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Research Paper

Comparison of ZAMAK 2 and ZAMAK 3 Alloys Produced by Powder Metallurgy Process

Abdolhamid Azizi[1*], Gholamali Gheyratmand Haghighi[2], Pooya Bahrami[3], Sahebali Manafi[4]

[1]Mechanical Engineering Department, Ilam University, Ilam, Iran

[2]Direct Manager, Acidsazan Zanjan, Iranian Sulfuric Acid Association, Iran construction engineering organization (IRCEO), Zanjan, Zanjan, Iran

[3]Department of Mechanical Engineering, Kermanshah Science and Research Branch, Islamic Azad University, Kermanshah, Iran

[4]Department of Materials Engineering, Shahrood Branch, Islamic Azad University, Shahrood, Iran

[*]Email of Corresponding Author: ah.azizi@ilam.ac.ir

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Abstract

The predominant method to produce ZAMAK alloys is casting. But this process is not without flaws. Factors such as low melting temperature, creep stresses, aging, and dimension change over time are the main problems in ZAMAK’s casting process. We embarked on this research to investigate the new production routes. In this regard, the powder metallurgy can be highlighted because of the non-occurrence of melting and non-solid-liquid phase changes. ZAMAK 2 and 3 are the most commonly used ZAMAK alloys. In this way, we study the comparison of ZAMAK 2 and 3 produced by powder metallurgy. The powder was prepared by the mechanical method. As we proceed, the effect of particle size, pressure, and sintering temperature will be investigated. The comparison was done in consideration of mechanical properties such as density, tensile strength, and hardness. The density of ZAMAK 2 obtained by the powder metallurgy method increases with increasing working pressure up to 400 MPa, but after this pressure, little change in density is observed. While in ZAMAK 3 the density increases with increasing pressure. The maximum ultimate stress obtained in ZAMAK 2 is approximately equal to 300 MPa, while, it is equal to 230 MPa for ZAMAK 3. In ZAMAK 2, we will see a 16.7% increase in density by selecting fine grains, but in Zamak 3, this enhancement is only equal to 7%, which indicates the intensive effect of particle size on the density obtained in ZAMAK 2.

Keywords

Tensile Strength, ZAMAK 2, ZAMAK 3, Density, Powder Metallurgy

1. Introduction

ZAMAK is a family of alloys with a base metal of zinc and alloying elements of aluminum, magnesium, and copper which are used in various industries such as automotive, decorative, etc. ZAMAK alloys are practical alloys used in various industries such as decoration, automotive, furniture, and other mechanical parts. The main elements of ZAMAK's formation are the base element of zinc, copper, aluminum, and manganese. Based on the percentage of alloying elements, various

ZAMAKs can be produced, including the most widely used ones: ZAMAK 2, 3, 5, and 7. ZAMAK 2 and 3 are the more pervasive of all among them [1]. The predominant method in producing ZAMAK alloys is casting [2]. Due to the low melting temperature, there are many problems with the casting process in the production of ZAMAK which include creep stresses, aging and dimension change over time [3]. Most research conducted on these alloys is studies based on the mentioned casting objections [4-6]. Another area, where many types of research have been conducted in the investigation of the sliding wear and frictional characteristics of ZAMAK alloys [7-10]. So far, no comprehensive research has been done on other processes to produce these alloys. In this regard, in the previous study, we investigated the process of ZAMAK 2 production using powder metallurgy. After that, the effect of powder particle size, pressing pressure, and sintering temperature on tensile behavior, hardness, and density of ZAMAK 2 fragments were investigated. Additionally, the conditions that lead to the production of maximum hardness, maximum tensile strength, and maximum density, were investigated [11]. Powder metallurgy is known as an efficient method in the manufacturing industry. The basis for powder metallurgy is to compress the powder into the desired shape and then sinter in the controlled atmosphere. Sintering takes place at temperatures below the melting point. By applying powder metallurgy, the alloying process occurs smoothly. Advantages of powder metallurgy include low cost, near-net-shape dimensional control, and controllability of component properties. Due to the non-occurrence of melting, all considerations of solid-liquid phase changes can be ignored, thus powder processes are more flexible than casting, extrusion, or forging techniques [12]. In a previous study [12], the powder metallurgy method for the production of ZAMAK alloys (ZAMAK 2) was studied for the first time. The working pressure, sintering temperature, and powder particle size were considered as process inputs, and the density, hardness, and tensile strength of the produced part were considered as the output of the process. The effect of input parameters on process outputs was studied. The results showed that the selection of the highest working pressure and sintering temperature along with the selection of coarse grains led to the highest density of the produced part. The highest density was 91.2% of the density of the alloy produced by casting. Among the input parameters, the sintering temperature had the least effect on the process outputs. The maximum tensile strength was 351 MPa, which in comparison with the tensile strength obtained from casting shows a strength ratio of 88%.

This research aims to investigate and compare the production of parts of ZAMAK 2 and 3 using powder metallurgy. For this purpose, ZAMAK 2 and 3 powders are supplied first, then they are compressed and sintered at three different pressures and three different temperatures. In the following, the Density, tensile strength, and hardness of manufactured alloys are discussed and compared with each other.

2. Material and Experimental Work

Zinc is the basic element of ZAMAK alloys. To produce pure zinc, the electrolytic process was used. For this purpose, a pure zinc sulfate electrolyte solution was prepared, then a zinc sheet with a thickness of fewer than 200 μm was provided by electrolysis. It is noteworthy that the anode and cathode material was selected from lead and aluminum respectively. In order to prevent contamination of zinc sheet, Mn^{+2} was used in the electrolyte solution. In addition, a 2cm distance between anode and cathode, 500 A/m^2 current intensity, and a potential difference of 3.2 V was employed. The solvent temperature was also determined at 30 °C and the zinc concentration was 40 gr/lit. The analysis of the provided sheet is shown in Table 1. Finally, the zinc sheets peeled from the aluminum cathode blanks are powdered.

Table 1. chemical composition of produced zinc sheet

Zn	Ni	Sn	Cd	Pb	Fe	Cu	Mn	Al
Remaınder	0	0	0.001	0.0038	0.002	0.0001	0	0

For powdering, a Φ200×400mm laboratory ball mill made of stainless steel was used. To prevent the contamination of powder by iron, the ground chrome-coated balls with the size of 30 and 35 microns were selected. After 48 hours of milling, zinc powder was prepared in three meshes (sizes) shown below:

1- Between 150 and 212 microns (150 µm ≤ X ≤ 212 µm – Course particle)
2- Between 100 and 150 microns (100 µm ≤ X ≤ 150 µm – medium particle)
3- Between 44 and 100 microns (44 µm ≤ X ≤ 100 µm – Finest particle)

During powdering, lead tended to be fine thus, the percentage of lead in the fine meshes increased (greater than 60 ppm). As a result, it was not possible to produce powders with a size below 44 µm. The analysis of produced powder is reported in Table 2.

Other metal powders were chosen in sizes of less than 25µm. The reason for the use of smaller sizes is their uniform distribution in the base metal during homogenization. The analysis of added powders is shown in Table 3. The photographs of the produced zinc powder and added metal powders are shown in Figure 1.

Table 2. Chemical composition of zinc powders

Zn	Ni	Mg	Cd	Pb	Fe	Cu	Mn	Al	Powder particle size (µm)
99.9944	0	0	0.001	0.0025	0.002	0.0001	0	0	**150 < X < 212**
99.9837	0	0	0.001	0.0032	0.012	0.0001	0	0	**100 < X < 150**
99.9802	0	0	0.001	0.0037	0.015	0.0001	0	0	**44 < X < 100**

Table 3. chemical composition of added powders

					Al Powder				
Al	**Ni**	**Sn**	**Cd**	**Pb**	**Fe**	**Cu**	**Mn**	**Zn**	**Mg**
Remaınder	0.0005	0	0	0	0.051	0.002	0.0014	0.005	0
					Cu Powder				
0	0	0	0	0.016	0	Remaınder	0	0.0068	0
					Mg Powder				
0	0	0	0	0	0.0033	0.0012	0.0174	0.0135	Remaınder

For preparing ZAMAK 3 powder, firstly 478.4 g of zinc was mixed with 21 g of aluminum powder, then 0.2 g of magnesium powder and 0.4 g of copper powder were added. Next, the powder was blended into a laboratory mixer for two hours. This procedure was continued for producing ZAMAK 2 powder. Notably, the only difference was the number of combined powders. In this experiment, the amount of alloying powder was 464.8 g zinc, 21 g aluminum, 0.2 g magnesium, and 14 g copper. The analysis of produced ZAMAK 3 and 2 powder are summarized in Tables 4 and 5 respectively.

Table 4. Chemical composition of ZAMAK 3

Zn	Ni	Mg	Cd	Pb	Fe	Cu	Mn	Al	Powder particle size (μm)
95.9125	0	0.04	0.0010	0.0024	0.0041	0.09	0	3.95	**150 < X < 212**
95.9023	0	0.04	0.0010	0.0031	0.0136	0.09	0	3.95	**100 < X < 150**
95.8988	0	0.04	0.0011	0.0036	0.0165	0.09	0	3.95	**44 < X < 100**

Table 5. chemical composition of ZAMAK 2

Zn	Ni	Mg	Cd	Pb	Fe	Cu	Mn	Al	Powder particle size (μm)
92.9550	·	0.04	0.0009	0.0028	0.004	2.7995	0.0001	4.1975	**150 < X < 212**
92.9453	·	0.04	0.0009	0.0034	0.0133	2.7995	0.0001	4.1975	**100 < X < 150**
92.9420	·	0.04	0.0009	0.0039	0.0161	2.7995	0.0001	4.1975	**44 < X < 100**

The dog-bone shape tensile test samples were made according to the ASTM E8 standard. Likewise, the required pressure to compress the samples selected were 350, 400, and 500 MPa respectively. A sample of the produced parts is shown in Figure 2. The samples were compacted employing Instron 8502 testing machine with 250 kN maximum loading and 150mm maximum travel range and a designed compacting mold (Figure 3).
Formation and growth of bond between particles of PM (Powder Metal) components, the sintering process is required. Moreover, the proper temperature of the sintering process zinc-aluminum phase diagram as shown in Figure 3 is used.

Figure 1. The photograph of produced Zink powder and added metal powders

Figure 2. produced samples after tensile test

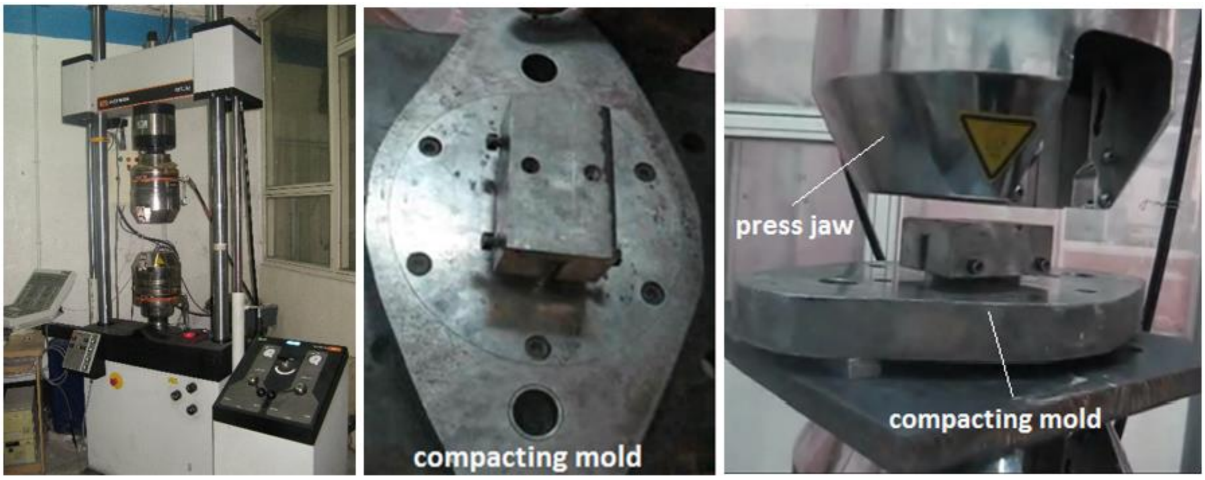

Figure 3. Press machine and compacting mold used in this study

According to Figure 4, it can be concluded that the melting temperature of ZAMAK 2 (93% Zn) and 3 (96% Zn) is 382 °C. Nearing the eutectic line, the temperature of 375 °C will be one of the choices for sintering. To further examine the temperature effect, two temperatures, one near the eutectoid line (260 °C) and the other in the α+β phase stability range (160 °C) were selected.

In the present experiment, carbon monoxide was used as the sintering atmosphere. In this atmosphere, the specimens were successfully sintered in temperatures of 260 °C and 375 °C. However, it can be concluded that the specimens were not sintered appropriately and were successful at 160 °C. It should be noted, to ensure sintering and formation of alloys, the time of sintering for all samples was selected as 24 hours.

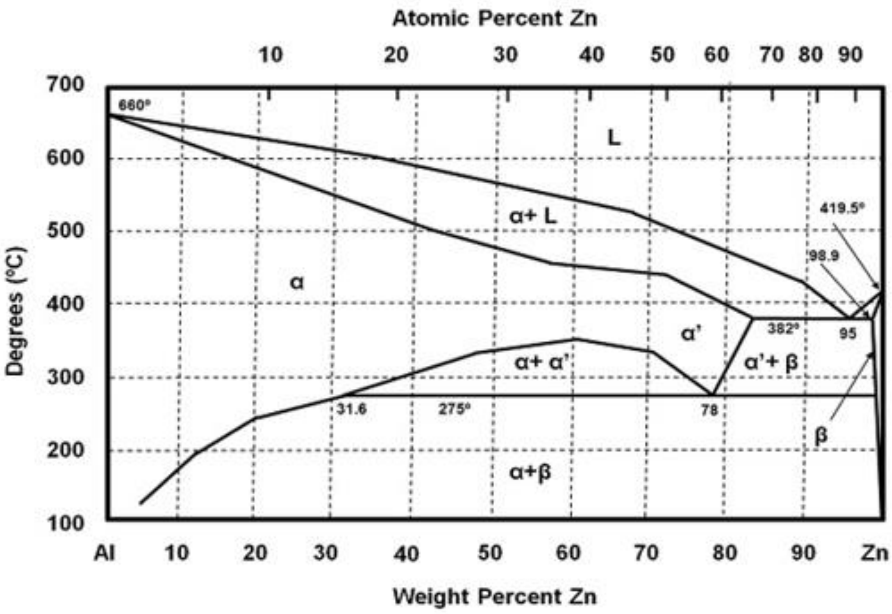

Figure 4. Zn-Al phase diagram [13]

3. Results and discussions

3.1 Density

In order to investigate the density of parts, the density of components before (green density) and after sintering were studied. The density of the parts was measured by measuring the mass and dimensions of the parts by the AND digital scales model EK61001 and Mitutoyo micrometer with an accuracy of 0.01 mm, respectively. The density of produced ZAMAK 2 and 3 parts is listed in Table 6. The highest ZAMAK 2 density is equal to 6199 kg/m^3. This value, compared to 6800 kg/m^3 produced by casting, indicates achievement of 80% baseline density. In like manner, this value is 93% for ZAMAK 3. Accordingly, the result shows good compressibility for ZAMAK 3 in comparison to ZAMAK 2. It can be concluded that using coarse particles with high pressure leads to achieving the highest density. Additionally, the sintering temperature has no severe influence on density.

According to Figure 5, it can be concluded that in the case of ZAMAK 2, increasing the pressure leads to higher density. This increase is observed up to 400 MPa. Following this, the increase in pressure does not necessarily affect the density of the produced specimens. However, this is not the case for ZAMAK 3, since the pressure increases; density increases accordingly (Figure 6). The difference in the trend of the effect of pressure changes on the density of ZAMAK 2 and 3 can be due to the different percentages of alloying elements (especially copper and aluminum) in ZAMAK 2 and 3. In addition to the above table, the sintering of the samples at 160 °C was not well performed and the increase of the temperature range from 160 °C up to 260 °C, in comparison to the increase from 260 °C up to 375 °C, which has a small effect on the density of produced samples.

According to Figure 7, it can be concluded that the increase in pressure in ZAMAK 3, as opposed to ZAMAK 2, has a significant effect on density, therefore, the slope of density experiences an intense upward. Additionally, this figure shows the importance of choosing the proper pressure on ZAMAK 3 production by PM.

The effect of powder particle size on the density of ZAMAK 2 and 3 components is shown in Figure 8. It can be concluded that increasing the particle size of the powder leads to higher density. In ZAMAK 2, the relationship between increasing the size of powder particles and the density is almost linear and the increase in the sintering temperature has a small effect on density while this is not the case in ZAMAK 3.

Table 6. The density (kg/m³) of produced samples after sintering (a) and before sintering (b)

Alloy	Powder particle size (µm)	Pressure (MPa)	Sintering Temperature (°C) 375		260		160	
			a	b	a	b	a	b
ZAMAK 2	150 < X < 212	500	6199	5954	6081	5926	6024	5982
		400	6125	5885	6038	5872	5968	5899
		350	5968	5740	5831	5676	5766	5766
	100 < X < 150	500	5701	5481	5766	5614	5714	5423
		400	5481	5277	5541	5400	5493	5223
		350	5150	4960	5245	5119	5202	4884
	44 < X < 100	500	5366	5170	5411	5277	5366	5119
		400	5088	4902	5202	5068	5150	4828
		350	4912	4739	4979	4856	4931	4687
ZAMAK 3	150 < X < 212	500	6260	6010	6110	5954	6053	6053
		400	5753	5529	5614	5469	5565	5565
		350	5565	5355	5505	5366	5458	5343
	100 < X < 150	500	5926	5701	5858	5701	5792	5714
		400	5676	5458	5626	5481	5577	5446
		350	5355	5160	5310	5181	5266	5139
	44 < X < 100	500	5805	5589	5727	5577	5676	5601
		400	5234	5038	5139	5008	5088	5058
		350	4940	4765	4837	4721	4792	4783

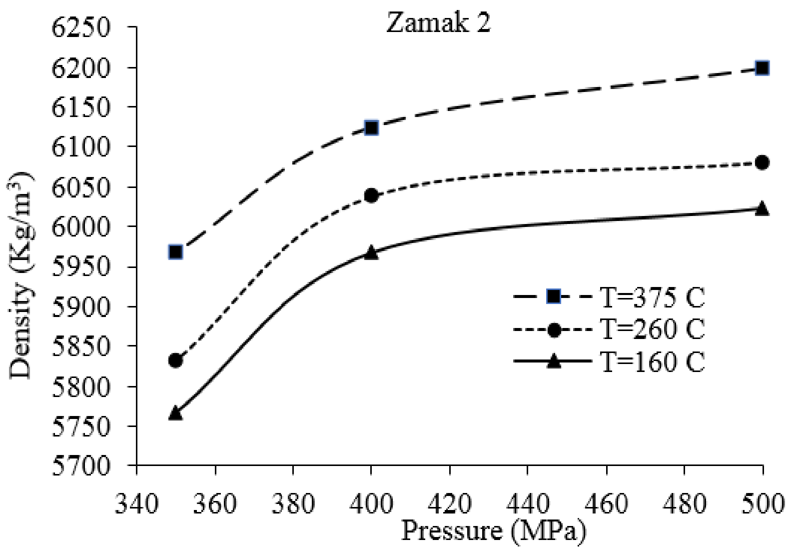

Figure 5. Effect of pressing pressure on the density of the produced ZAMAK 2 samples

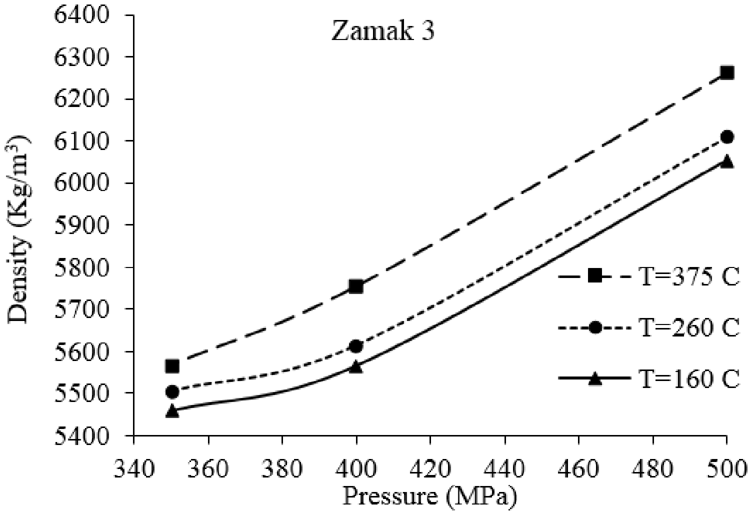

Figure 6. Effect of pressing pressure on the density of the produced ZAMAK 3 samples

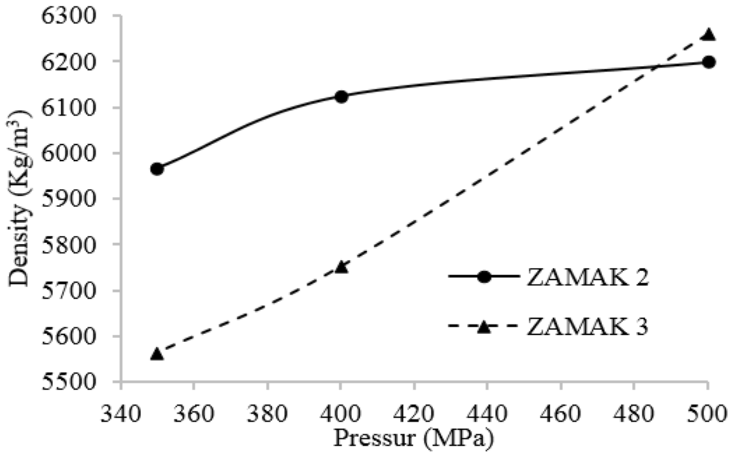

Figure 7. Comparison of ZAMAK 2 and 3 at T=375 °C with Coarse particle

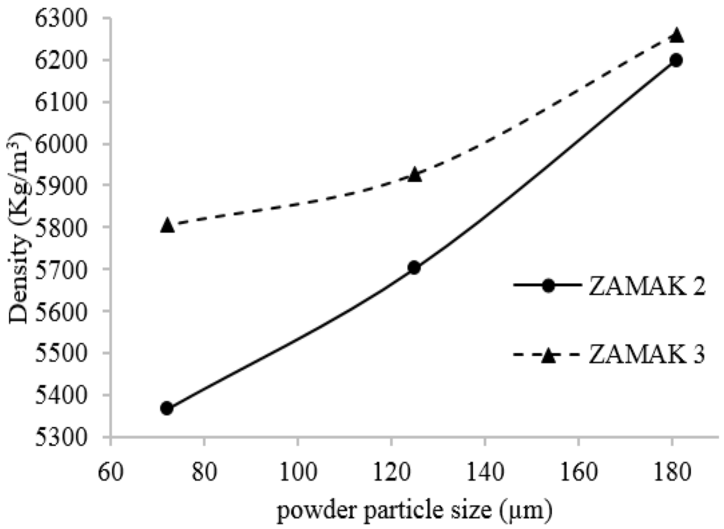

Figure 8. Comparison of the effect of powder particle size on density for ZAMAK 2 and 3, T=375 °C, P=500MPa

The microstructure of samples that have the highest density is shown in Figure 9. The microstructural examination was conventionally carried out on the ground and polished samples using an optical microscope. The etching agent used was 1 % HF. Overall, this figure shows a good appearance of the produced ZAMAK 2 and ZAMAK 3 alloy using a PM technique. The void content and their size show a great homogeneity of the produced alloy.

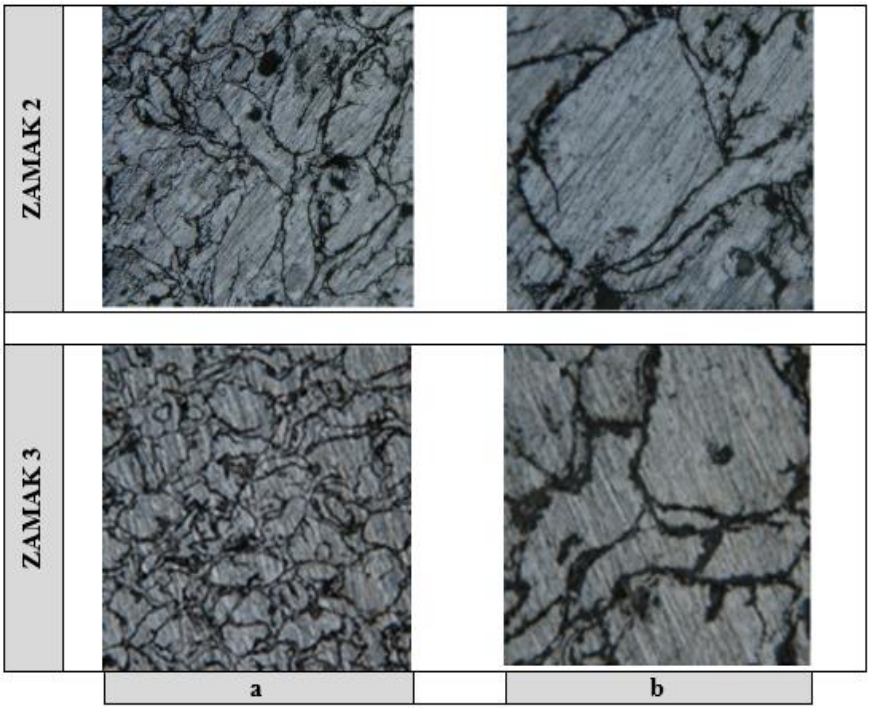

Figure 9. Microstructure of produced samples at P=500MPa, T=375 °C with Coarse Particles (a) with 2sec etching time and 50x magnification, (b) with 2sec etching time and 200x magnification

3.2 Tensile strength

The samples produced after sintering are currently ready for tensile testing. For this purpose, the Instron 8502 apparatus was used. It should be noted, only samples that were performed at a pressure of 500 MPa were subject to tensile testing.

Figures 10 and 11 show that the particle size of the powder does not have a significant effect on the tensile strength of the ZAMAK. By comparing ZAMAK 2 and 3, it becomes evident that the latter is more brittle than the former (Figure 12). This can be attributed to the low percentage of copper in the base metal of ZAMAK 3.

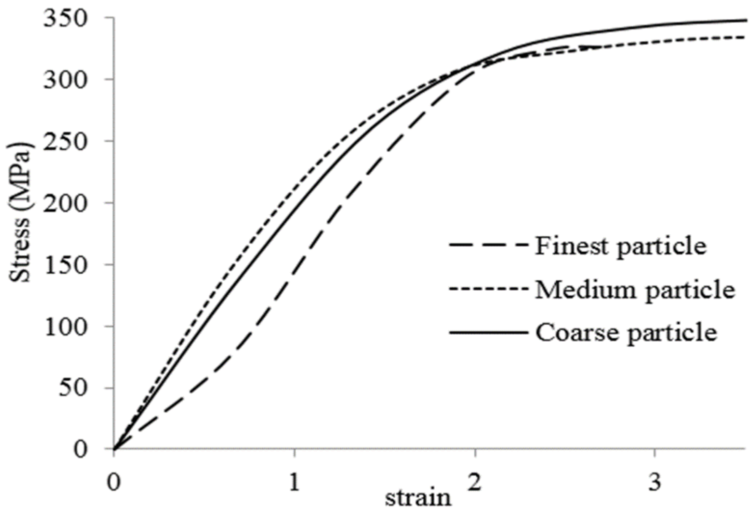

Figure 10. Stress-strain behavior of the ZAMAK 2 samples at P=500MPa, T=375°C

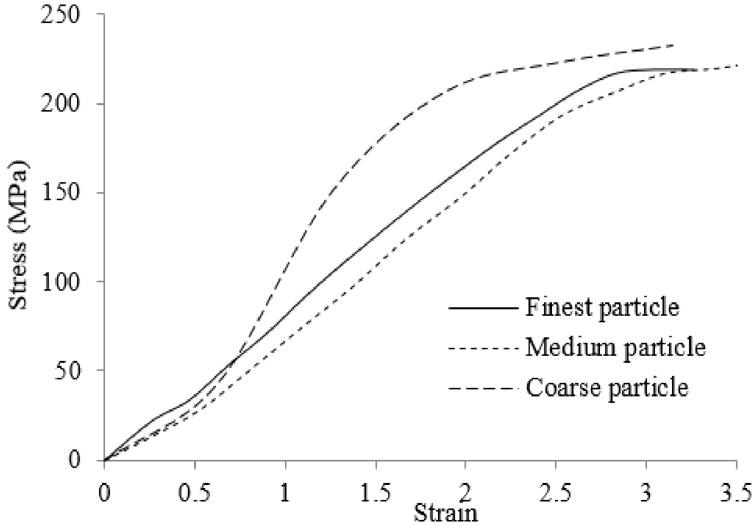

Figure 11. Stress-strain behavior of the ZAMAK 3 samples at P=500MPa, T=375°C

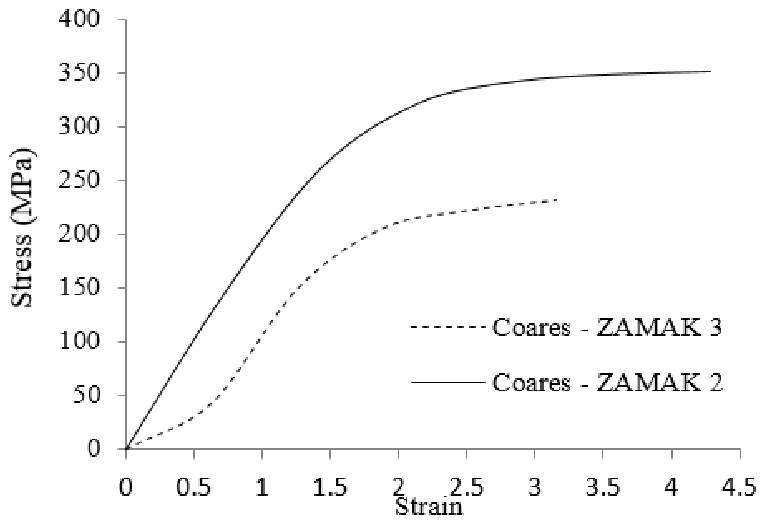

Figure 12. Comparison of ZAMAK 2 and 3 at achieved high tensile strength

Figures 13 and 14 show more fragility for samples that were sintered at low temperatures (160 °C). This is due to the dissolution of copper and aluminum in the base metal (zinc) and alloying was not well performed. The maximum tensile strength obtained for ZAMAK 2 and 3 is 351 MPa and 232 MPa, respectively. This compared to the strength obtained by casting (379MPa for ZAMAK 2 and 268 MPa for ZAMAK 3), represents a gain of 93% and 86% of base strength respectively for ZAMAK 2 and 3.

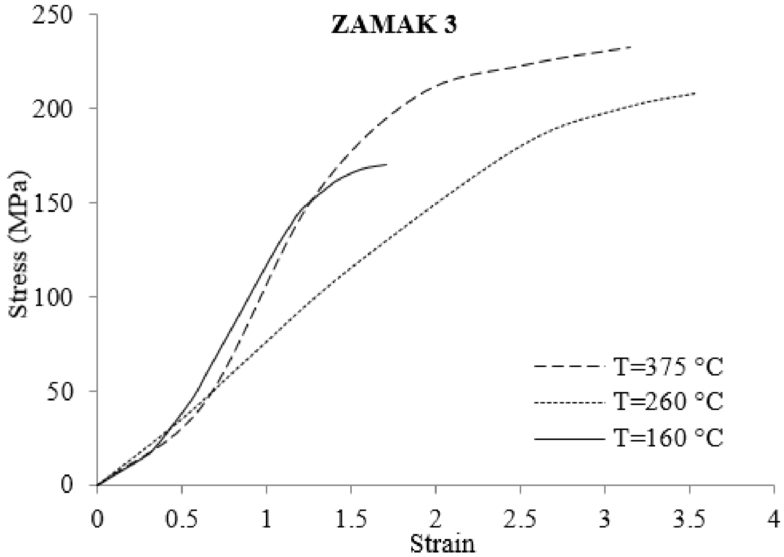

Figure 13. Effect of sintering temperature on tensile strength (ZAMAK 3)

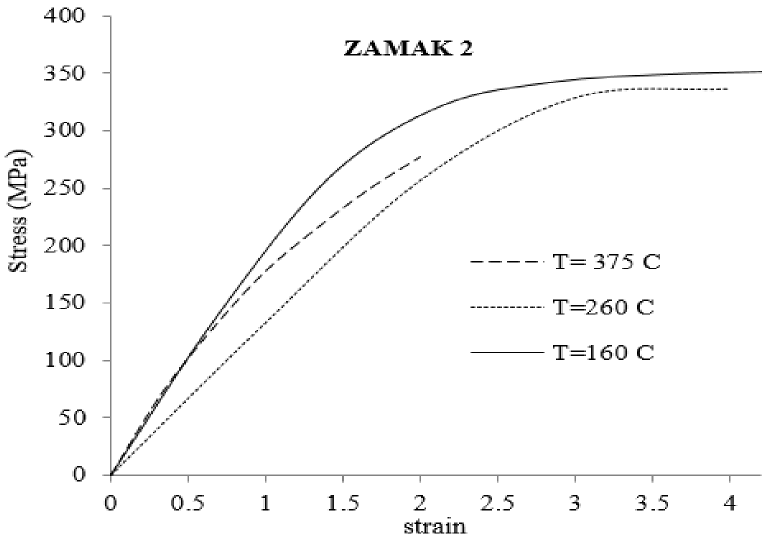

Figure 14. Effect of sintering temperature on tensile strength (ZAMAK 2)

3.3 Hardness

The hardness tests were performed utilizing Ogawa Seiki digital hardness tester type DVKH-1. For different particle sizes, the highest hardness was achieved at 500 MPa pressure and 375 °C sintering temperature. Table 7 reports the maximum achieved hardness of ZAMAK 2 and 3. The maximum hardness of the ZAMAK 2 parts is 101 HB, compared to the casting (150 HB), which shows 67%

basic hardness achievement. The maximum value for ZAMAK 3 is 75 HB, which indicates 77% achievement of base hardness (97 HB).
In the case of ZAMAK 3, using coarse particles as opposed to finest particles causes a remarkable increase in hardness value, which is not the case for ZAMAK 2.
The difference in the hardness of ZAMAK 2 and 3 is shown in Figure 15. This is due to the addition of 3% copper to increase ZAMAK 2 strength. Concurrently, as the Cu improves, the mechanical properties and hardness of the alloy increase by the formation of the $CuZn_4$ [14].

Table 7. hardness values (HB) of the samples compressed at a pressure of 500 MPa

Alloy	Powder particle size (µm)	Sintering Temperature (°C)	hardness values (HB)
ZAMAK 2	150 < X < 212	375	101
		260	97
		160	80
	100 < X < 150	375	96
		260	92
		160	81
	44 < X < 100	375	94
		260	88
		160	71
ZAMAK 3	150 < X < 212	375	75
		260	70
		160	62
	100 < X < 150	375	69
		260	65
		160	58
	44 < X < 100	375	67
		260	60
		160	49

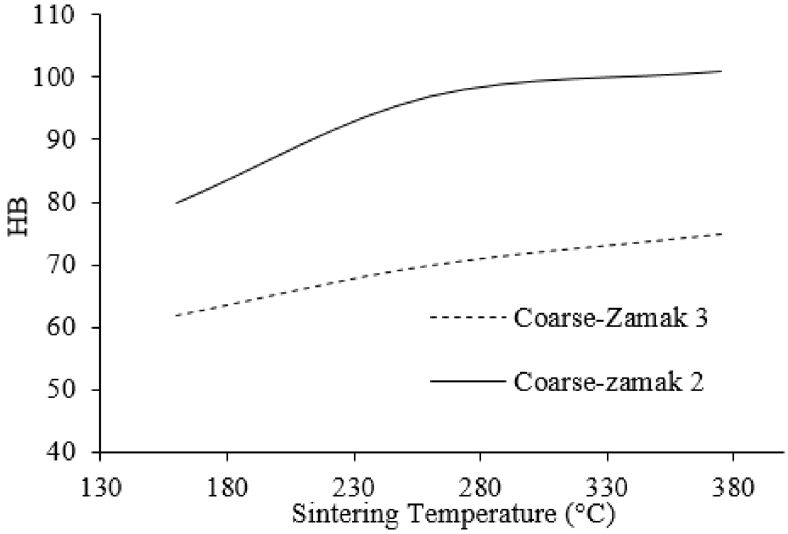

Figure 15. Comparison of ZAMAK 2 and ZAMAK 3 hardness

4. Conclusions

In this research, ZAMAK 2 and 3 alloys were successfully produced by powder metallurgy as a new method for ZAMAK production. By comparing the results of ZAMAK 2 and 3 productions, the following findings could be drawn:

1- ZAMAK 3 shows good compressibility. The relative density of 90%, as opposed to the 80% baseline of ZAMAK 2, was achieved.
2- Increasing pressure up to 400 MPa leads to a remarkable increase in density of ZAMAK 2 after which, the increase in pressure has no intense effect on density. Such behavior was not seen in ZAMAK 3 production since as the pressure increases the density increases accordingly.
3- ZAMAK 3, compared to ZAMAK 2, shows more fragility which can be attributed to the amount of copper in the base metal.
4- Because of the dissolution of copper and aluminum in the base metal, sintering was not performed at the temperature of 160 °C.
5- In ZAMAK 3, compared to ZAMAK 2, choosing a coarse particle leads to a remarkable effect on hardness.
6- Because of the formation of precipitates, the difference between ZAMAK 2 and 3 hardness is very high.

5. Acknowledgments

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