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Investigations of microstructure and mechanical properties of brass alloys produced by sand casting method at different casting temperatures

H Yilmaz Atay, G Uslu, Y Kahmaz and Ö Atay

İzmir Katip Çelebi University, Faculty of Engineering and Architecture, Department of Materials Science and Engineering, Çiğli 35620 İzmir, Turkey

hgulyilmaz@gmail.com

Abstract. Brass, which is an alloy of copper and zinc, is of historical and lasting importance due to its hardness and workability. Indeed, to make this metal alloy, ancient metalworkers around the Mediterranean Sea were able to melt copper with zinc as early as 3000 B.C. Brass is stronger and harder than copper. The amount of copper varies between 55% and 95% by weight, depending on the type of brass and its intended use. It is easy to form into various shapes, it is a good conductor of heat and generally resistant to corrosion from salt water. It can be used to make pipes and tubes, weather-stripping and other architectural trim pieces, screws, radiators, musical instruments, and cartridge casings for firearms. The manufacturing process involves combining the appropriate raw materials into a molten metal, which is allowed to solidify. The shape and properties of the solidified metal are altered through series of carefully controlled operations to produce the desired brass alloy. Temperature used in the process is one of the parameter to affect the product properties. In this study, the brass alloys were produced by a sand casting method at different casting temperatures. Structural and mechanical properties were observed. Optical microscope, XRD and the SEM analysis were performed for the microstructure and phase analysis of the material. Charpy impact test and tensile test were applied to consider the mechanical properties of the samples. As a main purpose of this study, the results were evaluated and then the optimum temperature for the brass material production was determined.

1. Introduction

Brass is the most important alloy of copper. Because of its yellow colour, the copper-zinc alloy is known as “yellow”. It has easy workability, high corrosion resistance and beautiful appearance. In addition, brass has higher toughness than bronze which is a copper-tin alloy. History of the brass dates too far back. The pre-dynastic Egyptians knew copper very well, as proved in hieroglyphs. The Greeks described brass as 'orefalos'. Some Roman writers mentioned brass in their work and called it 'Aurichalum'. It was used for production of coins and golden helmets. They also preferred brass for all kinds of jewelry and for ornamented works. Actually, after the Copper Age, the Bronze Age came, and was later followed by the Iron Age. There was no 'Brass Age', because it was not easy to make brass [1-5].

Brass contains other metals in its structure according to its intended use. Addition of 10% zinc to copper causes the bronze colour, while 15% adds gold colour and 20-38 % yellow colour. When the amount of zinc added achieves 45%, a silvery white colour is obtained. The alloy exhibits a brittle structure [1, 2]. Brass has higher malleability than copper. The low melting point of brass is 900 to 940 °C, and it is easy to cast. The density of brass is 8.4 to 8.73 grams per cubic centimeter (0.303 to 0.315 lb/cu in) [3].

Brass used for commercial purposes is separated into the alpha and alpha-beta brass, according to their structure. Alpha brass is a kind of brass that contains only an alpha phase. Unbalanced cooling causes that beta phase is formed in very small amounts. Owing to their ductility at room temperature, they can be easily processed at cold temperatures. If a high amount of cold deformation is applied to the alpha brass, annealing and slow cooling must be applied to remove the stress. In this case, the brass should be annealed to a temperature of 625 °C. In case of higher temperatures, grain growth occurs. It can be easily applied to alpha brass, such as deep drawing, bending and cold rolling. Alpha-beta brass contains 54-61 % of copper. The structures have hard and brittle α and β' phases at the room temperature. When high temperatures are reached, β phase is formed. For this reason, plastic forming to $\alpha + \beta$ phases of brass are applied at high temperature [3]. As it affects the properties of the brass, production process is important. Especially with the development of the industrial revolution, brass production has diversified. In 1738, William Champion succeeded in obtaining a patent for the production of zinc through the distillation of calamine and charcoal. Although the first rolling mills were established in the 17th century, the establishment of strong rolling mills came in the middle of the 19th century [4-7]. Muntz made it possible to make cheap, hot-processed brass plates with 60/40 brass in 1832 [4]. In 1957, Bungardt published a patent in which he selected three different casting temperatures and investigated the effect of temperature [8].

In this project, microstructure and mechanical properties of brass materials produced in a sand mould at different temperatures were observed and evaluated. Sand casting, also known as sand moulded casting, is a metal casting process characterized by using sand as the mould material. During this process, material is heated to the correct temperature to melt. Sometimes, it is treated to modify the chemical composition, in order to achieve the required material properties. Then the molten metal is poured into a mould of the desired shape cavity to cool down and solidify [9]. Design flexibility, high complexity shapes, wider material choice, low cost tooling and short lead time are the advantages of this method. After obtaining the samples, Optical microscope, XRD and SEM-EDS analyses were performed for the microstructure and phase analysis of the material. Also, the tensile-bending strength and elongation amounts of the mechanical properties of the material were tested.

2. Materials and methods

The raw materials used in experimental studies and provided by EMSA DÖKÜM were the scrap materials from other companies' processes (Figure 1). The current paper is a recycling study, in this respect.

Figure 1. Raw materials and a furnace.

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The brass alloy production started by melting the scrap. The obtained melt was poured into sand moulds which were prepared separately for each group. Casting processes were applied in three different temperatures of 1000 °C, 1100 °C and 1200 °C. The brass production for this purpose consisted of five stages. The steps are given in the flowchart diagram in Figure 2.

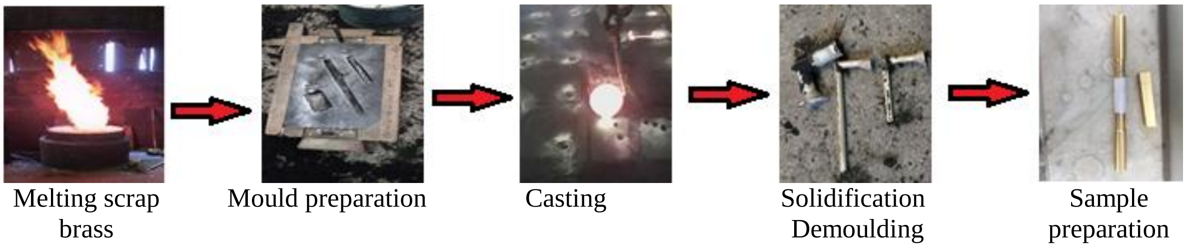


Figure 2. Flowchart of brass production process.

The moulding process is done using mould sand. It consists of silica, clay, water and other materials. The gap of the model is formed in the compressed sand. The melted alloy is poured into the mould cavity and allowed to solidify (Figure 3). The surface separator powder is poured on the surface of the model. The sand mass around the model is carefully compacted.

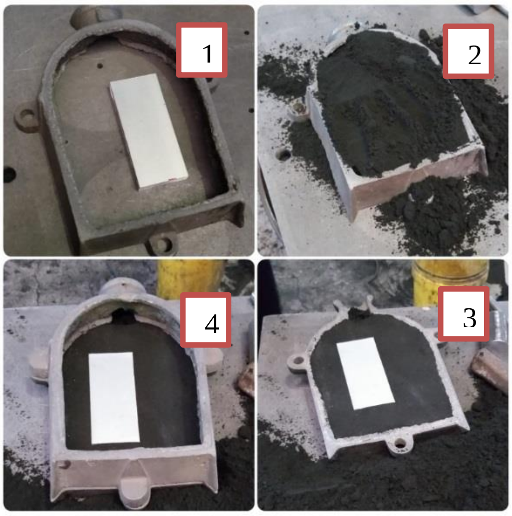


Figure 3. Moulding steps.

The sum of the ducts that allow the melt to reach the mould cavity is called a moulding runner system. The material melted from the pot passes through the horizontal and vertical channels forming the gating system, and fills the mould cavity. The ducts that are opened ensure that the gases emerge from the mold during the casting. When the mould is filled with the liquid metal, the mould gases are trapped in the gradually decreasing mould cavity. They form a pressure within the mould. These gases may cause various casting faults. The liquid metals and alloys pouring into the mould cool down and solidify, while their volumes shrink. The resulting gaps are called collapses. Collapses cause faulty castings. The feeders move the debris out of the part.

After casting, the samples were allowed to solidify. It is not possible to solidify all of the liquid metal filled into the mould at the same time. Solidification first begins in thin sections where cooling is rapid. Spontaneous shrinkage and volume reduction occur in these regions. Then these regions are fed with the material which is still liquid in the thick regions. After the solidification and cooling of the brass, the casting is separated from the sand mould.

Regarding the mould type, a two-piece model was used in the process. The bottom and top moulds are demonstrated in Figure 4.

Figure 4. Two-piece model of a mould.

After obtaining the cast samples, the desired dimensions were provided by using the milling and cutting equipment. The samples were processed on CNC machines to be prepared for mechanical research. The phase analysis of the metal alloys was performed with the help of a Empyrean X-ray diffractometer with Cu Kα radiation (λ=1.540 Å), in the 2θ range of 20-800. The surface morphology was characterized by using a Scanning Electron Microscope (SEM, Zeiss Sigma 300 VP-FESEM). Mechanical behavior of the samples was tested by the Charpy impact test machine (ALŞA) and a tensile testing machine (SHIMADZU AGS-X) according to the EN ISO 148-1.

3. Results and discussion

XRD analysis results of the obtained samples are demonstrated in Figure 5. The equivalent of the peaks seen in XRD test analysis is equivalent to Pd1.15Cu2.85 for Sample 1, Sb0.20Cu3.80 for Sample 2, and Zn0.20Cu3.80 for Sample 3.

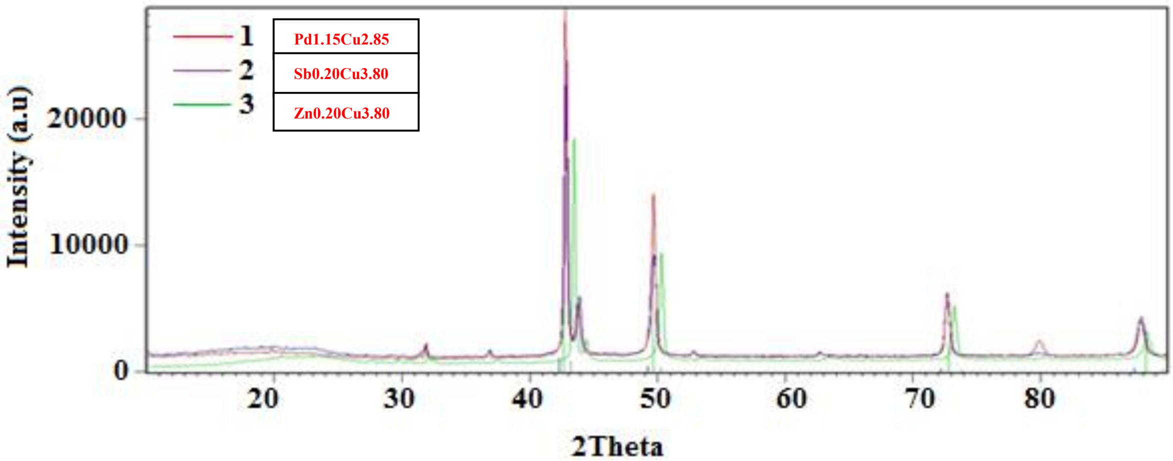


Figure 5. XRD Graphic of Count -2 Theta.

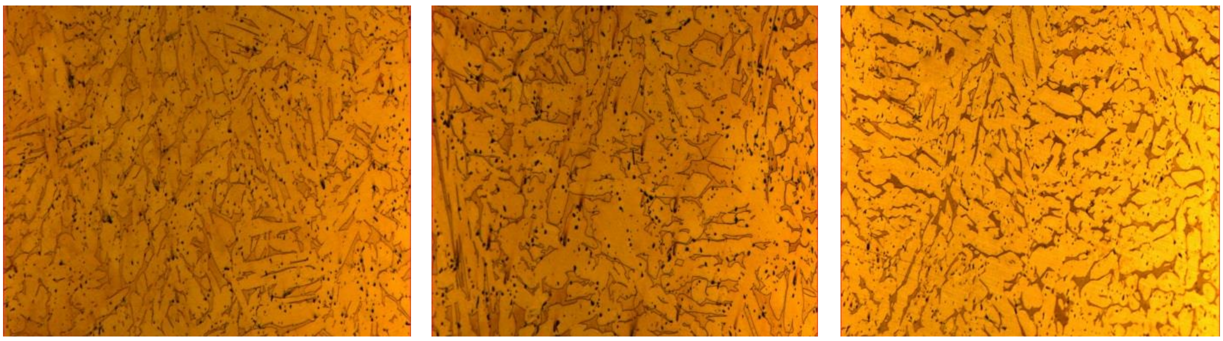
An X-ray fluorescence spectrometer was used to determine the elemental and chemical composition of our alloy. The results are shown in Table 1. According to our XRF test results, the concentration of copper was 58.84 %, and the concentration of zinc was 32.83 %.

Table 1. XRF test results.

Symbol	Element	Concentration
Mg	Magnesium	0.28 %
Al	Aluminum	0.25 %
P	Phosphorus	0.15 %
Fe	Iron	0.38 %
Ni	Nickel	0.25 %
Cu	Copper	58.84 %
Zn	Zinc	32.83 %
Sn	Tin	0.32 %
W	Tungsten	0.58 %
Pb	Lead	2.42 %

The optical microscope was used to observe the effect of the casting temperature on the microstructure. Samples were cut, grinded, polished and etched in order to examine the samples under optical microscope. Etching was carried out with ethanol. Figure 6 depicts the optical analysis results of the samples. As the casting temperature fell from 1200 °C to 1000 °C, a smaller particle size was observed in the third sample (1000 °C). One of the most important problems encountered in casting process are pores. In the microstructures of the samples, homogenous pores were observed as black spots. A smaller particle size was observed in the microstructure of our third sample having 1000 °C casting temperature. A more homogeneous structure was seen. In the first sample having 1200 °C casting temperature, irregular and larger grain size was observed.

When casting at different temperatures, the low temperature material will cool down earlier. As mentioned above, the complete cooling of the poured material cannot be achieved in an instant. The earlier cooling zones are fed with liquid material from the later cooling zones due to the shrinkage and volume reduction. When this liquid transfer is completed, then grains are formed. If the solidification occurs before this transfer is completed at low temperature, a network image is obtained, as shown in Figure 6.



Sample 1 (1200 °C) Sample 2 (1100 °C) Sample 3 (1000 °C)

Figure 6. Microstructure of prepared samples (magnification 100 x).

The results of Charpy impact test are shown in Table 2. This test is the process of determining the energy used to break the sample with a hammer at the tip of a pendulum at the end of the sample resting on the 2-notch base in horizontal and simple beam and the effect of multi-axis stresses occurring at the base of the notch. As can be seen, the average fracture energy of our first sample (casted at the casting temperature of 1200 °C) is according to the impact test 2.33 kpm. The second sample with the casting temperature of 1100 °C has the average fracture energy of 2.57 kpm and the third sample with the casting temperature of 1000 °C 2.63 kpm. According to the Charpy impact test results, the third sample having 1000 °C casting temperature had higher breaking energy compared to samples casted at 1200 °C and 1100 °C. This finding in the current study is similar to Jha's research [10] proving that fracture energy had increased by decreasing the temperature.

Table 2. Charpy test results.

Sample No	Wall thickness (mm)	Width (mm)	Test temperature (ºC)	First energy (kpm)	Last energy (kpm)	Fracture energy (kpm)	Average fracture energy (kpm)	Measurement error
1 (1200 ºC)	10.00	8.10	Avg. 19 ºC	0	2.30	2.30	2.33	2.33 ± 0.058
	9.96	8.12	"	0	2.30	2.30		
	9.96	8.12	"	0	2.40	2.40		
2 (1100 ºC)	9.94	7.88	Avg. 19 ºC	0	2.60	2.60	2.57	2.57 ± 0.058
	9.96	8.00	"	0	2.60	2.60		
	9.90	7.87	"	0	2.50	2.50		
3 (1000 ºC)	9.96	8.04	Avg. 19 ºC	0	2.60	2.60	2.63	2.63 ± 0.058
	10.00	8.12	"	0	2.70	2.70		
	9.96	8.08	"	0	2.60	2.60		

The tensile test results are depicted in Figure 7. It is used to determine the behaviour of a sample when applying an axial tensile load. Tensile test was applied to the samples at a speed of 5 mm/min.

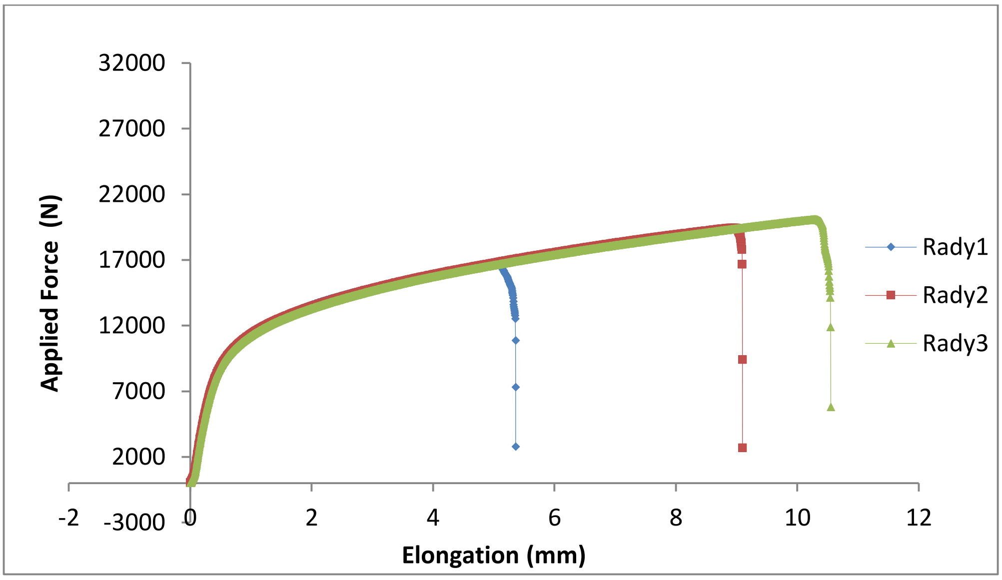


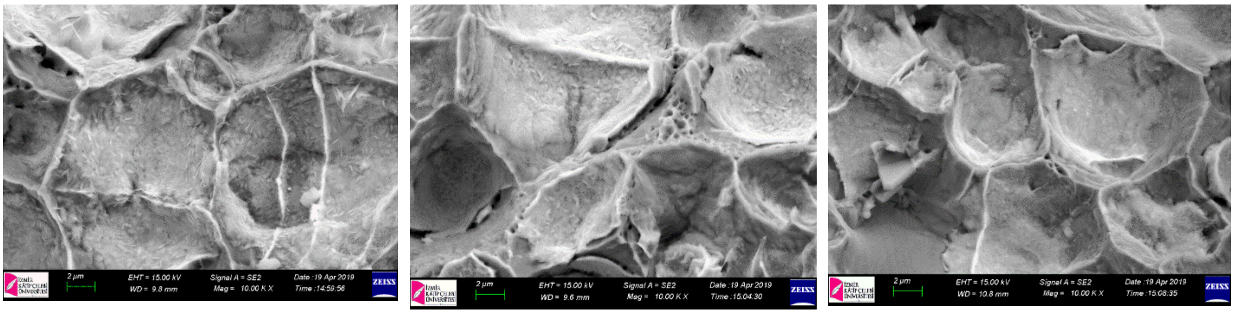
Figure 7. Tensile test results of the samples.
(Seri 1=Sample 1, Seri 2=Sample 2, Seri 3=Sample 3)

Table 3 demonstrates the total tensile test results. According to those results, the maximum stresses are 212 N/mm^2, 247 N/mm^2 and 255 N/mm^2. Therefore, decreasing the temperature increased the stress value. Regarding the elongation, it increased from 5.06 mm to 10.29 mm by decreasing the temperature. It can be said that ductility also improved in this way. The obtained results are similar to Ref [10].

Table 3. Results of tensile tests.

	Elongation (mm)	Maximum stress (N/mm^2)
Sample 1 (1200 °C)	5.06	212
Sample 2 (1100 °C)	8.92	247
Sample 3 (1000 °C)	10.29	255

SEM analysis results are demonstrated in Figure 8. As a result of this analysis, the fraction patterns of the first sample (1200 °C) and the second sample (1100 °C) show a relatively brittle fracture. However, it can be said that there is higher ductile fraction in the third sample (1000 °C). In particular, the full depression obtained in the third image reminds us of the concave shape of ductile fracture. It did not occurre in brittle fractures in the inner parts of surfaces. The results are similar to Ref [11]'s results in the macroscopic or binocular microscope observations; the fracture surfaces of the Charpy specimen have similar patterns.



Sample 1 (1200 °C) Sample 2 (1100 °C) Sample 3 (1000 °C)

Figure 8. SEM images of the samples.

All these results were evaluated, and the optimum temperature for the brass material was determined. It is our greatest ambitions that the final product, mechanical properties of which were tested and developed, is brought into our present life.

4. Conclusion

In this study, the effect of casting temperature on the mechanical properties of brass alloy was investigated. Mechanical properties were tested, all results were evaluated and the optimum temperature for the brass material was determined. In the third sample (1000 °C), the temperature was observed to improve the mechanical properties. According to the Charpy and tensile test results, the third sample (1000 °C) exhibited more ductile behaviour under higher load, and the elongation value was higher than that of the second (1100 °C) and the first (1200 °C) samples. Tensile tests and the Charpy test were supported by SEM, XRD and optical microscope. At the end of the analyses, the optimum temperature was found to be 1000 °C. At this temperature, mechanical properties were improved and energy saving was obtained. The cost of production were positively influenced.

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