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THE INFLUENCE OF THERMAL TREATMENTS ON THE MECHANICAL PROPERTIES OF ALUMINUM BRONZES

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Abstract: *The purpose of the work is to present the influence of hardening and tempering heat treatments on the mechanical properties of aluminum bronzes.*
After processing, the material was cast into metal shells in the form of bars with dimensions ø 40×300 [mm] and later these were subjected to thermal treatments of tempering (850-900^{0}C) and holding for 120 minutes, and tempering (350-550^{0}C) with holding time between 60-240 minutes. Subsequently, the mechanical properties, such as hardness and tensile strength, of aluminum bronzes were determined depending on the heat treatment parameters.
It is found that during the tempering treatment the values of the mechanical characteristics change significantly in relation to the tempering temperature and the holding time at this temperature, the holding time at the tempering temperature influencing the mechanical properties of the alloy. The analysis of the mechanical properties, hardness and breaking strength of the tempered samples, shows that for the range of tempering temperatures 700-850^{0}C, these properties increase with temperature.
The experimental results indicated that the best operating characteristics for the analyzed alloy were obtained at a tempering temperature of 875^{0}C and a holding time at the tempering temperature of 1 hour, with a tempering at a temperature of 4000C, with a holding time of 90 minutes. Quenching and tempering heat treatment is a fundamental engineering process for improving the mechanical properties of metals, ensuring performance and reliability in various industrial and technological applications.

Key words: *aluminum bronze, hardening treatment, tempering treatment, hardness, mechanical strength*

1. INTRODUCTION

Copper alloys, depending on their properties and fields of use, can be grouped into antifriction alloys, with high electrical and thermal conductivity, anticorrosive, refractory, cryogenic, for cutting on automatic lathes, with special mechanical properties, for welded joints, superconducting, magnetic, resistive, for pressure casting, for deep drawing, with high modulus of elasticity, for the chemical, food, naval, aeronautical, automotive industries, etc [1-3].

Aluminum bronzes are the most widespread and valuable special bronzes due to their superior properties. In terms of corrosion resistance, aluminum bronzes are considered among the best copper-based alloys, being in many cases superior to stainless steels and Cu-Ni alloys [2-7].

These alloys resist well in hydrogen sulfide atmospheres, sulfur dioxide, in chloride and chlorate solutions, in mineral and organic acids, in fresh water and sea water, etc., as a result of the formation of the Al_2O_3 film, which behaves excellently under the action of reducing substances, but resists less in the presence of strong oxidants.Iron in aluminum bronzes refines the structure, increases strength and hardness, but reduces the fluidity of the alloy [5-9].

Manganese in aluminum bronzes increases strength, plasticity and antifriction properties, but significantly reduces fluidity. The simultaneous addition of iron and manganese substantially improves the mechanical and physical characteristics of aluminum bronzes.

Nickel is the most effective addition to aluminum bronzes, improving their mechanical characteristics, increasing their compactness and resistance to high temperatures.

Lead practically does not dissolve in the basic components of the alloy (Cu and Al), nor in other alloying elements. For this reason, this metal is found in the structure in the form of inclusions, negatively influencing the mechanical properties, corrosion resistance and making it impossible to process them by plastic deformation.

Cobalt has a similar action to nickel in aluminum bronzes, improving their mechanical characteristics, anti-corrosion properties and refractoriness. [5-11]
Chromium has a strong effect on the characteristics of aluminum bronzes if added in a proportion of 0.5...2.7%, increasing the mechanical properties, refractoriness and especially the corrosion resistance in different environments.

Tin is an element increasingly present in aluminum bronzes, because it leads to an obvious increase in the plasticity properties and to a lesser extent the resistance. Tin improves the corrosion resistance.
Silicon is added as a substitute for nickel, improving the antifriction properties, corrosion resistance and fluidity.

Beryllium is the alloying element with the strongest action on Cu-Al alloys, in the sense that its presence favors the spectacular improvement of the physical-mechanical characteristics, especially the resistance to cavitation corrosion, the mechanical properties, and the refractoriness. [7-9]

2. MATERIALS

In order to obtain the alloy of bronze with aluminum, the melting process starts from pure metal elements, in the form of ingots or waste. The metallic charge in the case of bronzes with aluminum can be composed of the following: cathode copper, (various brands); technical aluminum, SREN 576 - 2004 and SREN 1676 - 1998; technical aluminum waste from electrical engineering or from other fields: bars, wires, sheets, etc.; Cu-Al prealloy ingots; Cu-Al bronze waste, from dismantling and whose chemical composition is known; Cu-Al bronze shavings, from mechanical processing, whose chemical composition is known, own waste from the foundry such as scrap, slag, casting networks, but also copper prealloys, ferromanganese.

Non-metallic materials are represented by different types of fluxes specific to the elaboration of copper-aluminum alloys.The alloy was developed in an induction furnace.

Large pieces of copper cathodes or copper waste were introduced into the furnace, later introducing small pieces, when the metal bath is formed. Melting is continued until the temperature of the metal bath reaches 1150-1200 °C. The furnace is stopped and the deoxidation sample is poured. The bath is allowed to settle and cool to a temperature of 1120-1140°C in order to introduce the aluminum. Cooling is necessary because when introducing the aluminum, a large amount of heat is released, which causes the bath temperature to increase by 50-100°C. Aluminum is introduced in the form of metal or pre-alloy, preheated to 150-180°C, into the metal bath under the slag layer.

The bath is homogenized using a steel bar, so as not to "break" the slag layer or to be entrained in the melt. They will be introduced in the form of pre-alloy or in a solid state, the other alloying elements proceeding to homogenize the bath. These materials will be shredded or cut into small pieces and preheated. When casting into shells, the alloy temperature is 1200-1250°C, and the temperature of the metal shell is approx. 250°C.
Technical purity materials were used in the development (Cu – cathode 99.95% and Al – ingot 99.95%).

After preparation, the material was cast into metal shells in the form of bars with dimensions ø 40×300 mm. Table 1 shows the chemical composition of the cast alloy.

Table 1. Chemical composition of the cast alloy

Material	Chemical composition [%]				Maximum impurities [%]							
	Al	Fe	Mn	Ni	Cu	Pb	Zn	Sn	Si	As	Sb	P
Cast alloy	9,98	0,65	1,23	0,045	residue	0,008	0,3	0,0018	0,0017	traces	0,0012	traces

From the experimental data provided by the specialized literature, for the studied alloy it can be considered that the temperature of approximately 850^{0}C represents the optimal temperature that delimits the α+β and β domains.

At the same time, the specialized literature mentions that the casting properties, mechanical characteristics and antifriction properties improve with increasing aluminum content.

The variation of the mechanical characteristics of aluminum bronzes, depending on the aluminum content and the state of the material are presented in the diagram in figure 1.

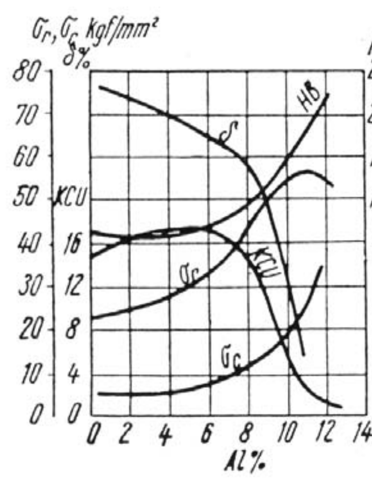

Figure 1. The variation of the mechanical characteristics of bronzes with aluminum, depending on the aluminum content [15]

3.RESULTS AND DISCUSSIONS

3.1 Determination of mechanical properties

The mechanical tests consisted of determining the tensile strength and hardness.
The tensile strength τ_r was determined according to STAS 200-75. Normal cylindrical specimens with M10 threaded head, with diameter d_0=7 mm, were used.

The hardness values were obtained using a Brinell hardness tester with a ball ø=2.5 mm and a load of 187.5 [daN] according to STAS 165-66.

Table 2. Variation of hardness according to the tempering temperature

Temperature [^{0}C]	Hardness
725	165
750	175
800	243
850	254
900	259
950	280
1000	246

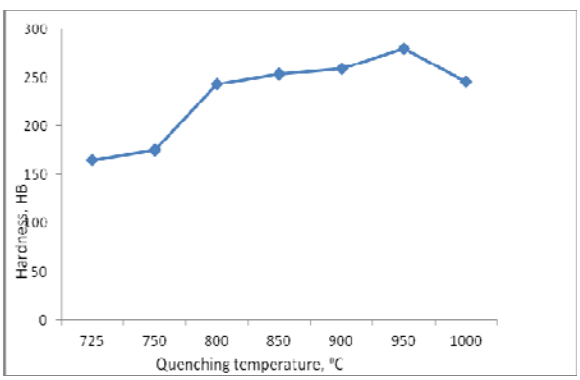

Figure 2. The variation of hardness depending on the tempering temperature for the alloy analyzed

According to figure 2, we find that the optimal temperature for determining the mechanical characteristics is (850-950)^{0}C, and the hardness value increases while remaining constant in the range of values 250-300 HB. In order to determine the thermal parameters of heat treatment, the tensile specimens were heat treated according to the complete regime indicated in figure 3. Table 3 presents the heat treatment parameters.

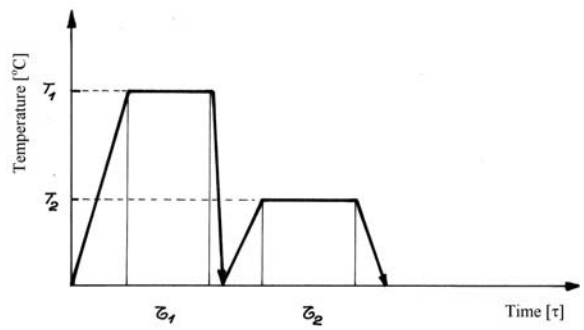

Figure 3. Temperature variation diagram with time for the thermal treatment

Table 3. Variation of temperature with holding time

Heat treatment	Temperature	Holding time
Quenching	T_1=850^{0}C,875^{0}C, 900^{0}C	δ_1=120'
Tempering	T_2=350^{0}C,400^{0}C, 450^{0}C,500^{0}C, 550^{0}C	δ_1=60 ', 90 ', 120 ',240'

The samples were subjected to thermal treatment, tempering at 850^{0}C with a holding time of 120 minutes and the tempering temperature between (350-550)^{0}C.
It is found that the value of the tensile strength for the bronze alloy alloyed with aluminum is found and has a value of 79.5[daN/mm2].

Therefore, for a quenching temperature between (850-900)^{0}C with tempering at a temperature of 400^{0}C and a holding time of 90 minutes, the following results were obtained, presented in figures 4 and 5.

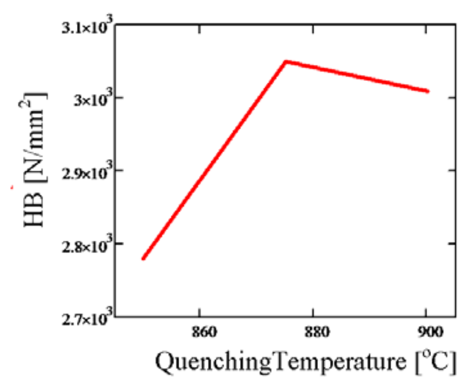

Figure 4. Variation of hardness with quenching and tempering temperature at 400^{0}C

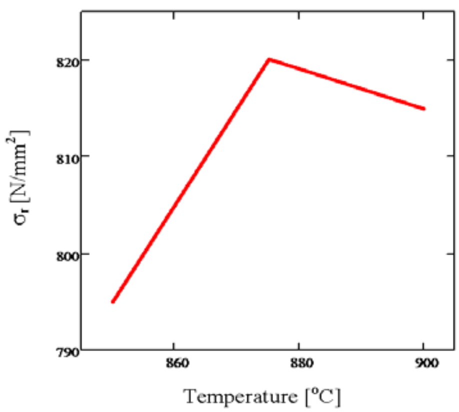

Figure 5. Variation of tensile strength with quenching and tempering temperature at 400^{0}C

Therefore, for a quenching temperature between (850-900)^{0}C with a recovery temperature of 4000C and a holding time of 90 minutes, it is found that both hardness and tensile strength increase with increasing temperature up to a value of 880^0 C, after which they decrease.

After a quenching heat treatment at 875^{0}C and with a recovery temperature that is between (350-550)^{0}C and a holding time of 90 minutes, hardness and tensile strength curves were drawn, obtaining graphs 6 and 7.

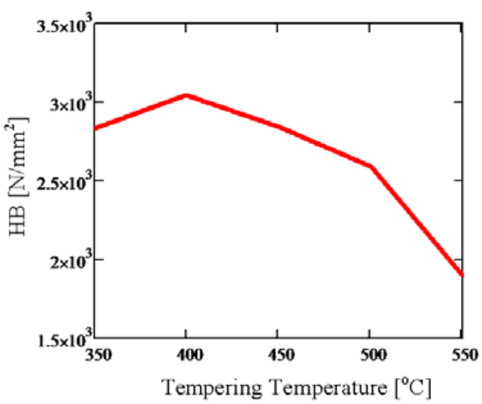

Figure 6. Variation of hardness depending on tempering temperature

According to figure 6, we observe that once the annealing temperature increases, the hardness of the researched material decreases, the same thing is obtained for the tensile strength, reaching a maximum at a temperature of 400^{0}C after which the hardness and strength values decrease with increasing annealing temperature.

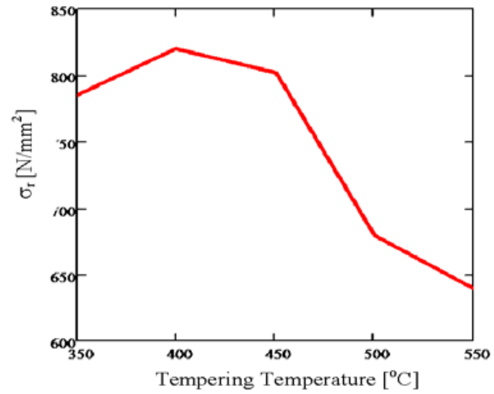

Figure 7. Variation of tensile strength as a function of tempering temperature

Graphs were drawn at the quenching temperature of 875^{0}C with tempering at 400^{0}C, depending on the holding time of the tempering heat treatment ranging from 60-240 minutes. According to the graphs in figures 8-12, from which we find that both mechanical properties decrease with the holding time, the hardness reaching a maximum at a holding time of 100 minutes, and the tensile strength reaching a maximum at 120 minutes.

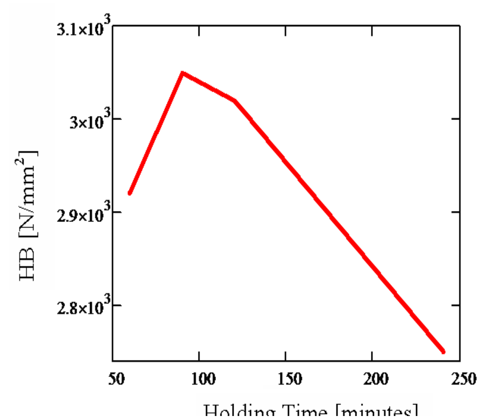

Figure 8. Variation of hardness according to holding time

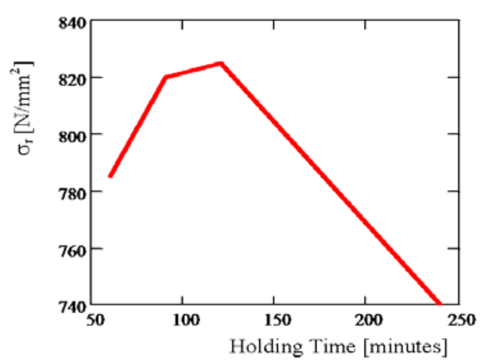

Figure 9. Variation of breaking strength depending on the holding time

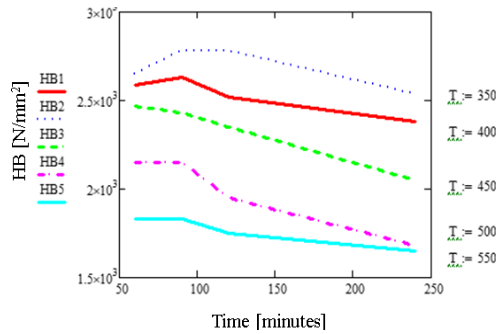

Figure 10. Variation of hardness with holding time at tempering temperatures (350-550)^{0}C at quenching temperature of 850^{0}C

Graphs were drawn at a quenching temperature of 8500C with tempering at (350-550)^0 C, depending on the holding time of the tempering treatment between 60-240 minutes, figure 11. According to figure 11, we find that the lowest hardness is obtained at a tempering temperature of 550^{0}C, and the highest at a tempering temperature of 400 ^{0}C.

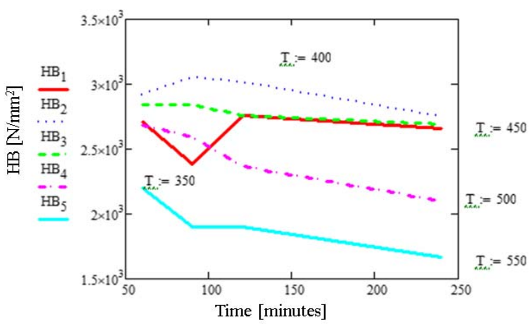

Figure 11. Variation of hardness with holding time at tempering temperatures (350-550)^{0}C at the quenching temperature of 875^{0}C.

According to figure 12, we find that the lowest hardness is obtained at a tempering temperature of 550^{0}C, and the highest at a tempering temperature of 400^{0}C, the hardness values for the other tempering temperatures being between the two tempering temperatures.

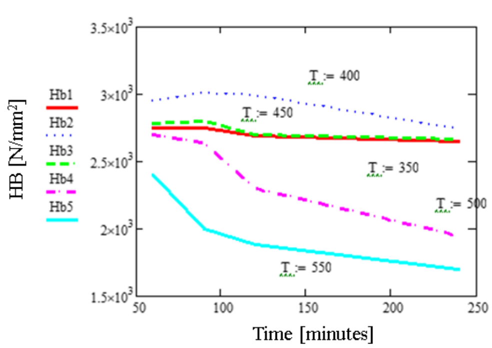

Figure 12. Variation of hardness with holding time at tempering temperatures (350-550)^{0}C at the quenching temperature of 900^{0}C

At a quenching temperature of 900^{0}C, the lowest hardnesses are obtained at a tempering temperature of 550^{0}C, and the highest at a tempering temperature of 400^{0}C.

At temperatures higher than 4000C, the diffusion rate is high enough for the precipitation processes to occur rapidly so that at a holding time longer than 60 minutes, the coalescence of the precipitates occurs, influenced by the decrease in strength properties.

4. CONCLUSIONS

In the tempering process, the values of the mechanical characteristics change significantly in relation to the tempering temperature and the holding time at this temperature.

The holding time at the tempering temperature influences the mechanical properties and the structure of the material.

The influence differs in relation to the tempering temperature, so if at the tempering temperature located up to 400^{0}C the resistance properties variation curves show a maximum in the range of 90-120 minutes, at temperatures higher than 400^{0}C, the resistance properties decrease continuously. The explanation of this phenomenon lies in the diffusion rate (determining factor in precipitation processes) which is relatively low at temperatures up to 400^{0}C. Consequently, a longer time is required for the precipitation of the secondary phases (maximum resistance properties being between 90-120 minutes).

The analysis of the mechanical properties, hardness and tensile strength of the hardened samples shows that for the range of hardening temperatures (700-850)^{0}C, these properties increase with temperature.

Regarding the hardening temperature, an increase in hardness values was found in the range (850-900)^{0}C, followed by a decrease in hardness at hardening temperatures higher than 900^{0}C.

Therefore, following the experimental results obtained, we consider that, under the conditions in which the aluminum bronze is heat treated, according to the regime, namely a hardening temperature of 875^{0}C, a holding time at the hardening temperature of 1 hour, a return to a temperature of 400^{0}C, with a holding time of 90 minutes after the temperature is uniformized on the product section, the best operating characteristics are ensured for this alloy.

Quenching and tempering heat treatment is a crucial process in the metallurgical industry, used to improve the mechanical properties and durability of metals. This process involves exposing the metal material to high temperatures, followed by cooling and tempering at lower temperatures to obtain a controlled structure and properties.

Quenching and tempering heat treatment is essential in the production of critical components for various industries, such as the automotive, aerospace and energy industries. By precisely controlling the temperature and exposure time, this process allows for the production of metal components with superior mechanical properties, wear resistance and dimensional stability.

The benefits of this heat treatment include increased durability, corrosion resistance and the ability to withstand extreme conditions of use. It also optimizes the performance of components in high-stress applications.

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