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Investigation on the deformability of tin bronzes CuSn6 modified with zirconium on the industrial hot rolling of flat ingots

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Materials

ABSTRACT

Purpose: The basic aim of the investigations was to determine the effect of a microadditions of zirconium on the improvement of the plasticity of tin bronze type CuSn6 and its deformability during the production test of hot rolling of flat ingots.
Design/methodology/approach: The principle method of testing the deformability of flat ingots at elevated temperature was rest of their hot rolling under industrial conditions.
Findings: In result of the investigations it has been found that a microadditions of zirconium in an amount of about 0.03÷0.05% ensures an optimal structure and also a higher plasticity and deformability of industrial bronze type CuSn6 in the temperature range of hot rolling.
Research limitations/implications: Attempts of hot rolling permitted only in a limited degree to determine the favourable effects of the modifications of the tested bronze with zirconium. In future these effects ought be verified in other processes of hot plastic working.
Practical implications: The investigations proved that the applied technology of rolling is an effective way of hot plastic deformation of flat tin bronze ingots modified with zirconium.
Keywords: Tin bronzes; Zirconium addition; Ductility minimum; Intergranular fracture; Hot rolling

1. Introduction

An essential problem in the production of copper and copper alloy products particularly continuously cast tin and tin-phosphorus bronzes plastically working by hot rolling, press-forming, extrusion etc., is the phenomenon of low deformability, usually identified as intergranular brittleness. This phenomenon considerably limits or even eliminates the application of such alloys in practice. Intercrystalline brittleness is conditioned by the effect of many physico-chemical, structural and mechanical factors, connected implicité mainly with the chemical composition and structure of the alloys as well as the parameters of plastic deformation [1-5].

Numerous investigations [6-9] have shown that essentially responsible mechanisms of hot fracture of copper alloys may be liquid films and the segregation of impurities at the grain boundary and intercrystalline precipitation, inclusions and intermetallic phases, and also microfractures resulting from grain boundary sliding or from the nucleation, growth and coalescence of cavitation or pores. The presented factors conditioning the hot brittleness of copper alloys particularly tin bronzes, now permit to determine the fundamental mechanisms of intergranular cracking under limited conditions of deformation, mainly in the range of strain rates ($\dot{\varepsilon}$) about $10^{-5} \div 10^{2} s^{-1}$ and temperature of deformation about (0,4÷0,6) of the melting point (Tm) or homological temperature (T/Tm). It has also been found that in many cases these mechanisms are generally compatible with experimental results [10].

A contribution to the explanation of the decreased deformability of copper alloy products at elevated temperature of plastic deformation may from the technological point of view be the method of plastic hot working, patented in Canada and the USA, concerned tin-phosphorous bronzes modified with rare earth elements [11,12]. Due to a number of reasons this method has not so far been industrially applied in a wider range. It has been found, that the plastic properties of tin and tin-phosphorus bronzes increase in result of introducing at least one or more rare earth elements in an amount of 0.005% to 0.4% [11]. Similar effects were achieved by introducing transient elements in a global amount of about 0,2 to 0,8% or simultaneous introduction of several such elements. It has also been found that a restriction of the contents of phosphorus to about 0,03% in bronzes containing about 2÷12% tin permits their hot plastic working after continuous casting. The analysed microadditions ensure an improved plasticity of the alloys and their greater deformability within the temperature range from about 650^{o}C to about 50^{o}C below the solidus temperature [12]. A favourable effect of mischmetal (cerium standard alloy) in an amount of about 0,06% on the refinement of the structure of cast bronze CuSn10 has been demonstrated in reference [13]. A similar effect of the refinement of copper grains was also attained in the case of the simultaneous effect of phosphorus and zirconium.

The actual state of this problem still leaves open the univocal interpretation of the essence of this phenomenon, particularly in the case of the global effect of several mechanisms of fracture and under conditions of a high strain rate applied in numerous technologies of processing non-ferrous alloys. Therefore, the aim of these investigations is the determination of the optimal chemical composition of the investigated tin bronze type CuSn6 modified with zirconium, within the tested concentration of a microaddition of zirconium, ensuring a fine-grain structure of the alloy and an essential limitation of its intercrystalline brittleness in the temperature range of minimum plasticity and deformability of the products and the possibility of hot rolling under the given technological conditions of deformation.

2. Experimental procedure

The investigations concerned industrial bronzes, type CuSn6(B6), modified with zirconium within the range of 0.01÷0.15% obtained from open crucible smelts according to the industrial technology of the Institute of Non Ferrous Metals in Gliwice, the chemical composition of which is to be seen in Table 1. The temperature of hot rolling was determined basing on earlier investigations [14,15] concerning the assessment of the plasticity of tin bronzes modified with zirconium type CuSn6Zr(B6Zr) and basing on the determination of the temperature of the minimum plasticity of these alloys (Fig.1). Flat ingots, size 120x35x265 mm, cast in metal moulds and annealed homogenously for 5 hours at 720^{o}C, and then cooled down in water, were hot rolled from about 760^{o}C. The annealed ingots were then subjected to surface treatment (the so-called skinning). The mechanically treated ingots were heated up in an industrial chamber gas furnace at about 760^{o}C for about 2 hours, then rolled directly in an industrial two-high rolling mill with rolls about 500 mm in diameter. The reduced thickness of the strips in the respective roll passes amounted on the average to 4÷7 mm.

Table 1.
Chemical composition of the investigated alloys

Kind of the alloy	Chemical composition in mass %										
	Sn	Zr	S	P	Bi	Pb	Fe	Si	Zn	Ni	Cu
CuSn6 (B6)	6,75	-	0,002	0,15	0,0004	0,007	0,007	0,001	0.,039	0,003	res.
CuSn6Zr (B6Zr)	7,07	0,15	0,006	0,15	0,0004	0,015	0,008	0,002	0,086	0,006	res.

The overall rolling reduction obtained in the course of rolling of both kinds of bronzes amounted to about 80% of the cross-section band.

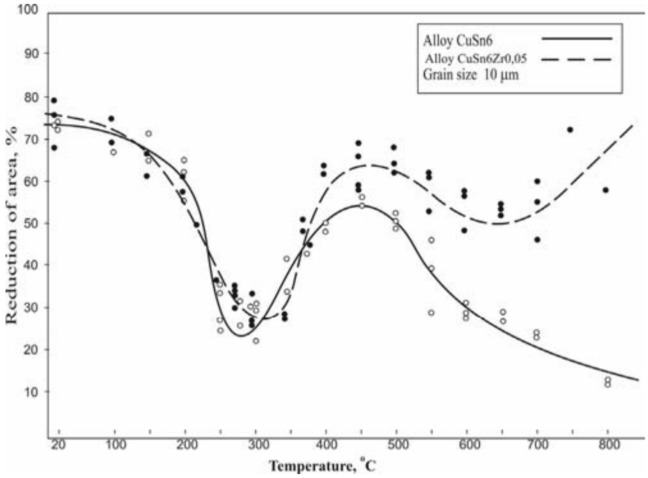


Fig.1. Reduction of area at fracture versus the tensile temperature of industrial tin bronzes modified with zirconium [14]

The logarithmic degree of deformation was about 1.85 respectively. The mean dimensions of the band amounted after rolling to 130x5.4x1270 mm and about 130x57x1200 mm respectively, in the case of bronze B6 and B6Zr.

3. Experimental results and discussion

The mechanical properties of the investigated bronzes after hot rolling have been gathered in Table 2. It has been found that the values of the proof stress ($R_{p0,2}$) of bronze modified with zirconium are by about 15% higher. A similar difference (about 20%) occurs also in the case of the mean values of elongation (A_{50}), compensating the attained increment $R_{p0,2}$.

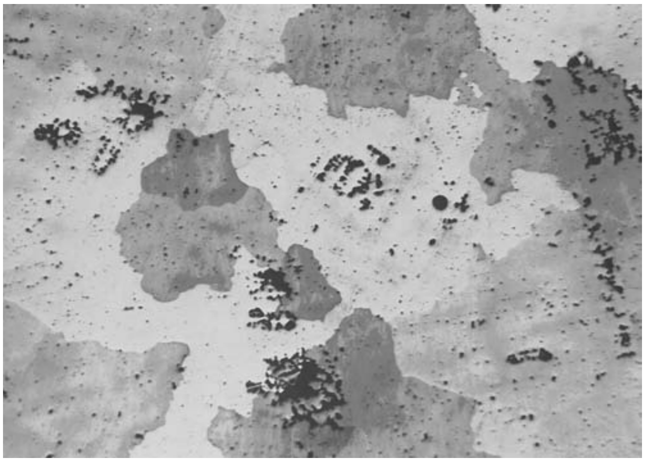


Fig. 2. Coarset-grained structure of industrial bonze type CuSn6 after homogenized annealing, Etched $K_2Cr_2O_7$ in H_2O (H_2 SO_4), (x25)

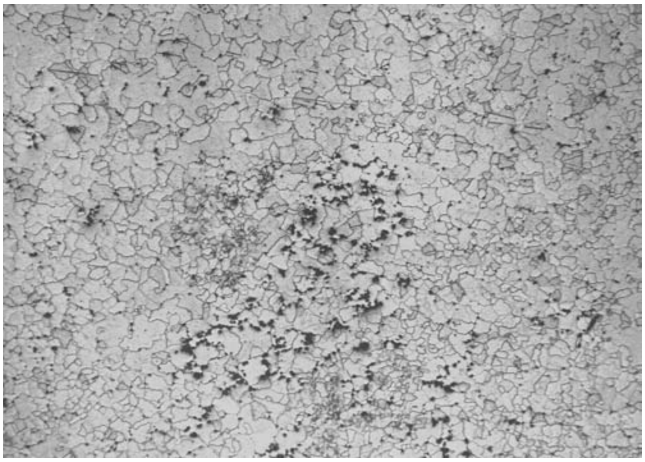


Fig. 3. Fine-grained structure of industrial bronze type CuSn6Zr after homogenized annealing, Etched $K_2Cr_2O_7$ in H_2O (H_2 SO_4), (x25)

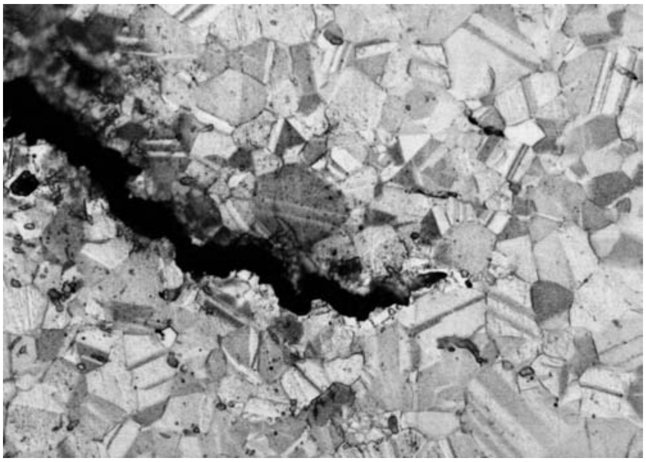


Fig. 4. Structure of industrial bronze type CuSn6 after hot rolling, hot crack from the surface band, (x1000)

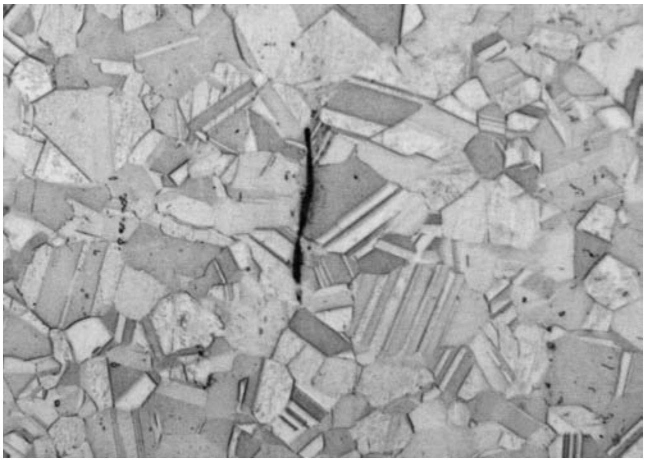


Fig. 5. Structure of industrial bronze type CuSn6 after hot rolling, elongated metallic inclusions in the recrystallized solid solution-α matrix, (x1000)

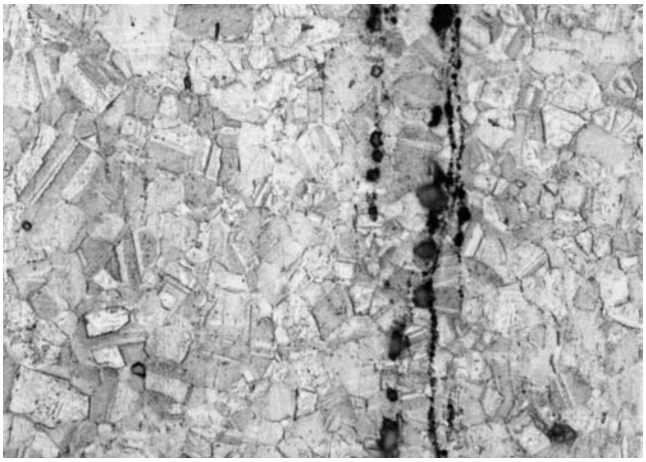


Fig. 6. Structure of industrial bronze type CuSn6Zr after hot rolling, inclusions banding parallelly to RD, (x1000)

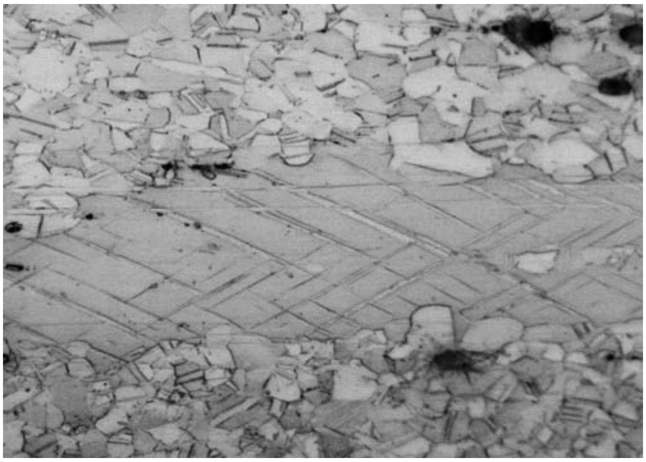


Fig. 7. Structure of industrial bronze type CuSn6Zr after hot rolling, shearing bands with slip lines and inclusions, (x1000)

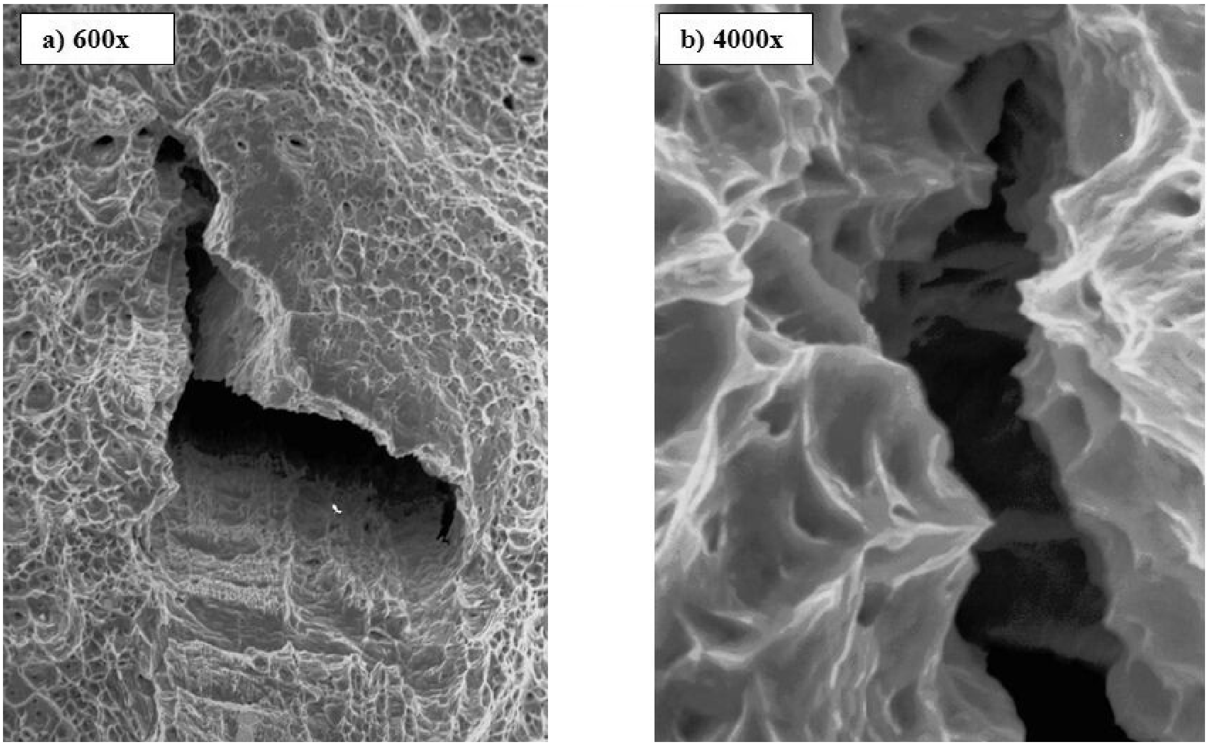


Fig. 8. Ductile fractures with hot cracks of industrial bronze CuSn6 from extreme strip segments after hot rolling, b) magnification of a)

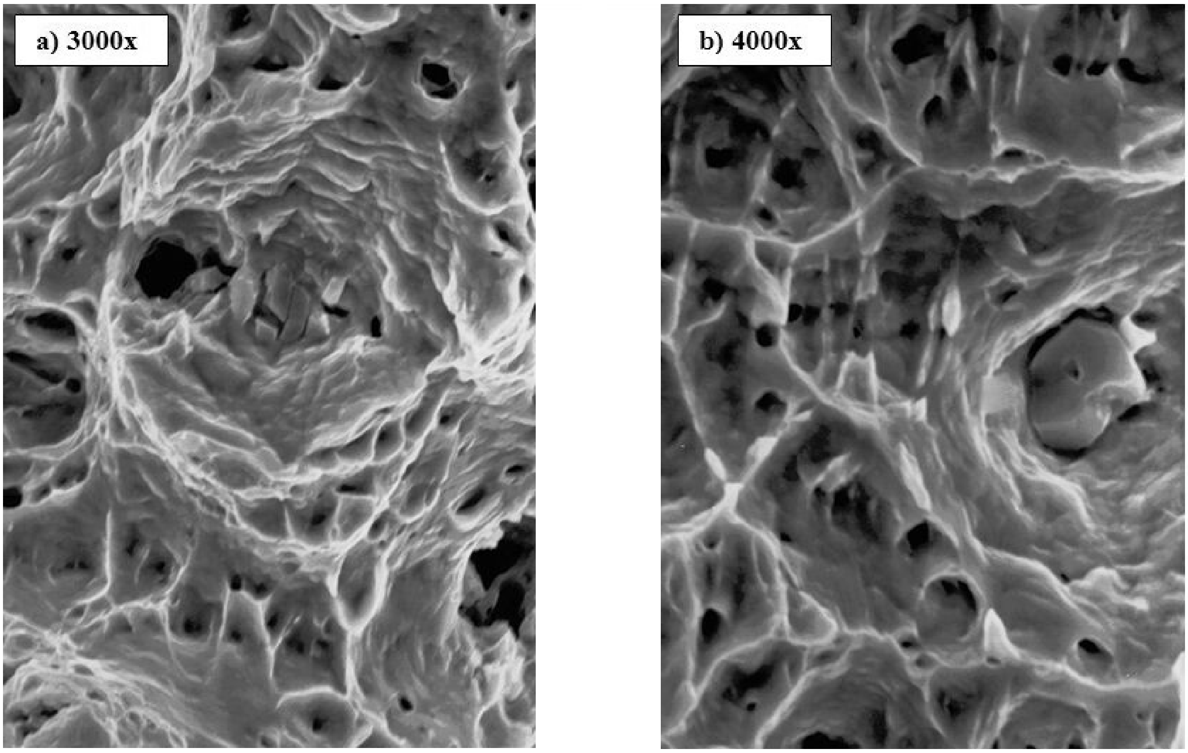
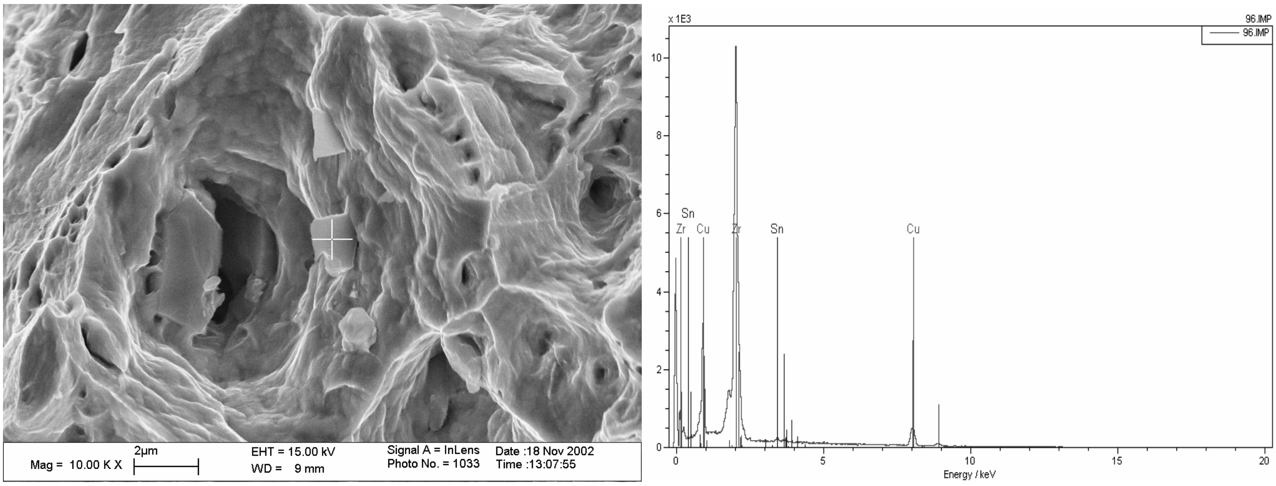
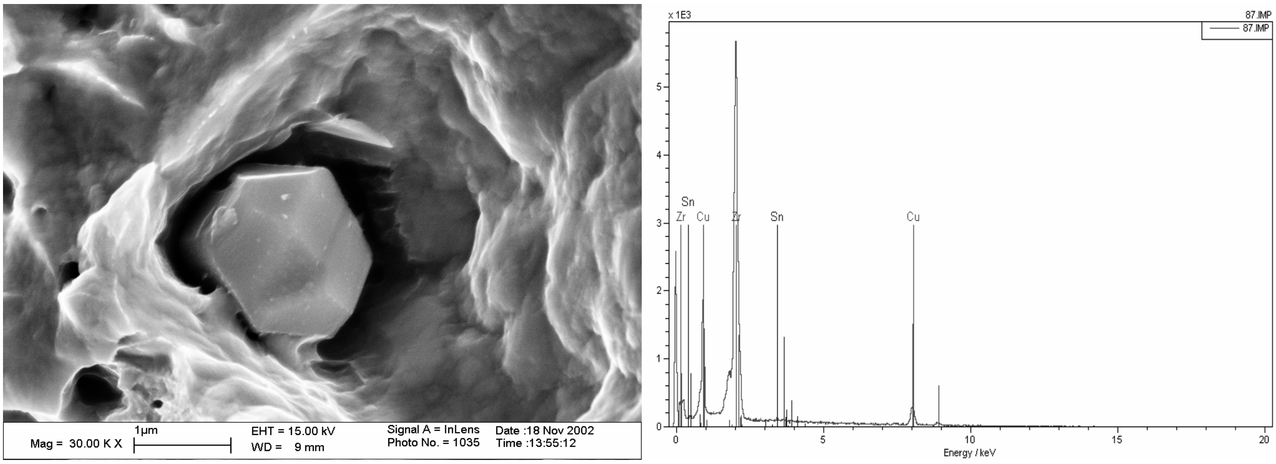


Fig.9. a) b) Ductile fractures of industrial bronze type CuSn6Zr modified with zirconium from extreme strip segments after hot rolling



a) b)

Fig. 10. a) Fractography and b) special pointwise microanalysis of the chemical composition of inclusions in industrial tin bronze type CuSn6Zr alter hot rolling



a) b)

Fig. 11. a) Fractography and b) special pointwise microanalysis of the chemical composition of inclusions in industrial tin bronze type CuSn6Zr alter hot rolling,

Table 2.
Mechanical properties of industrial tin bronze after hot rolling

Kind of the alloy	Mechanical properties		
	$\overline{R}_{p0.2}$ [MPa]	$\overline{R}_{m}$ [MPa]	$\overline{A}_{50}$[%]
CuSn6 (B6)	184.7	384.6	76.6
CuSn6Zr (B6Zr)	215.7	394.7	60.8

In the cast alloys the original dendritic structure was revealed containing numerous clusters and micro-shrinkages with a heterogeneous distribution. After annealing the investigated alloy displays a grain structure with grains of various sizes (Fig.2,3) and with varying intensities of micropores and shrinkage clusters. Industrial bronzes are characterized by a relatively large amount of casting defects if compared with previously investigated model bronzes obtained from laboratory vacuum smelts.

Metallographic observations of rolled bands revealed in the structure of bronze CuSn6 mostly recrystallized grains in the matrix-α with cracks from the surface through the thickness of the band (Fig.4) and single inclusions, elongated in the rolling direction (Fig.5). In the structure of bronze CuSn6Zr modified with zirconium also single effects of cracking have been detected from the surface of the band and numerous band-chain inclusions in the direction of rolling (Fig.6). In the structure of the matrix of the solution-α several effects of cold work could be observed, such as bands of deformation or shearing bands (Fig.7) and inclusions deformed in the course of hot rolling.

The results of fractographic observations of stretched samples, resulting from various zones of the hot-rolled bands of bronzes have been presented in Fig. 8÷11. It has been found that independent of the chemical composition of the bronzes and the place of testing, band transcrystalline ductile fractures do occur. They differ from each other only in the number, distribution and morphology of the inclusions. A common feature is the occurrence of cracks, tearing and stratifications of the material. A detailed fractographic analysis of bronze CuSn6 revealed various kinds of inclusions and cracks and tearings (Fig.8). The chemical composition of the inclusions has been analysed applying the EDX method. The inclusions contain such impurities as Ca, Si, As, S, Al and Fe. Fractographic investigations of bronze modified with zirconium type CuSn6Zr after hot-rolling revealed a ductile fracture with numerous single, mostly crushed inclusions (Fig.9) and some cracks. The identification of the chemical compositions of the inclusions permits to find that they are intermetallic phases of the type CuZr or CuSnZr (Fig.10,11). Characteristic morphological features of these inclusions are flat walls of regular solid bodies, size of the order 2.5÷3µm, distributed mainly at the bottom of the carter and cavings of ductile fractures (Fig.11). Testes of hot-rolling permit to determine to some degree the favourable effects of modifying bronzes CuSn6 on the results of plastic hot deformation, particularly in the case of hot rolling. The analysis of the technology of such hot rolling permits to find that this process is a successful way of hot plastic deformation. At this stage of investigations, however it is rather difficult to decide that this is the optimal way of hot plastic working of these bronzes. Tests of rolling permit also to determine preliminarily the parameters of this process conditioning the favourable improvement in the changes of the structure of bronzes and increasing their plasticity and deformability at elevated temperature by eliminating successfully the cause of intercrystalling fracture.

4. Conclusions

Favourable effects of hot rolling of the investigated bronzes require the following material factors and technological parameters:

[1] The optimal content of microadditions of zirconium in industrial tin bronzes type CuSn6 ought to amount to 0.03÷0.05% and the content of impurities (Pb, S, As, Bi, O) must be restricted to a minimum.

[2] The optimal temperature of diffusion annealing, of the investigated bronzes as well as the preheating temperature for hot rolling should be kept in the range of about 700÷800ºC.

[3] The initial temperature of hot rolling of the investigated bronzes should in the case of the industrially applied strain rate amount to about 750÷780ºC.

[4] The maximum reduction of the band thickness should not exceed 3 mm per roll pass.

[5] The maximum number of roll passes ought to be restricted to the appearance of cracks at the edges of the bands or at the edges of its extreme segments.

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