study of the mechanical characteristics of the alloy BrTZn4-3 after each pressing cycle at different temperatures are presented in figure 2.



a)



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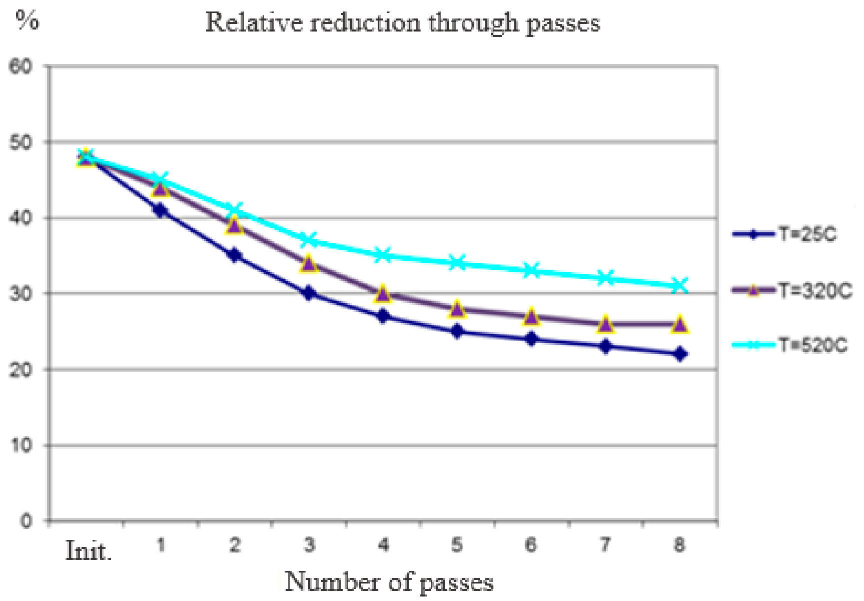

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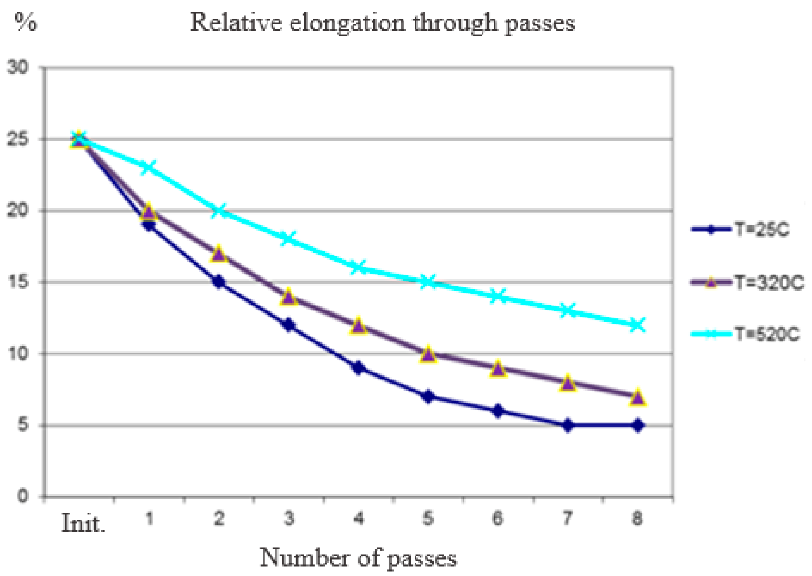

d)

Fig. 2 - Depending mechanical properties of the BrTZn4-3 alloy from the number of passes

During ECA-pressing the most intense hardening of the alloy is observed at the first 2-3 passages, and then the process of strain hardening is slowing, but the characteristics of durability increases. The increase of pressing temperature up to 230°C leads to a significant decrease of the deformation resistance of the alloy. The most intense hardening of the alloy at this temperature occurs at relatively small degrees of deformation, then the process of strain hardening slows and begins to occur dynamic weakening during subsequent deformation. At a pressing temperature of 520°C, the tensile strength is increasing slightly due to the dynamic weakening.

Analyzing graphs of yield stress it can be said that intense increase of the yield stress is a consequence of the reduction of a flow platform on stress-deformation graphs in a tensile test.

After analyzing graphs of relative reduction and elongation, it can be seen a significant decrease of plastic indicators to the fourth pressing cycle. Further, decrease of plastic indicators is virtually nonexistent. Increasing of pressing temperature also leads to the performance reduction, but not so intensively.

Furthermore, at a pressing temperature of 520°C there is a strong anisotropy of properties lie in the fact that strength characteristics is higher in transverse direction than the longitudinal direction.

4. Conclusions

In the course of the experiment, it was found that during ECAP of single-phase tin bronze BrTZn4-3 the size of grain structure is consistently refining with each new deformation cycle. Moreover, the analysis of influence of temperature of the beginning of deformation on the evolution of microstructure and mechanical characteristics of single-phase tin bronze BrTZn4-3 showed that the pressing of the alloy at a temperature of 320°C is the most rational.

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