

# Properties of continuously casted Cu-Al alloy

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# PROCEEDINGS BOOK

## 17<sup>th</sup> INTERNATIONAL FOUNDRYMEN CONFERENCE

**Hi-tech casting solution and  
knowledge based engineering**



Opatija, May 16<sup>th</sup> – 18<sup>th</sup>, 2018

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**PROCEEDINGS BOOK****17<sup>th</sup> INTERNATIONAL FOUNDRYMEN CONFERENCE**

Hi-tech casting solution and knowledge based engineering

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## PREFACE

Foundry industry as a base branch represents an important factor contributing to the economic potential of each country. Current market development as well as technical and economic objective, the production of high-quality, low-cost and environmentally friendly casting, requires application of recent and advanced materials, as well as production technologies, followed and supported by understanding of production process.

Production imperative is pointed into the recent technologies and improved materials for everyday usage in our homes, workplaces, as well as materials with special requirements for specific applications such as those for the automotive or space industry. Industrial activities, which are defined as strategic activities in the Republic of Croatia are Metal Casting and Production of Final Metal Products, recognized as "economic growth drivers" because they are expected to realize higher rates of growth and employment.

What does knowledge based engineering actually means? The following abstract indicate the definition:

*“The handling of knowledge represents the key to competitiveness, with company-specific product and process knowledge marking a unique position with respect to competition. Knowledge-based engineering (KBE) is a comprehensive application of artificial intelligence in engineering. It facilitates new product development by automating repetitive design tasks through acquisition, capture, transform, retention, share, and (re-)use of product and process knowledge. The idea behind KBE is to store engineering knowledge once by suitable, user friendly means and use it whenever necessary in a formal, well documented, repeatable and traceable process. It works like design automation. This chapter begins with the definition of knowledge in an engineering context and subsequently addresses the state-of-the-art in KBE research. Three particular areas of research are discussed in detail: knowledge structuring, maintainability of knowledge and KBE applications, and the technological progress and weaknesses of commercial KBE applications like KBE templates. From case study examples, various recent developments in KBE research, development and industrial exploitation are highlighted. By the resulting sequence optimization of the design process a significant time saving can be achieved. However, there are still notable drawbacks such as the complexity of KBE implementation and the adaptability of developed applications that need to be researched and solved. A view on KBE systems within the Concurrent Engineering context is synthesized, leading to the identification of future directions for research.”*

[J. Stjepandić, W. J. C. Verhagen, H. Liese, P. Bermell-Garcia, Knowledge-Based Engineering, in Concurrent Engineering in the 21<sup>st</sup> Century Foundations, Developments and Challenges; J. Stjepandić, N. Wognum, W. J. C. Verhagen (Editors) Springer International Publishing Switzerland, 2015, DOI 10.1007/978-3-319-13776-6, Chapter 10, pp. 255 – 286]

Hi-Tech casting solution comprehends to recent technology and educated and skilled engineers. The Conference topics were designed as presentations of the current "state of the art" research in collaboration with industry, and production innovation with the aim to improve the competitiveness.

The scope of **17<sup>th</sup> International Foundrymen Conference (IFC)** covers scientific, technological and practical aspects concerning research, development and application of casting technology with the common perspective – increase of competitiveness. Special attention will be focused towards the competitiveness ability of foundries, improvement of materials features and casting technologies, environmental protection as well as subjects connected to the application of castings.

During this Conference 44 papers will be presented. Book of Abstracts of the 17<sup>th</sup> International Foundrymen Conference includes summaries of the papers. The Proceedings book consists of papers *in extenso* published in electronic format (CD). Full length papers have undergone the international review procedure, done by eminent experts from corresponding fields, but have not undergone linguistic proof reading. Sequence of papers in Proceedings book has been done by category of papers in following order: plenary lectures, invited lectures, oral and poster presentation, and inside the category alphabetically by the first author's surname.

Within the Conference Student section is organized. This is an opportunity for industry to meet and recruit human resources as a main potential for business development. Correlation of material knowledge based engineering and technology improvement known as Hi-Tech solutions, represent a knowledge transfer between industry and higher education institutions. Higher education at the Faculty of Metallurgy (HEI), conceived through the program and the learning outcomes, is based, inter alia, on promoting students' scientific and research work on applied topics, enabling ambitious and creative young people to become independent problem solvers, developing and supporting their curiosity, analytics and communication: Graduates like the labour market need!

This occasion represents the opportunity to discuss and increase the mutual collaboration between HEIs' and industry with the aim of information exchange related to advanced experience in foundry processes and technologies, gaining the new experience in presentation and / or teaching process within lifelong learning process.

The organizers of the Conference would like to thank all participants, reviewers, sponsors, auspices, media coverage and all those who have contributed to this Conference in any way.

President of Organizing Board

A handwritten signature in blue ink, reading "Z. Z. Brodarac". The signature is written in a cursive style with a light blue background behind it.

Assoc.Prof. Zdenka Zovko Brodarac, PhD



THE HEAD OF ORIENTAL GOD (ATIS?)  
bronza  
2<sup>nd</sup> century AD  
SISCIA (modern Sisak, Croatia)



ILLYRIAN HELMET  
iron  
6<sup>th</sup> century BC

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## Hi-tech casting solution and knowledge based engineering

Opatija, May 16<sup>th</sup>-18<sup>th</sup>, 2018

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### PROPERTIES OF CONTINUOUSLY CASTED Cu-Al ALLOY

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**Poster presentation**

*Original scientific paper*

#### 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  $\alpha$  - 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



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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  $\alpha$ -phase up to about 8 wt. % aluminium and above that level is formed dual-phase  $\alpha+\beta$  alloy. Aluminium bronzes with  $\alpha+\beta$  microstructure have a similar resistance to general corrosion as  $\alpha$ -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  $\beta$ -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 ( $\phi 110$  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  $\mu\text{m}$   $\text{Al}_2\text{O}_3$ ). The prepared samples were etched in a solution composed of 2.5 g  $\text{FeCl}_3$  and 48 ml methanol in 10 ml HCl.



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Thermal analysis was carried out using differential scanning calorimeter (DSC) STA 449 F1 Jupiter<sup>®</sup> 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.

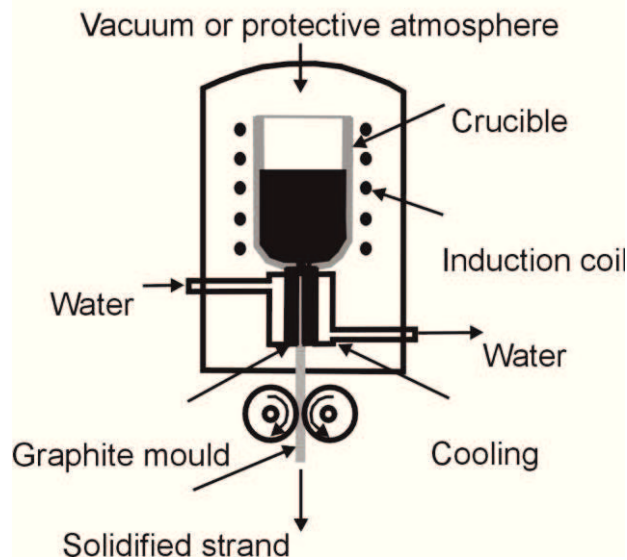


Figure 1. Schematic illustration of casting of Cu-Al alloy by vertical casting technology

## 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  $\alpha + \beta$  microstructure. The dual-phase  $\alpha + \beta$  microstructure is retained after quenching, although there is a certain change in  $\alpha$  - phase morphology i.e. more needle shape of the  $\alpha$  - phase is formed. According to the literature [4] when the 90% Cu - 10% Al is cooled in the equilibrium conditions  $\alpha + \beta$  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  $\beta$  phase transformed in the  $\gamma_2$  phase. During cooling at non-equilibrium conditions  $\beta$  phase can be replaced by a martensite phase  $\beta'$ . Cenoz and Gutierrez [4] mentioned that at the same time there may be present  $\alpha$  and  $\beta$  phases in 90% Cu - 10% Al alloy at a temperature of about 500 °C, according to Cu-Al phase diagram. If the  $\beta$  - phase is rapidly cooled it transforms into  $\alpha$  - phase of a similar composition. By cooling of the melt firstly is formed solid  $\beta$  - phase. Afterwards, at about 930 °C begins  $\alpha$  - phase precipitation from the  $\beta$  - phase. The growth of  $\alpha$  - phase is dependent on the rate of heat extraction. Depending on the cooling rate of  $\alpha$  - phase there may be existed in two morphological shapes. The



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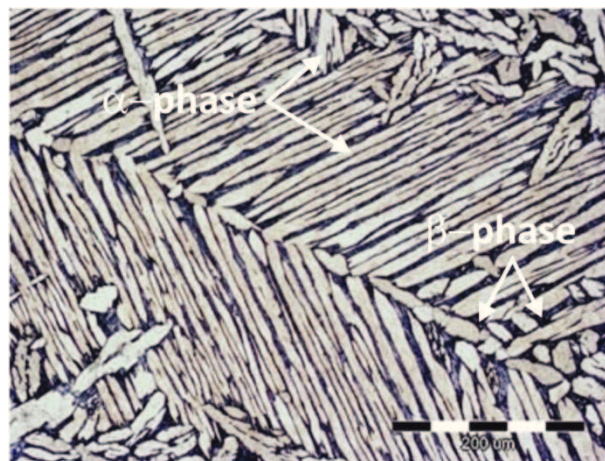
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spherical form of the  $\alpha$  - phase is formed at some medium rate of cooling and at low and high cooling rates the preferred shape is needle-like [5].



(a)



(b)

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

SEM micrographs can show a more in detail of the microstructural changes. SEM micrographs of as-cast state Cu-9.1Al alloy show the dual-phase  $\alpha + \beta$  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<sub>2</sub>O) shows a sporadically occurring appearance of properly oriented needles of  $\alpha$  - 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 ( $\phi$ 8 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



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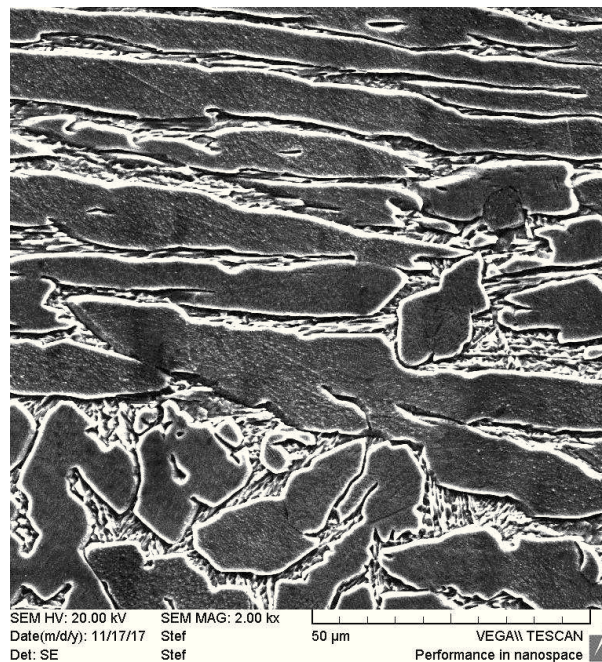
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associated with the error of the EDS measurement i.e. EDS point analysis was performed. Also, SEM micrographs confirmed the presence of dual-phase  $\alpha + \beta$  microstructure and formation of the needle shape  $\alpha$  - phase after quenching.



(a)



(b)

Figure 3. SEM micrographs of Cu-9.1Al alloy in as-cast state (a) and as-quenched state (900 °C/15'/H<sub>2</sub>O) (b)

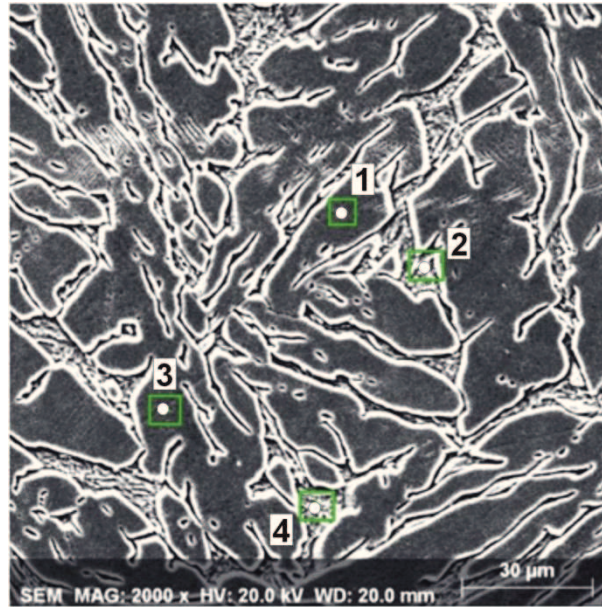


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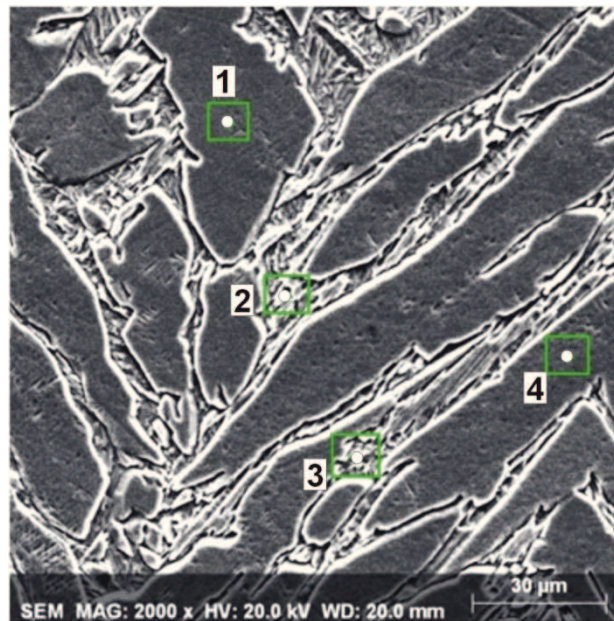
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(a)



(b)

Figure 4. SEM micrographs of Cu-9.1Al alloy in as-cast state (a) and as-quenched state (900 °C/15'/H<sub>2</sub>O) (b) with marked positions for EDS analysis



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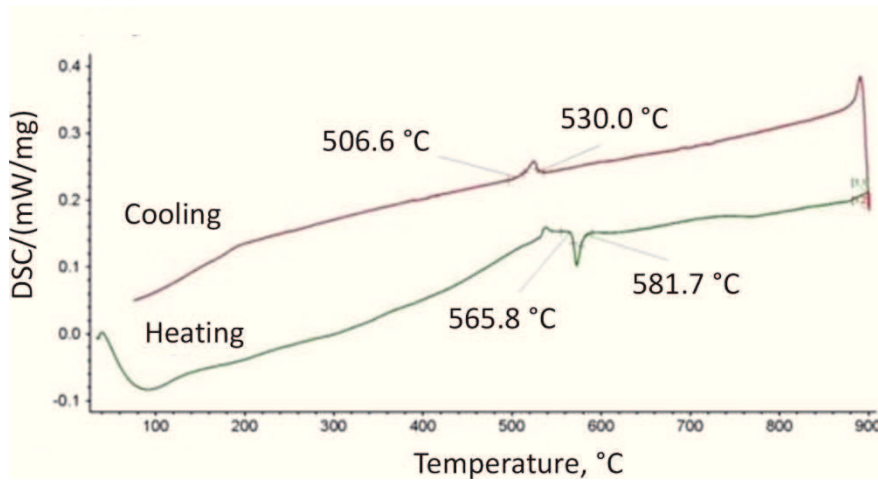
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Table 1. The chemical composition of the Cu-9.1Al alloy in as-cast state and as-quenched state (positions marked at the Fig. 3a and 3b), wt.%

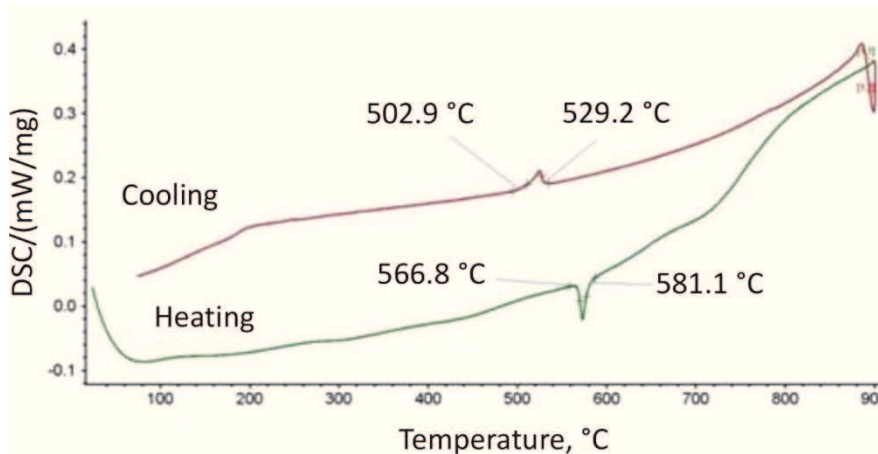
State of samples	Position	Chemical composition, wt.%	
		Cu	Al
As-cast state	1	93.10	6.90
	2	93.34	6.66
	3	92.42	7.58
	4	93.01	6.99
As-quenched state (900 °C/15`/H <sub>2</sub> O)	1	93.50	6.50
	2	92.24	7.76
	3	87.07	12.93
	4	93.57	6.43

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<sub>2</sub>O) (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



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Opatija, May 16<sup>th</sup>-18<sup>th</sup>, 2018

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contraction shows the same tendency. As-cast state has contraction value of 50.82% and as-quenched state 45.94%.

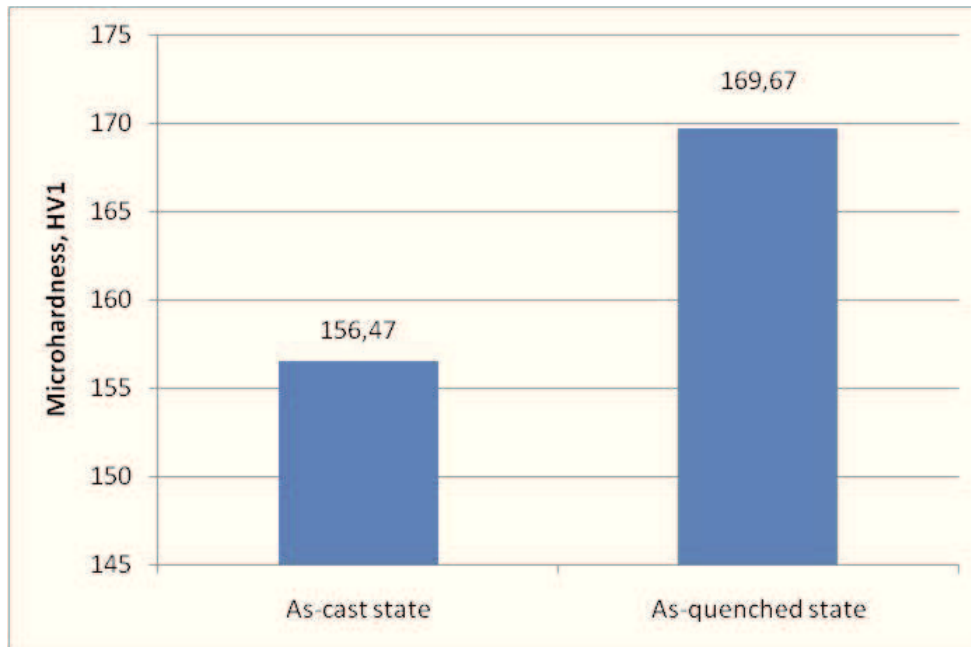


Figure 6. Hardness values (HV1) of investigated Cu-9.1Al alloy in as-cast state and as-quenched state (900 °C/15'/H<sub>2</sub>O)

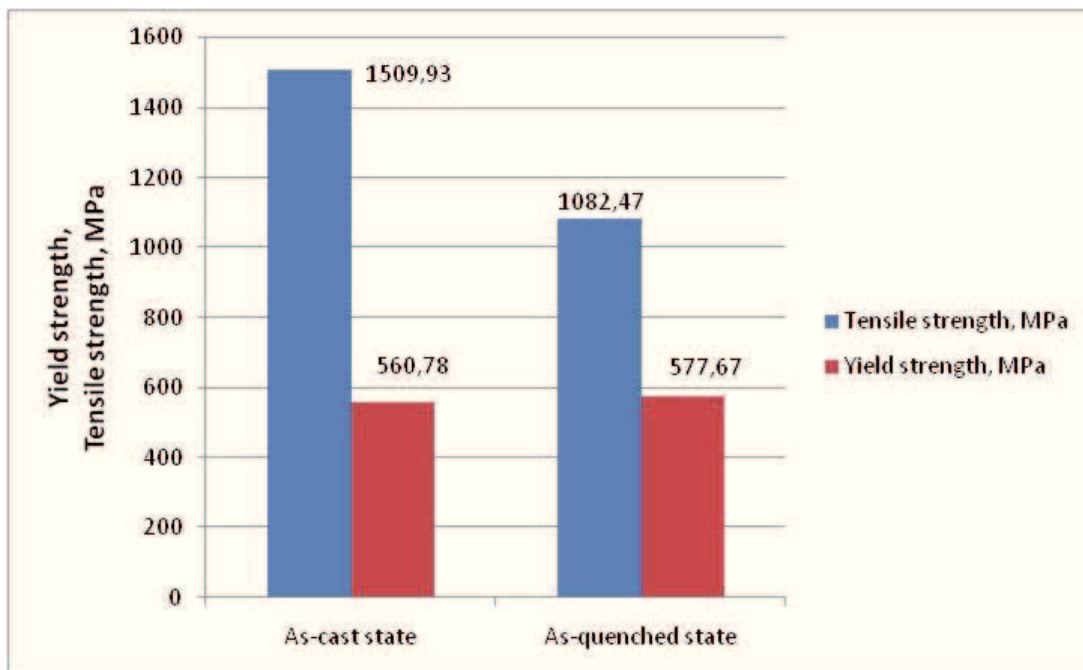


Figure 7. Tensile strength and yield strength of investigated Cu-9.1Al alloy in as-cast state and as-quenched state (900 °C/15'/H<sub>2</sub>O)



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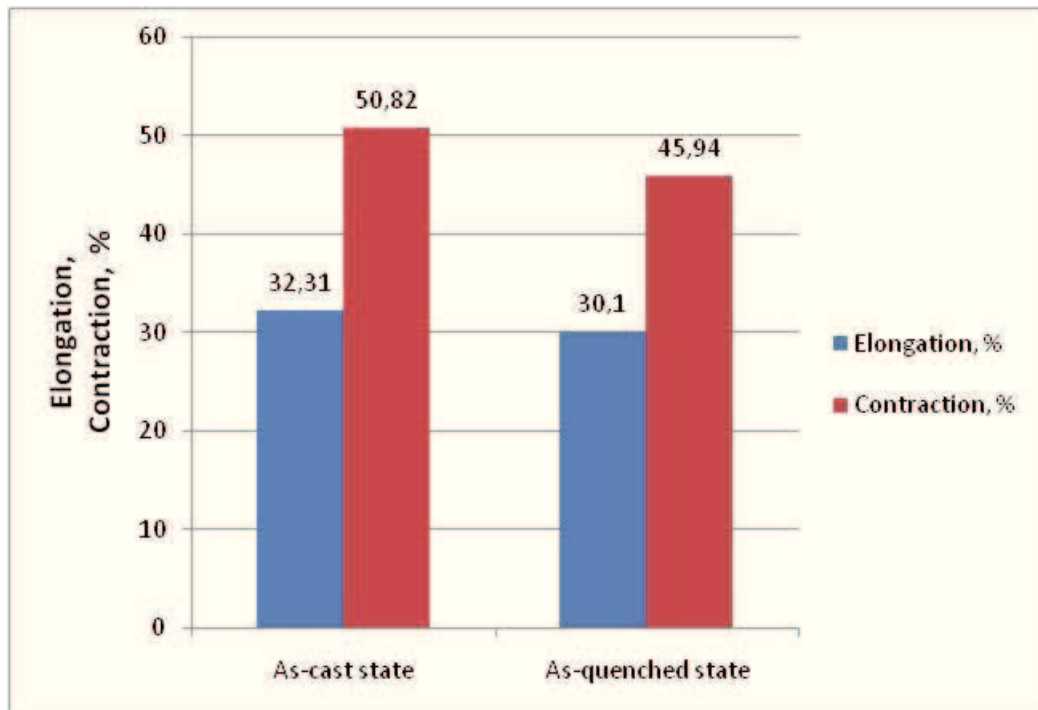


Figure 8. Elongation and contraction of investigated Cu-9.1Al alloy in as-cast state and as-quenched state (900 °C/15'/H<sub>2</sub>O)

### CONCLUSIONS

The microstructural analysis with hardness and mechanical properties were carried out on bar ( $\phi 8$  mm) of Cu-9.1Al alloy in as-cast state and as-quenched state (900 °C/15'/H<sub>2</sub>O). 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  $\alpha$  - 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).



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-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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### Acknowledgements

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