MINING AND METALLURGY INSTITUTE BOR
and
TEHNICAL FACULTY BOR, UNIVERSITY OF BELGRADE

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International October Conference

53rd International October Conference on Mining and Metallurgy

PROCEEDINGS

Editors:
Ana Kostov
Milenko Ljubojev

3 – 5 October 2022. Hotel "Albo" Bor, Serbia

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INFLUENCE OF THERMO-MECHANICAL PROCESSING PARAMETERS ON THE TENSILE STRENGTH OF COPPER WIRE PRODUCED BY THE "UP CAST" PROCESS

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Abstract

Copper wire with a starting diameter of Ø 8mm, produced by the "up cast" process, was used in this work. The obtained wire is subjected to drawing, whereby the profiled wires with the following dimensions are obtained: 2.5 x 1.8 mm (deformation degree ε=91 %), 2 x 1.25 mm (deformation degree ε=95 %) and 2.74 x 0.41 mm (deformation degree ε=99 %). 30 cm long samples were cut from each cross section, which were first annealed, then cooled in water and finally subjected to the tensile strength measurement. The annealing was carried out in a nitrogen atmosphere of very high purity at temperatures of 400, 500 and 600 ºC for 2 times, 4 times and 6 times, the time for which a semi-recrystallized structure is obtained. For greater accuracy of the results, three repetitions of the experiment were performed. An increase in tensile strength is observed at all annealing times with an increase in deformation degree.

Keywords: *"up cast" postprocess, profiled copper wires, tensile strength*

1 INTRODUCTION

The thermomechanical processing procedureis one of the most important chapters within the quantitative and qualitative consideration of parameters in the field of plastic processing of metals. A significant increase in interest in the thermomechanical processing procedure originates from the fact that some thermomechanical parameters of processing, such as: deformation degree, annealing temperatures and annealing time, are gaining more and more importance because these are the parameters that have a great influence on the subsequent properties of metals. With an increase in the deformation degree, the indicators of resistance to deformation increase: limit of elasticity, proportional limit, limit of elongation and tensile strength, and indicators of plasticity, such as: relative elongation, percent reduction of area and impact toughness, decrease. On the other hand, the subsequent recrystallization annealing achieves the opposite phenomena - indicators of resistance to the deformation decrease, and indicators of plasticity increase [1-3]. Numerous studies have shown that the correct selection of procedure for obtaining the copper wire and optimal thermomechanical procedure of processing can significantly improve its quality. One of the procedures for copper wire obtaining, where the surface of cast wire has very small defects, which is reflected in further plastic processing, is the "up cast" procedure.

In this procedure, the metal is continuously drawn through the graphite matrix in the vertical plane where it hardens. The upper end of matrix is fixed with a screw in a water-cooled copper mantle, while the lower end is immersed in the melt. The matrix position is vertical and coincides with the product drawn upwards. Output from the matrix i.e., casting speed depends only on the cooling capacity of a cooler. The low content of oxygen (0.0005%

to 0.001%) in cast wire enables the good exploitation properties, and therefore good quality. The cast wire is further molded to the final dimensions by the cold plastic processing [4].

2 EXPERIMENTAL

A copper wire with a starting diameter of Ø 8mm, produced by the upcast process, was used for examination. This wire was then subjected to direct drawing according to a special procedure, through a series of matrixes, where the profiled wires with the following dimensions are obtained: 2.5 x 1.8 mm (deformation degree ε=91 %), 2 x 1.25 mm (deformation degree ε=95 %) and 2.74 x 0.41 mm (deformation degree ε=99 %). 30 cm long samples were cut from each cross section, which were first annealed, then cooled in water and finally subjected to a tensile strength measurement. Annealing was performed in a high-purity nitrogen atmosphere at temperatures of 400, 500 and 600 °C for 2, 4 and 6, the time for which a semi-recrystallized structure is obtained. For a greater accuracy of the results, three repetitions of the experiment were performed. The tensile test was performed in the metal testing laboratory at the Technical Faculty in Bor on a universal machine for tensile, compression and bending tests. The samples, wedged in the jaws of machine, were exposed to the tensile forces until breaking, while the force flow was monitored on the load registration device, i.e. the force required to cause the break was read. Based on the determined maximum tensile force F_m for all samples, the tensile strength was determined according to the formula:

$$R_m = \frac{F_m}{A_0} \quad (MPa)$$

3 RESULTS AND DISCUSSION

This paper presents the results of studying the influence of thermomechanical processing parameters (degree of deformation, temperature and annealing time) on the tensile strength of copper wire, obtained by the "up cast" process. The overall test results are given in Table 1, where the influence of temperature and annealing time on the tensile strength of different cross-sections can be seen. The test results are also shown graphically in Figures 1 to 3, where the average values of three obtained experimentally were used to plot them (for R_m).

Table 1 *Test results*

		2,5 x 1,8 (mm)						2,0 x 1,25 (mm)						2,74 x 0,41 (mm)					
t (°C)	No. of annealling	R_m (MPa) 2x		R_m (MPa) 4x		R_m (MPa) 6x		R_m (MPa) 2x		R_m (MPa) 4x		R_m (MPa) 6x		R_m (MPa) 2x		R_m (MPa) 4x		R_m (MPa) 6x	
	I	248,50		237,60		226,70		247,20		233,50		235,40		262,00		262,00		257,60	
400	II	248,50	247,10	233,30	233,30	226,70	227,10	239,40	241,30	239,40	240,00	237,40	236,70	253,20	259,10	257,60	260,50	262,00	263,40
	III	244,20		228,90		227,80		237,40		247,20		237,40		262,00		262,00		270,70	
	I	240,90		234,40		227,80		261,00		266,80		257,00		296,90		301,30		310,00	
500	II	239,80	238,70	233,30	233,70	226,70	225,30	266,80	263,60	255,10	257,70	257,00	255,70	292,50	301,30	279,40	286,70	301,30	291,10
	III	235,40		233,30		221,30		262,90		251,10		253,10		314,40		279,40		262,00	
	I	231,10		226,70		233,30		249,20		239,40		239,40		296,90		262,00		257,60	
600	II	228,90	230,40	225,60	229,20	231,10	230,40	247,20	249,80	239,40	240,00	237,40	238,70	314,40	308,60	262,00	259,10	253,20	250,30
	III	231,10		235,40		226,70		253,10		241,30		239,40		314,40		253,20		240,10	

In the case of profiled wire with a cross-section dimension of 2.5 x 1.8 mm and annealing time of 2x, a slight decrease in tensile strength is observed with an increase in the annealing temperature, and it is approximately constant at annealing times of 4x and 6x.

In the case of wire with cross-section dimensions of 2.0 x 1.25 mm and 2.74 x 0.41 mm, a small increase in tensile strength occurs at annealing temperature of 500ºC, after which the tensile strength slightly decreases with increasing temperature, except for samples with the cross-section dimensions of 2.74 x 0.41 mm and annealing time 2x, where the tensile strength increases monotonically with increasing annealing temperature.

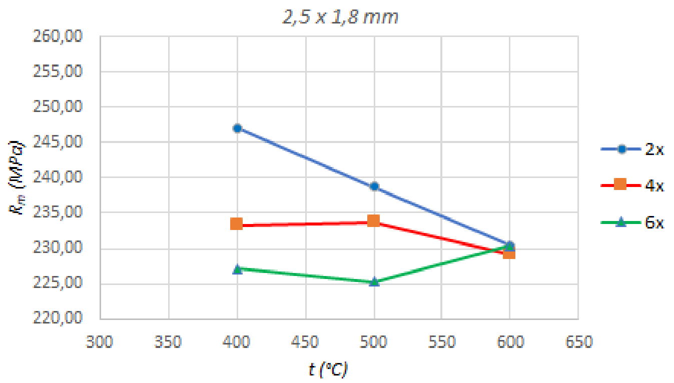

Figure 1 *Diagram of dependence the tensile strength on temperature and annealing time for a profiled copper wire with a cross section of 2.5 x 1.8 mm*

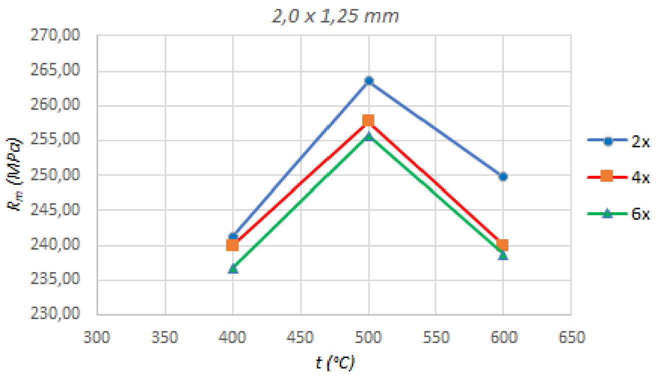

Figure 2 *Diagram of dependence the tensile strength on temperature and annealing time for a profiled copper wire with a cross section of 2.0 x 1.25 mm*

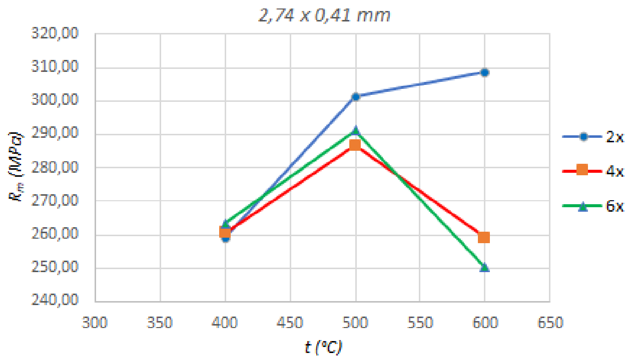

Figure 3 *Diagram of dependence the tensile strength on temperature and annealing time for a profiled copper wire with a cross section of 2.74 x 0.41 mm*

At all annealing times, with an increase in deformation degree, an increase in tensile strength is observed, especially at ε=99% due to the influence of the cross-section geometry of samples.

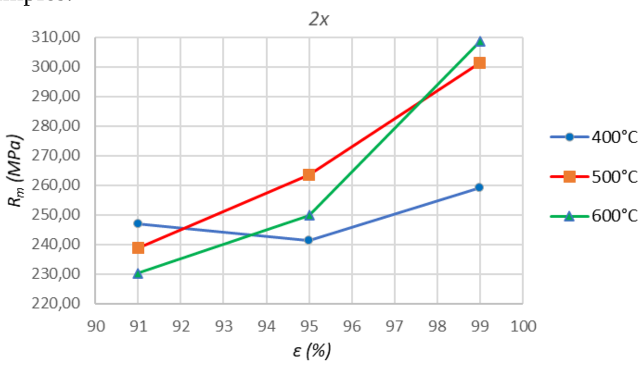

Figure 4 *Diagram of dependence the tensile strength on deformation degree and temperature during annealing time 2x*

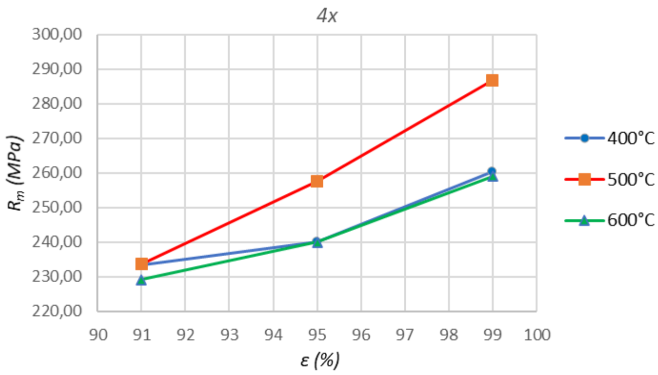

Figure 5 *Diagram of dependence the tensile strength on deformation degree and temperature during annealing time 4x*

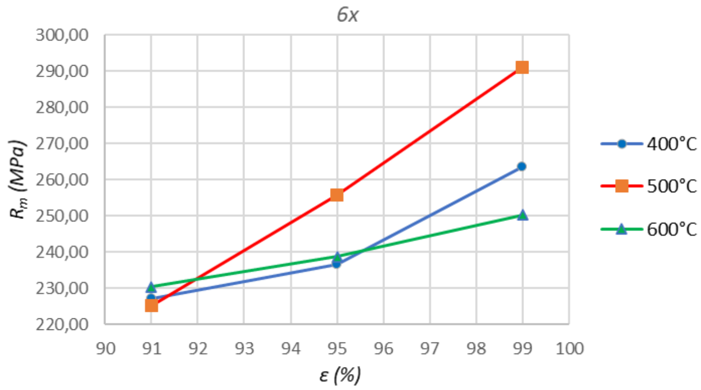

Figure 6 *Diagram of dependence the tensile strength on deformation degree and temperature during annealing time 6x*

The increase in tensile strength is probably an uneven deformation of profile before annealing for samples with the highest degree of deformation. After a certain number of passes, the deformation next to the contact zones of metal and tool affects the central parts of sample, and then, after a large reduction in height, it affects the side parts as well. The profile obtained in such a way received an uneven deformation across the cross-section, with the smallest deformation occurring in the side parts. Figures 4, 5 and 6 show the diagrams of tensile strength dependence on the defprmation degree.

4 CONCLUSION

The aim of this work was to determine the behavior of drawn copper wire depending on the degree of previous deformation and subsequent thermal treatment.

Based on the performed tests and obtained results, the following can be concluded:

- The tensile strength of profiled samples with the cross-section dimensions of 2.5 x 1.8 mm decreases slightly with increasing temperature.
- In the case of samples with the cross-section dimensions of 2.0 x 1.25 mm and 2.74 x 0.41 mm, a slight increase in the tensile strength value was observed at the annealing temperature of 500°C, after which this value decreased slightly.
- With an increase in deformation degree, an increase in tensile strength is observed at all annealing times.

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HARDNESS OF BIMETALLIC STRIP Cu – Č.4571 AFTER THE COLD ROLLING AND ANNEALING

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Abstract

Samples of bimetallic strip Cu-Č.4571 were cold rolled with different reduction degrees, and the ones deformed with the highest reduction degrees were annealed afterwards at different temperatures for different periods of time. The values of the hardness of the layers of the bimetallic strip were obtained as a function of the degree of deformation, and the annealing temperature. Global flow of curves hardness - total deformation, increases, where this flow, for both curves, can be divided into three parts. A global decrease in hardness was observed with an increase in the annealing temperature, for all periods of time, in both the steel layer and the copper layer.

Keywords: *bimetallic strip, hardness, deformation degree, annealing*

1 INTRODUCTION

Bimetals are widely used in the industry thanks to a combination of different properties in one material due to saving the expensive scarce metals, and their specific properties which the separated metals-components do not have.

In a bimetal, the expensive metals and alloys are used as the plating materials, with thickness of up to 25% of the bimetal thickness. Thanks to that, it is possible to get the relatively cheap materials with required properties where a performing layer keeps the properties that it has got before joining into bimetal, while cheaper, the basic material acts as a carrying material that provides the required mechanical properties.

Corrosion-proof bimetals with cooper as a plating layer are used more and more.

Cold rolling of a plated strip is a final operation in the plastic processing in all cases when the enhanced strength and deformation resistance are required [1-5].

2 EXPERIMENTAL

In this investigation, samples cut from a two-layer board Cu-Č.4571 (steel: C – 0.1%; Cr – 18%; Ni – 9%) 2 mm thick, obtained by the plating by explosion, were used. The initial thickness of steel in them was 1.05 mm, and copper 0.95 mm.

Prior to rolling of a bimetal strip, the gap between the working rolls was set to 2 mm, and then the strip was let between them for a few times till the total deformation of 10% was reached.

In order to simplify it, it was accepted that the deformation for a single pass was 2.5%. After the deformation of 10%, the total thickness and layers thicknesses were measured on various spots.

The same procedure was repeated for the total deformations of 20%, 30%, 40%, 50%, 60%, 70%, 80% and 85%.

Samples deformed with the maximum deformation degree, ε_{max}=85%, were subjected to annealing.

The annealing was done in a protective atmosphere of nitrogen at temperatures of 700, 750 and 780 ^{o}C, for periods of 1,5; 2 and 2,5 h for all temperatures.

Hardness measurements were performed after all degrees of deformation and annealing.

The experimental flow is shown schematically in Figure 1.

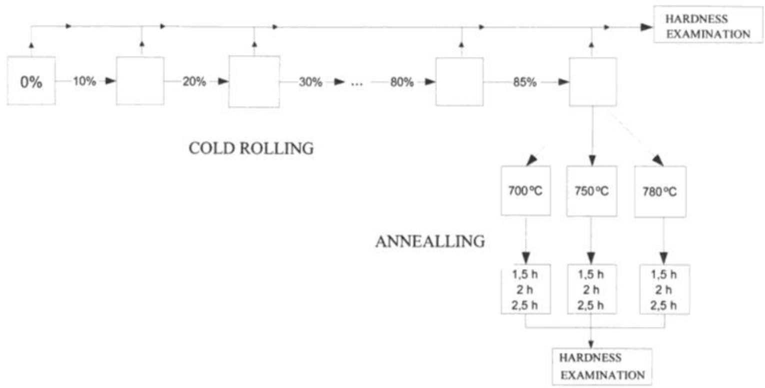


Figure 1 *Schematic diagram of the experimental flow*

3 RESULTS AND DISCUSSION

The obtained data for the hardness measurements, depending on the total deformation degree are given in Table 1 and Figure 2.

Table 1 *Dependence of the hardness of bimetallic strip layers on the deformation degree*

ε (%)	HV (daN/mm^2)	
	Č.4571	Cu
0	299	67.9
10	322.4	100.9
20	324.6	117
30	325.6	108.6
40	336.4	115.9
50	337.7	110.7
60	389.7	114.3
70	380.1	128.9
80	441.14	128.4
85	445.6	130.6

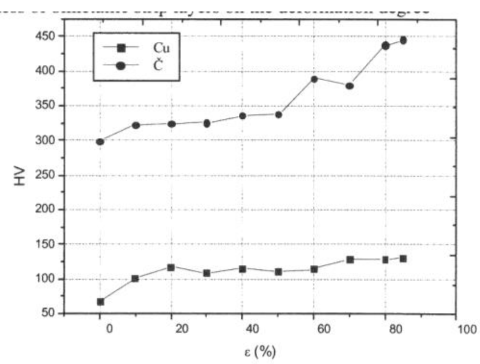


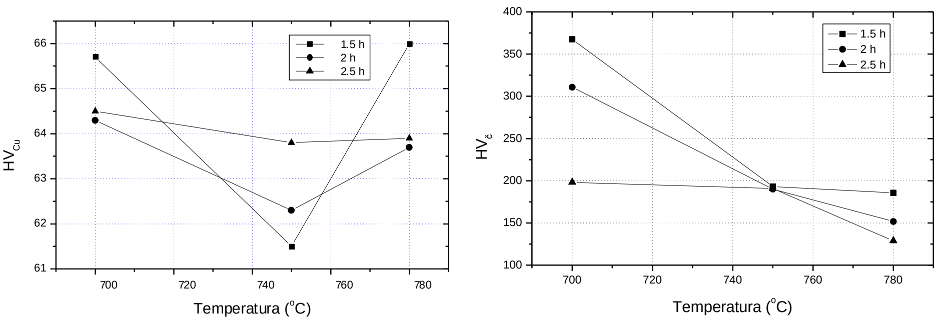
Figure 2 *Diagram of dependence the hardness of the bimetallic strip layers on the deformation*

Global flow of curves hardness - total deformation, increases, where this flow, for both curves, can be divided into three parts. In the first part of the curve, up to a deformation of about ε = 20%, the hardness of both layers increases sharply, with a more pronounced increase in the hardness of copper layer, which can be explained by the higher rate of deformation strengthening of copper compared to steel. In the second part of the curve (ε = 20 – 50%), the stagnation of increase in hardness is observed with the certain oscillations in the hardness values, which may be a consequence of the saw-tooth structure at the copper-steel junction. This saw-toothed structure is the result of steel penetration into a copper layer and vice versa due to the fusion by explosion. In the third part (ε = 50 – 85 %), there is an increase in hardness again with an increase in the deformation degree, and in this part the increase in hardness is more pronounced in steel because at these degrees of deformation, copper has almost reached its maximum hardness (about 130 HV).

The obtained test results, dependence of hardness (HV) from the annealing temperature and time are shown in Table 2, and diagrams in Figure 3 and Figure 4.

Table 2 *Dependence the hardness of bimetallic strip layers on the annealing temperature and time*

t(°C)	time (h)	HV (daN/mm²)	
		Č.4571	Cu
700	1.5	367.7	65.7
	2	310.7	64.3
	2.5	198.0	64.5
750	1.5	193.0	61.5
	2	190.1	62.3
	2.5	190.7	63.8
780	1.5	185.7	66.0
	2	151.7	63.7
	2.5	128.7	63.9



Figures 3 and 4 *Diagrams of dependence the hardness of bimetallic strip layers on the annealing temperature and time*

On the diagram of dependence, the hardness on temperature and annealing time for a copper layer (Figure 3), it can be seen a decrease in hardness with increasing annealing time at all annealing temperatures. However, when annealing is at 750°C, increasing the annealing time causes an increase in hardness of the bimetallic strip layer on the copper side. Also, after annealing at this temperature, the minimum hardness appears at all annealing times.

On the diagram of dependence, the hardness on temperature and annealing time for the steel layer (Figure 4), a decrease in hardness can be observed both with increasing annealing time and increasing annealing temperatures. This drop in hardness is more pronounced for annealing times of 1.5 and 2 hours up to temperature of 750°C, and annealing time of 2.5 hours, the decrease is more pronounced above this temperature.

4 CONCLUSION

As the degree of cold deformation increases, the hardness of layers of the bimetallic tape increases. Three areas can be observed on the hardness curves. In the first area, up to ε = 20% the hardness of a copper layer increases more intensively. In the second area, at ε = 20 - 50%, the hardness of both layers increases less intensively, and in the third area (ε = 50 - 85%), the hardness of a steel layer increases more intensively.

During annealing of samples. cold deformed at 85% at temperatures of 700, 750 and 780°C for a duration of 1.5; 2 and 2.5 hours, the hardness of both layers of bimetal changes. The hardness of the steel layer decreases continuously at all temperatures and annealing times. In the case of the copper layer, the minimum hardness occurs after annealing at temperature of 750°C, whereby an increase in hardness is observed at this temperature with the extension of the annealing time.

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INFLUENCE OF CHEMICAL COMPOSITION ON THE QUALITY OF CASTINGS OBTAINED BY THE EASY MELTING MODELS

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Abstract

This work presents the results of influence the chemical composition on the quality of castings, obtained using the wax models. After molding the wax models and melting the wax in a dryer, the mold cavity was filled with liquid metal. Four series of castings with the following chemical composition were cast: first series (Cu=90.5%; Sn=6.5%; Zn=3.0%), second series (Cu=83.7%; Sn=7.0%; Zn=9.3%), third series (Cu=90.2%; Sn=1.5%; Zn=3.0%; Pb=3.3%; Fe=2.0%) and fourth series (Cu=85.0%; Sn=5.0%; Zn=5.0%; Pb=5.0%). Based on the obtained results, a lack of filling was observed on a candlestick from the fourth series of castings. The quality of other castings is satisfactory, which refers to the external look. Faults in the form of voids are present, but minimal surface finishing allows obtaining the castings with relatively smooth surfaces.

Keywords: *Easy melting models, castings quality, wax model*

1 INTRODUCTION

Casting with easy melting models is a relatively new technology for making complex castings, which offers a number of advantages over other casting methods. This method of casting for a large number of products achieves considerable savings in processing, and sometimes this method is the only possible way to make castings. They are usually small castings that, in terms of their dimensions, shape and surface, must completely satisfy all technical regulations. The principle of this manufacturing process consists in making a model from wax, which is then covered with quartz sand scrum and covered with molding material. After blowing the mold with CO_2 gas, its complete hardening occurs. The mold prepared in this way is taken to the dryer and placed so that the bottom of the mold is facing upwards, and the pouring system is facing downwards. The mold is then exposed to an elevated temperature (wax melting point 80 ºC) to melt and drain the wax through the pouring system, thus forming a mold cavity, which is filled with molten metal and after solidification, the desired object is obtained.

The advantages of wax models are as follows: they keep their shape and dimensions well in high humidity, they are not hygroscopic, and they have a low cost.

The wax model is made in the following order: first, a prototype is made, then either a plaster mold or a sand mixture mold is made according to the prototype using the CO_2 process, then the model composition (melt) is prepared and poured into the mold. After hardening of the melt, up to 5 mm thickness, the model is removed from the mold, the surfaces of the finished model are cleaned and processed [1-3].

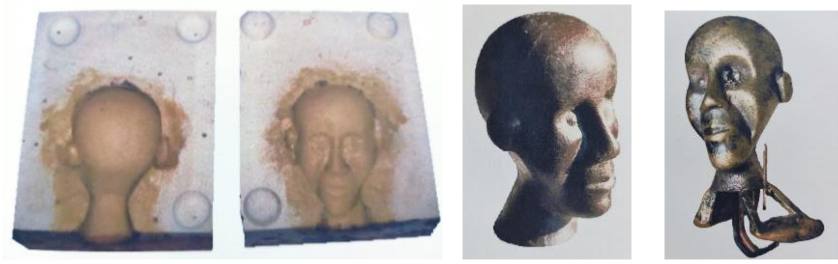
2 EXPERIMENTAL

The experiment was carried out in the following stages:

- preparation the sand mixture for the CO_2 process,
- molding the prototype, setting up the pouring system, vents and guides,
- making cores and obtaining the internal cavities, depressions, openings on castings,
- blowing with CO_2 gas until complete hardening,
- separating the upper and lower chassis and removing the prototype,
- filling the mold cavity with wax,
- removing the wax model,
- molding the wax model, setting the pouring system, casting feeding system, vents and guides,
- core making (for castings that have depressions and cavities),
- blowing with CO_2 gas,
- forming the mold cavity by melting the wax in the dryer,
- filling the mold cavity with liquid metal,
- shaking out and destruction of the mold and removing the casting after the metal solidification,
- removing the pouring system of the feeder,
- sandblasting of castings, and
- patination of castings.

Four series of castings with the following chemical composition were obtained: the first series (C_u=90.5%; S_n=6.5%; Z_n=3.0%), the second series (C_u=83.7%; S_n=7.0%; Z_n=9.3%), the third series (C_u=90.2%; S_n=1.5%; Z_n=3.0%; P_b=3.3%; F_e=2.0%), and the fourth series so called the red cast (C_u=85.0%; S_n=5.0%; Z_n=5.0%; P_b=5.0%).

Figure 1 shows the appearance of the wax model mold, wax model, casting with the pouring system, casting after sandblasting and casting after patination.



a) b) c)

d) e)

Figure 1 *a) Appearance of the wax model mold; b) Appearance of the wax model; c) Appearance of casting with pouring system; d) Appearance of the casting after sandblasting; e) Appearance of the casting after patination*

3 RESULTS AND DISCUSSION

The obtained castings from the first, second and third series are of satisfactory quality, where the external appearance is primarily concerned. Faults in the form of voids are present, but minimal surface finishing allows obtaining the castings with relatively smooth surfaces. In the case of these castings, underfilling did not occur.

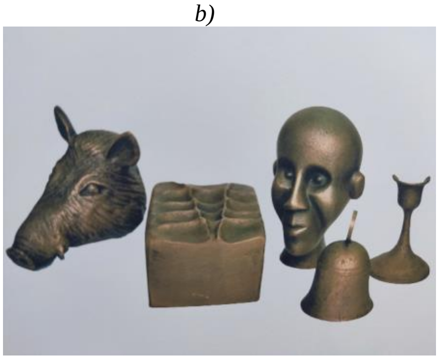
Castings from the fourth series are of similar quality as the previous ones. The only difference is that the candlestick from this series of castings has an underfill. The observed error in the casting is the cause of insufficient drying time of the mold, whereby the entire wax was not melted and removed from the mold. When pouring the metal, the residual wax reacted with the metal, i.e., there was the so called "cooking", which is the main cause of underfill occurrence.

Figure 2 shows the castings obtained by series.

a)

b)

c)



d)

Figure 2 *Appearance of the obtained castings by the series: a) The first series of castings; b) The second series of castings; c) The third series of castings; d) The fourth series of castings*

4 CONCLUSION

The wide practical application of copper alloys with tin and zinc for obtaining the shaped castings is explained by the good mechanical and anti-friction properties, good corrosion resistance and good machinability. Another characteristic feature of these alloys is that they have a wide solidification interval, even up to 150-160°C. A wide solidification interval significantly affects the casting properties, fluidity, appearance and distribution of dents and porosity. Due to their properties, these alloys can be used for the complicated castings with sharp transitions from thin to thick walls. On the other hand, these alloys cannot be used for castings that require greater hermeticity, since the castings are usually permeated with porosity. The porosity that occurs in these alloys is a positive feature for bearing type castings, because the lubricant circulates through the pores and extends the life of bearings.

The content of iron in copper-tin-zinc-lead alloys, up to 0.03%, is useful, because it increases the mechanical properties, reduces the structure and strongly prevents recrystallization. With a further increase in iron, the corrosion resistance and technological properties of these alloys decrease, so it must be maintained within the prescribed limits [4].

The application of the red cast (alloy of copper with tin, zinc and lead) is very wide and varied. Very good casting and technological properties of the red cast have contributed to the production of castings from these alloys ranging from 50 to 70% of the total production of castings from the copper-based alloys. The quality of castings made of the red cast does not significantly differ from the quality of castings made of tin bronzes, but that is why these products are cheaper, because zinc and lead are used instead of expensive and scarce tin.

The quality of castings also depends on the quality of the model. All errors that occur during the model making process are reproduced on the casting. Wax model castings have a smooth surface and are characterized by dimensional accuracy. The only deficiency of castings obtained from wax models is the possibility of underfilling, which is a consequence of a worker's error during the experimental work due to the insufficient holding of mold in a drier.

Based on the appearance and quality of castings obtained by the casting technology according to easily melting models, it can be concluded that the chemical composition of the used alloys was well chosen, because the castings were with satisfactory quality. The results of experimental research and advantages have showed in practice that the applied casting procedure can be considered successful for obtaining the castings of this type [5].

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