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PROPERTIES OF CONTINUOUSLY CASTED Cu-Al ALLOY

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Abstract

In this work are shown properties of continuously casted Cu – 9.1Al alloy before and after heat treatment. The continuously cast cylindrical bar with 8 mm diameter was produced using the device for the vertical continuous casting which is connected with the vacuum induction furnace. Heat treatment was consisted of annealing at 900 °C/30 minutes and water quenching. Microstructural analysis was performed by optical microscopy (OM), scanning electron microscopy (SEM) equipped by device for energy dispersive spectroscopy (EDS) and using differential scanning calorimeter (DSC). Also, hardness and mechanical properties were measured. EDS analysis confirmed that as-cast state of Cu – 9.1Al alloy is successfully done and alloy with homogeneous composition was produced. Optical and scanning electron microscopy showed existence of dual-phase $\alpha+\beta$ microstructure, which keeps after heat treatment but with certain sporadic changes of α - phase shape. DSC analysis on all samples presented one endothermic change of the heat flow during the heating, which probably represents $\alpha \rightarrow \beta$ transformation and one exothermic change of the heat flow during the cooling which probably represents $\beta \rightarrow \alpha$ transformation. The effect of heat treatment on the hardness and yield strength values is insignificant, while the tensile strength decreases with annealing.

Keywords: *Cu-Al alloy, heat treatment, microstructure, mechanical properties, hardness*

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INTRODUCTION

Copper and copper alloys constitute one of the major groups of metals which have commercial application. They are widely used because of their good electrical and thermal conductivities, excellent resistance to corrosion, ease production and favorable strength and fatigue resistance. Copper alloys are generally nonmagnetic and can be readily soldered and brazed [1]. The aluminium bronzes are a group of copper-base alloy with approximately 5 to 11 wt. % aluminium with/without other additions. They have good resistance to atmospheric

corrosion with high strength and often can be used for bearing bushes in aircraft frames. Bronzes which containing only copper and aluminium have microstructure with a single α-phase up to about 8 wt. % aluminium and above that level is formed dual-phase α+β alloy. Aluminium bronzes with α+β microstructure have a similar resistance to general corrosion as α-alloy [2]. Alloy with about 10 wt. % aluminium exhibits the best comprehensive properties [3]. Also, in literature [4-6] was obtained that the heat treatment have interesting effects on mechanical properties and microstructure of aluminium bronzes.
Also, copper alloys can belong to a group of shape memory alloys. Good electrical and thermal conductivity makes shape memory alloys on Cu-basis very interesting for practical application. The main Cu-based alloys with potential for shape memory behavior can be classified in three groups: Cu-Al, Cu-Zn and Cu-Sn systems. Shape memory alloys are characterized by high-temperature stable β-phase. However, the base alloys have bad cold workability and martensite stabilization. Therefore, ternary and quaternary elements have been added to improve upon the properties and remove the drawbacks.
The aim of this paper is characterization of the base Cu-Al alloy, which will be used in the next step for production of quaternary alloy with shape memory effects and favorable properties. Consequently, in this research the microstructure and mechanical properties of Cu-9.1Al alloy, before and after heat treatment were analyzed.

MATERIALS AND METHODS

The Cu-9.1Al alloy was prepared by melting of pure elements (copper purity 99.9%, aluminium purity 99.5%). Melting was performed in a vacuum induction furnace under protective argon atmosphere. Chemical composition of investigated alloy was estimated by Optical Emission Spectrometer ICP-OES AGILENT 700. Firstly, the ingot (ϕ110 mm x 180 mm) was produced by graphite mould casting and it was then remelted in the same furnace. Afterwards, continuous casting was followed. The continuously cast cylindrical bar with 8 mm diameter of Cu-Al alloy was produced using the device for the vertical continuous casting which is connected with the vacuum induction furnace, Fig. 1. Solid bars were produced directly from about 13.2 kg melt. The temperature of melted alloy during casting was maintained at 1050 °C. The process of remelting was performed in vacuum 1 mbar. During casting, pressure of argon protective atmosphere was set around 500 mbar. Casting speed was constantly 260-265 mm/min.
Heat treatment of samples was performed in laboratory electro-resistance chamber furnace. Solution annealing of samples was carried out at 900 °C for 15 minutes, followed by quenching in the room temperature water.
The microstructure is characterised by optical microscopy (OM) and scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS). For OM and SEM analysis the samples were ground (from 120 to 1200 grade paper) and polished (0.3 μm Al_2O_3). The prepared samples were etched in a solution composed of 2.5 g $FeCl_3$ and 48 ml methanol in 10 ml HCl.

Thermal analysis was carried out using differential scanning calorimeter (DSC) STA 449 F1 Jupiter® Netzsch, in the temperature range from 20 °C to 900 °C, in the inert atmosphere of argon. DSC investigations were done through two cycles of heating and cooling, with heating/cooling rate of 10 °C/min.
Hardness was tested by Vickers method (HV1). Mechanical properties of samples were determined by tensile testing Zwick machine 50 kN.

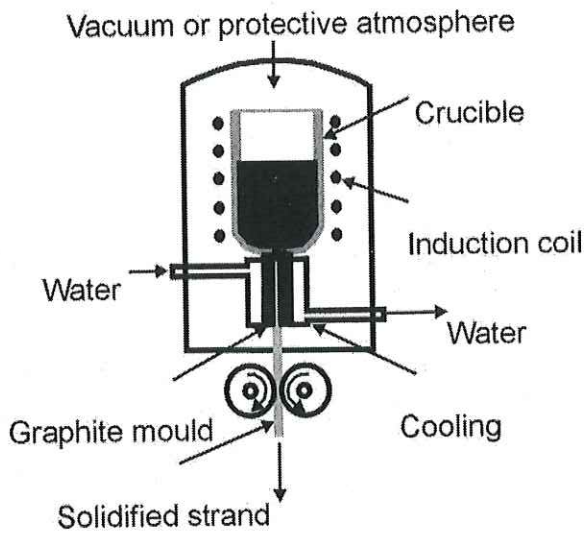
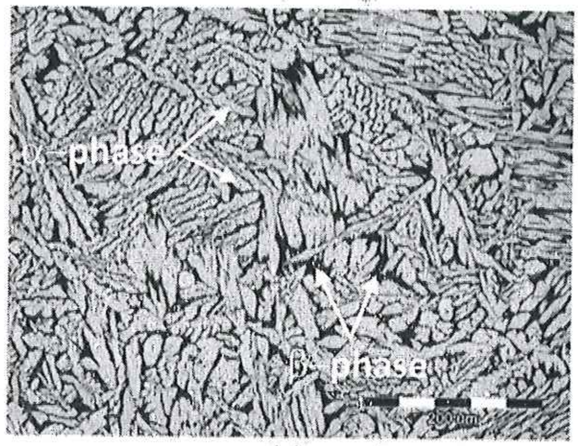


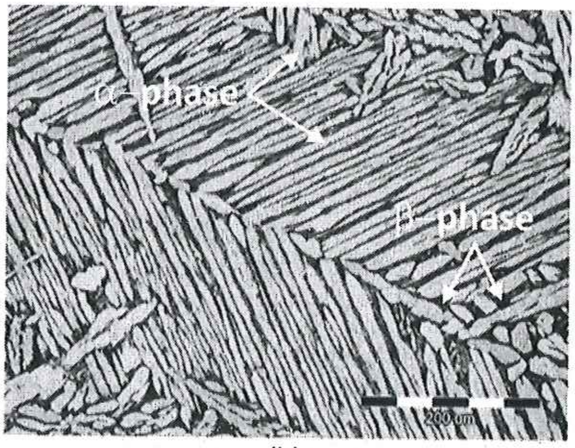
Figure 1. Schematic illustration of casting of Cu-Al alloy by vertical casting technology

RESULTS AND DISCUSSION

Fig. 2 shows micrographs obtained by optical microscopy of the investigated Cu – 9.1 Al alloy. A more detailed analysis of micrographs obtained by optical microscopy in the as-cast state of Cu – 9.1Al alloy shows the dual-phase α + β microstructure. The dual-phase α + β microstructure is retained after quenching, although there is a certain change in α - phase morphology i.e. more needle shape of the α – phase is formed. According to the literature [4] when the 90% Cu - 10% Al is cooled in the equilibrium conditions α + β phase can be formed. The eutectic reaction takes place at 1037 °C and 8.5% Al and at 565 °C and 11.8% Al and β phase transformed in the γ_2 phase. During cooling at non-equilibrium conditions β phase can be replaced by a martensite phase β '. Cenoz and Gutierrez [4] mentioned that at the same time there may be present α and β phases in 90% Cu - 10% Al alloy at a temperature of about 500 °C, according to Cu-Al phase diagram. If the β - phase is rapidly cooled it transforms into α - phase of a similar composition. By cooling of the melt firstly is formed solid β – phase. Afterwards, at about 930 °C begins α - phase precipitation from the β - phase. The growth of α - phase is dependent on the rate of heat extraction. Depending on the cooling rate of α - phase there may be existed in two morphological shapes. The spherical form of the α - phase is formed at some medium rate of cooling and at low and high cooling rates the preferred shape is needle-like [5].



(a)

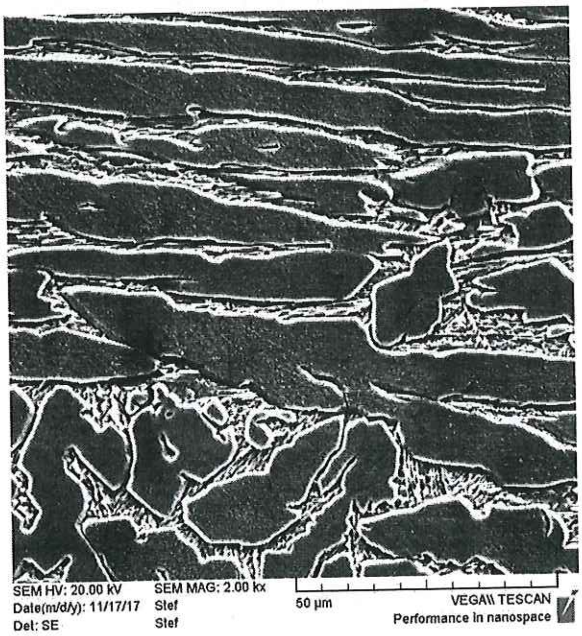


(b)

Figure 2. Optical micrographs of Cu-9.1Al alloy in as-cast state (a) and as-quenched state (900 °C/15'/H_2O) (b)

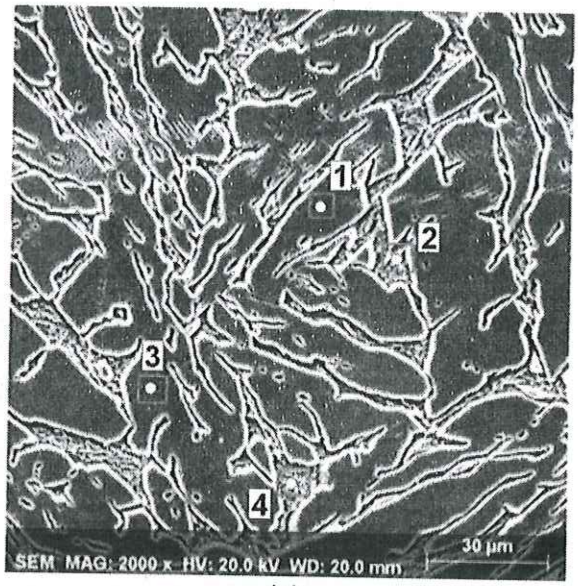
SEM micrographs can showed a more in detail of the microstructural changes. SEM micrographs of as-cast state Cu-9.1Al alloy show the dual-phase α + β microstructure throughout the cross-section of investigated sample (Figs. 3 and 4). From the results of EDS analysis (Table 1) it can be seen that there is no significant difference in chemical composition in all investigated positions. The as-quenched state (900 °C/15'/H_2O) shows a sporadically occurring appearance of properly oriented needles of α - phase which were like martensite shape. With a more detailed analysis of SEM micrographs and EDS results it can be concluded that vertical continuous casting process produced a rod (ϕ8 mm) in the as-cast state with a homogeneous microstructure with a copper content of 92.42 to 93.34 wt. % and aluminum 6.66 to 7.58 wt. % (Table 1). A somewhat lower part of aluminum content obtained by EDS analysis in regards to the chemical composition of Cu – 9.1 Al alloys can be associated with the error of the EDS measurement i.e. EDS point analysis was performed. Also, SEM micrographs confirmed the presence of dual-phase α + β microstructure and formation of the needle shape α - phase after quenching.

(a)

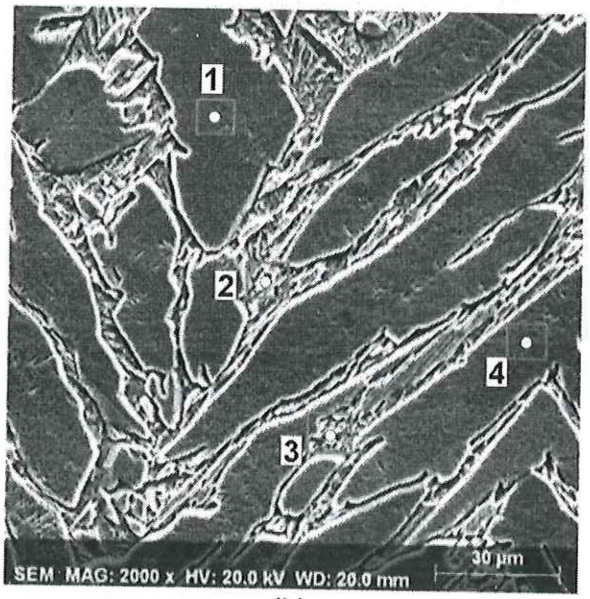


(b)

Figure 3. SEM micrographs of Cu-9.1Al alloy in as-cast state (a) and as-quenched state (900 °C/15'/H_2O) (b)



(a)



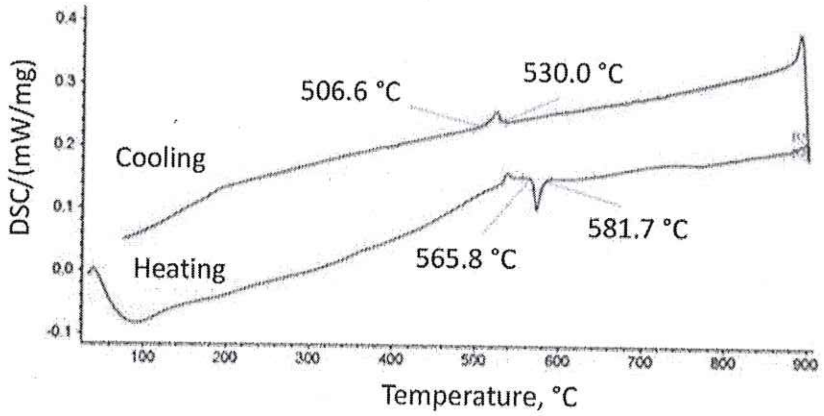
(b)

Figure 4. SEM micrographs of Cu-9.1Al alloy in as-cast state (a) and as-quenched state (900 °C/15'/H_2O) (b) with marked positions for EDS analysis

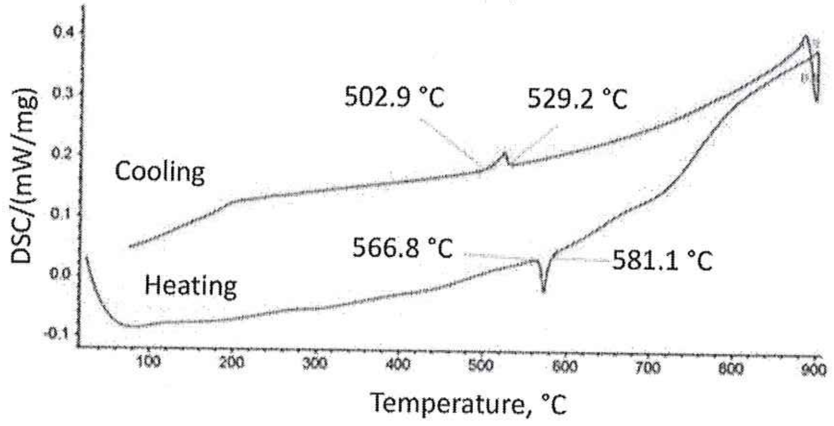
Table 1. The chemical composition of the Cu-9.1Al alloy in as-cast state and as-quenched state (positions marked at the Fig. 3a and 3b), wt.%

State of samples	Position	Chemical composition, wt.%	
		Cu	Al
As-cast state	1	93.10	6.90
	2	93.34	6.66
	3	92.42	7.58
	4	93.01	6.99
As-quenched state (900 °C/15\`/H_2O)	1	93.50	6.50
	2	92.24	7.76
	3	87.07	12.93
	4	93.57	6.43

From the results of the DSC analysis it can be seen that in all investigated samples the almost identical changes of the thermal flow at about the identical temperature occurred (Fig. 5). In Fig. 5a it can be seen that the as-cast Cu – 9.1 Al alloy showed endothermic peak at 565.8-581.7 °C (DSC heating curve). One exothermic peak can be observed at the DSC cooling curve at 530.0-506.6 °C. In Fig. 5b it can be seen that on the DSC heating curve of the as-quenched Cu – 9.1Al alloy, the significant change of the thermal flow (endothermic peak) at 566.8-581.1 °C is occurred. Also, one exothermic change can be observed at the DSC cooling curve at 529.2-502.9 °C for as-quenched state. Compared of as-cast to as-quenched state, it can be concluded that there is no change in the temperatures of the endothermic and exothermic reactions. By analyzing the DSC curves obtained during the heating of the investigated samples and microstructures, endothermic reaction probably represents the $\alpha \rightarrow \beta$ transformation. In contrast, on DSC cooling curves noted exothermic peak (both samples) at approximately the same temperature, probably represents the $\beta \rightarrow \alpha$ transformation.



(a)



(b)

Figure 5. DSC diagrams of Cu-9.1Al alloy in as-cast state (a) and as-quenched state (900 °C/15'/H_2O) (b)

In Fig. 6 it can be seen that the as-cast state of Cu-9.1Al alloy has the lowest hardness value (156.47 HV1), in comparison with hardness value of as-quenched state (169.67 HV1). However, these differences are negligible and can be related to changes in microstructure and to error of measurement. The influence of quenching on the yield strength and tensile strength can be seen on Fig. 7. By the analysis of Fig. 7 it can be seen that the quenching has a low influence on the yield strength (values of 560.78 MPa in as-cast state and 577.67 MPa in as-quenched state). In the contrast, the values of tensile strength show a significant drop after the quenching. In as-cast state the tensile strength value was 1509.9 MPa, while after quenching it decreases to 1082.47 MPa. Fig. 8 shows the influence of quenching on elongation and contraction of Cu-9.1Al alloy. The largest elongation value was observed in the as-cast state (32.31%) and slightly decreased in as-quenched state (30.10%). The contraction shows the same tendency. As-cast state has contraction value of 50.82% and as-quenched state 45.94%.

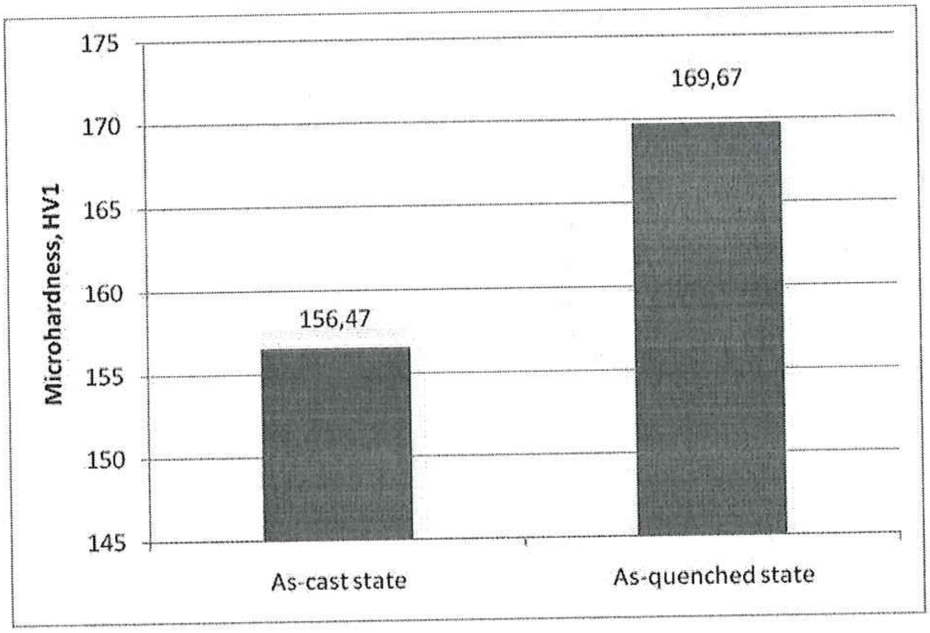


Figure 6. Hardness values (HV1) of investigated Cu-9.1Al alloy in as-cast state and as-quenched state (900 °C/15'/H_2O)

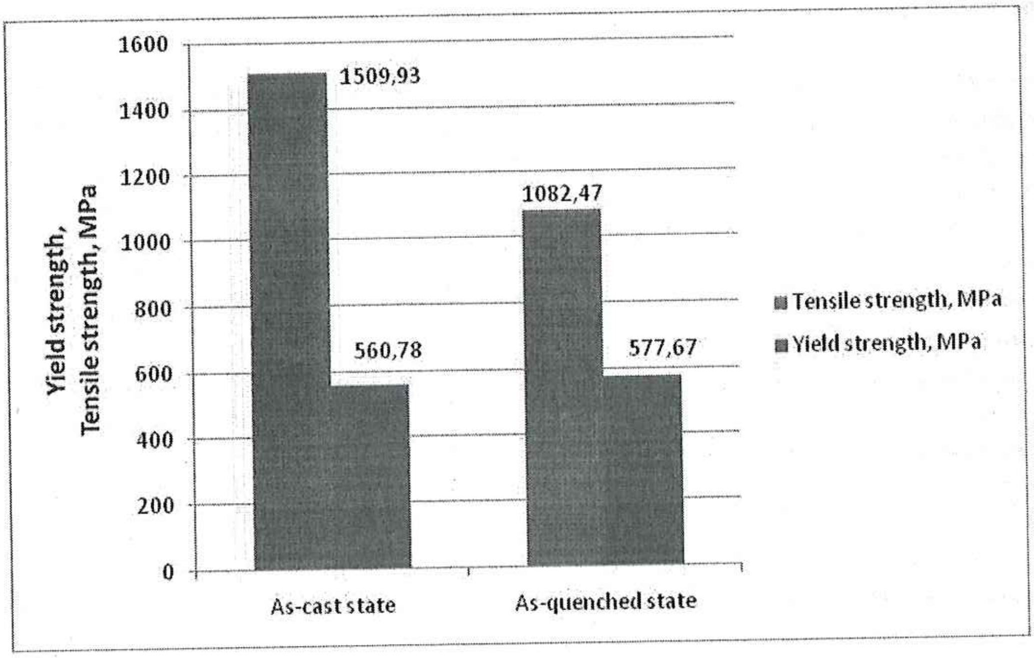


Figure 7. Tensile strength and yield strength of investigated Cu-9.1Al alloy in as-cast state and as-quenched state (900 °C/15'/H_2O)

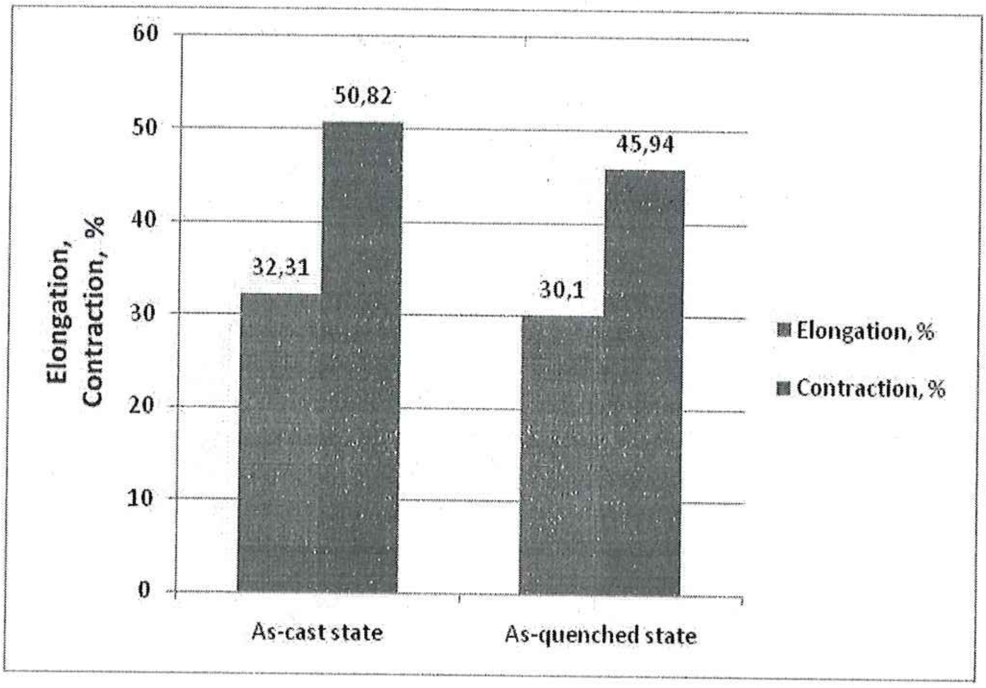


Figure 8. Elongation and contraction of investigated Cu-9.1Al alloy in as-cast state and as-quenched state (900 °C/15'/H_2O)

CONCLUSIONS

The microstructural analysis with hardness and mechanical properties were carried out on bar (ϕ8 mm) of Cu-9.1Al alloy in as-cast state and as-quenched state (900 °C/15`/H_2O). From the obtained results we can draw the following conclusions:

- Optical microscopy established the presence of dual-phase $\alpha + \beta$ microstructure in investigated alloy in the as-cast state. The dual-phase $\alpha + \beta$ microstructure is retained after quenching but more needle shape of the α - phase is formed. Detailed SEM analysis confirmed the existence of dual-phase $\alpha + \beta$ microstructure at room temperature in both samples.
- The EDS analysis noted some small differences in the chemical composition in both investigated samples and all analyzed positions. This suggests that high homogeneity of alloy composition in as-cast state was achieved successfully.
- DSC analysis showed no change in the temperatures of the endothermic and exothermic reactions. The endothermic peak (at about 566-582 °C) in both investigated state probably represents the $\alpha \rightarrow \beta$ transformation. Also, the exothermic peak in both samples was at approximately the same temperature and probably represents the $\beta \rightarrow \alpha$ transformation.
- The as-cast state has the lowest hardness value (156.47 HV1), in comparison with hardness value of as-quenched state (169.67 HV1).

-The quenching has a low influence on the yield strength (values of 560.78 MPa in as-cast state and 577.67 MPa in as-quenched state). The values of tensile strength show a significant drop after the quenching. The largest elongation value was observed in the as-cast state (32.31%) and slightly decreased in as-quenched state (30.10%). The contraction shows the same tendency.

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