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Cold Pressed Pure Aluminum Powders Sintering With Ultra High Frequency Induction

Research Article

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Abstract

Metals both have good mechanical and electrical qualities, besides, they are also created as light as possible by using recent manufacturing techniques. In that scope, this study aims to use an ultra-high frequency sintering technique to sinter aluminum powders of 15 µm in size. A mold and 30 bar pressure were used to compress the powders before sintering. For the sintering temperature optimization, 3 experiments were conducted in the induction system at 600°C, 650°C, and 700°C temperatures. Sintering conditions were determined at different time intervals of 3 minutes, 5 minutes, and 10 minutes to find an optimum value for sintering time. Finally, furnace sintering was used for 1 hour at these temperatures. With 2 different sintering, 3 different temperatures, and 3 different time parameters, size, density, porosity, and hardness values were obtained. Obtained results were compared among themselves.

Keywords: Induction, Aluminum, Sintering, Hardness

1. INTRODUCTION

Aluminum (Al) and aluminum alloy materials are among the most important metals in today's industry. It is necessary to conduct a further investigation of the aluminum materials. Besides the low density, its electrical conductivity [1] requires comprehensive research to improve its mechanical properties through alloying or various manufacturing methods. Since it is a recyclable metal, there is a rapid increase in the use of aluminum in various industries [2,3]

Powder metallurgy (PM) covers the production and assembly of powder metal parts that can be refined or homogeneous [4,5]. However, the difficulties that may arise during the sintering of light metals such as aluminum pave the way for creating a new field of study in traditional powder metallurgy technologies. Besides investigating alloying elements in pressing and sintering processes, applying and discovering the advantages of fast production techniques such as induction is also important. Regarding the further studies, the obtained strength and density values can be improved [6-8].

Induction is a much faster heat treatment method than the furnace [8-10]. Performing the sintering process by induction in a material with electrical conductivity is based on the principle of a vortex flow [10]. Vortex flow allows the determination of the depth, called the 'depth of penetration,' on the material's exterior surface. In this process, one of the most important parameters is the frequency of the induction device [10-12]. Even though the devices are easy to maintain, the induction sintering process is used for smaller samples than it is used for conventional furnaces. The induction sintering process provides rapid heating, reducing sintering times and providing energy efficiency [10]. Induction hardening or heat treatment is used to improve the mechanical properties of metals such as aluminum. In the hardening process, various parameters are taken into consideration [11-16]. Induction hardening is an important manufacturing process to control the mechanical properties of metal parts. It controls an increase in surface hardness while maintaining the core original structure and toughness properties. Appropriate phase transformation in the exterior surface of the material is possible by inducing [17-22].

This study investigated the effects of induction and furnace sintering applied to pure aluminum powders at different times and temperatures after cold pressing. It is found that the values of the density, size, hardness and porosity of the samples and the results were compared among themselves.

2. MATERIALS & METHODS

2.1. Material

In this experiment, the environment is at room temperature. After the literature review, material and molds were provided, and conditions were determined for the experiment. The aluminum powders used are spherical micron powders with a purity of 98.85%. It is produced by the gas atomization method. The average particle size of the powders is approximately 15 µm, the molecular weight is 26.98 g/mol, and the density is 2.7 g/m^2. The chemical content of aluminum powder is given in Table 1.

Table 1. Chemical Composition of Pure Aluminum Powder

Component (Max)	***Al***	***Fe***	***Si***	***Cu***	***Zn***	***Ti***
Weight %	98.85	0.50	0.35	0.15	0.08	0.07

A single-axis single-effect mold was used for the compaction of powder mixtures. 30 bar pressure was used to press to compact the powdered material. The mold is made of an alloy-hardened steel cylinder. The outer diameter of the mold is 56mm, the height is 60mm, and the outer diameter of the penetrating punch is 16mm. Figure 1 shows a photograph of a single-axis single-effect mold. On the other hand, the induction device is an Ultra High-Frequency Induction Device that works with 20% power with 2.8 kW, 900 kHz. The induction coil is a single wounded. Its outer diameter is 26mm, and its wall thickness is 0.5mm.

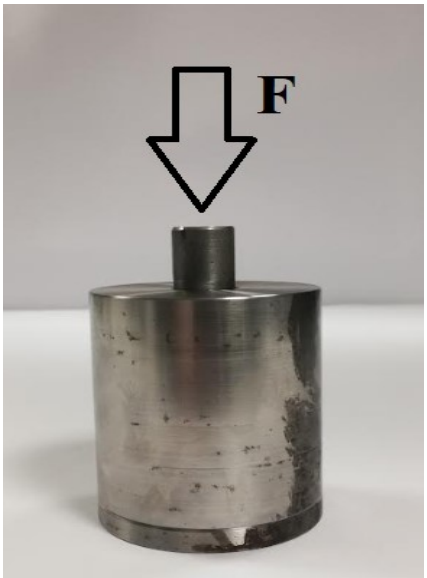


Figure 1. A Single-Axis Single-Effect Mold and Applied Force

2.2. Method

Al powders were pressed as 2.50 grams' packages. A press device was used to supply the powder as a compacted sample. Pressing was done in a single-axis single-acting press under 30 bar pressure. The raw sample dimensions were formed in a coin-like shape approximately 16mm in diameter and 2mm in height (E.R. [Error Range] ±0.3%). After providing the raw material, 9 samples were subjected to the induction sintering process. To optimize the sintering temperature, the induction system was run at 3 different temperatures at 600°C, 650°C, and 700°C. For the sintering time optimization, appropriate values for sintering conditions were determined at time intervals of 3 minutes, 5 minutes, and 10 minutes. The sintering process was run in the furnace for 60 minutes. After the sintering process, all samples were cooled naturally. Figure 2 shows the samples that are prepared for sintering. Besides, the parameters applied to pure aluminum are shown in Table 2 and the process steps in Table 3.

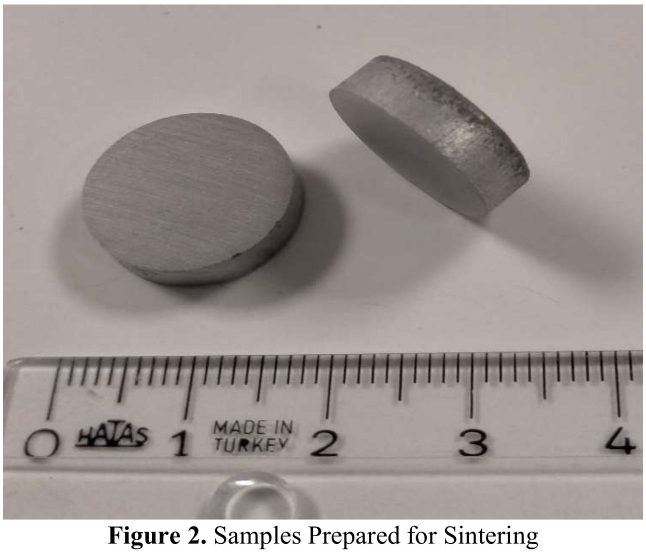
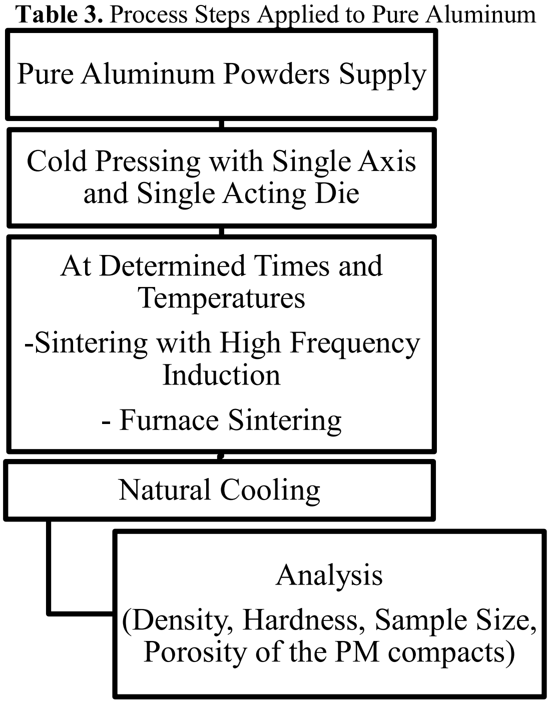


Figure 2. Samples Prepared for Sintering

Table 2. Parameters of Pure Aluminum Sintering Process

No.	**Al**	**Sintering Process**	**Heat-treated Time (min)**	**Pressure Applied in Cold Press (Bar)**	**Heat (°C)**
1	Pure Al	Induction	3	30	600
2	Pure Al	Induction	5	30	600
3	Pure Al	Induction	10	30	600
4	Pure Al	Induction	3	30	650
5	Pure Al	Induction	5	30	650
6	Pure Al	Induction	10	30	650
7	Pure Al	Induction	3	30	700
8	Pure Al	Induction	5	30	700
9	Pure Al	Induction	10	30	700
10	Pure Al	Furnace	60	30	600
11	Pure Al	Furnace	60	30	650
12	Pure Al	Furnace	60	30	700

Table 3. Process Steps Applied to Pure Aluminum



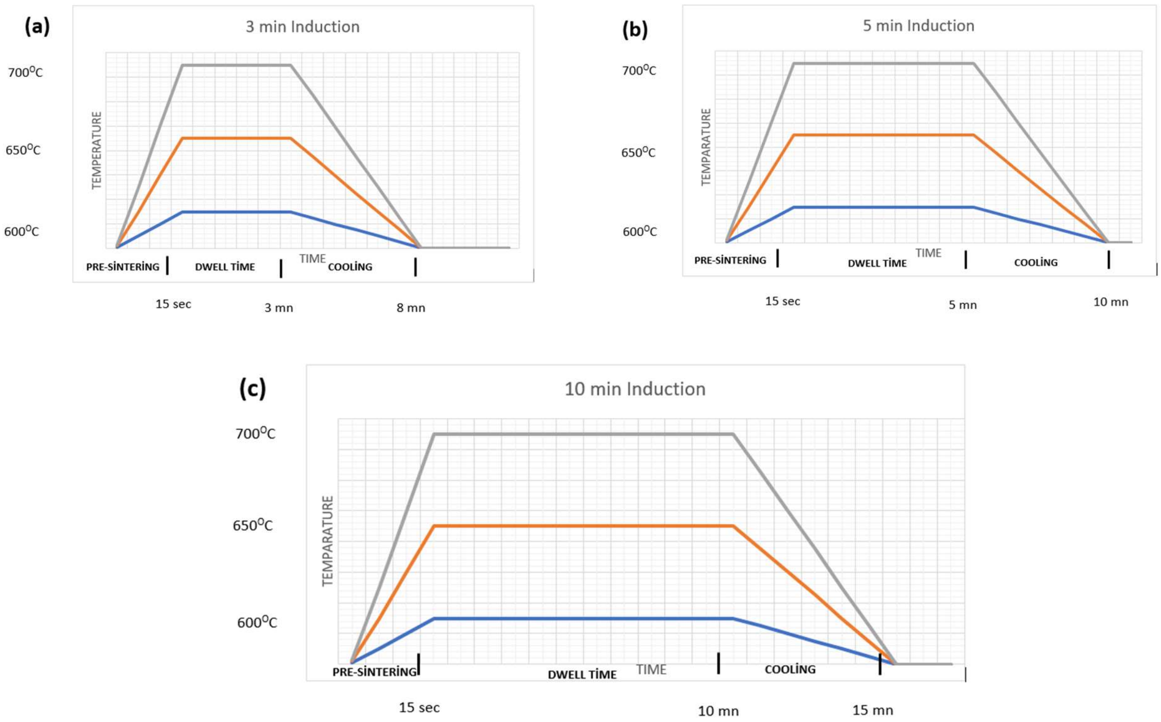


Figure 4. Temperature time graph of the induction process in 3min (a) , 5 min (b) , and 10 min (c)

3. FINDINGS

3.1. Density Values

Raw density and sintered density values of pure aluminum, sintered with an induction device operating at 20 percent power at 600°C, 650°C, and 700°C at different induction times, are given in Table 4. The raw density refers to the density of the raw material after it is printed in the mold, and the sintered density refers to the density measured after induction.

Table 4. Density Change According to Temperature and Time Parameters as a Result of Sintering of Pure Aluminum in Induction Device

SAMPLE NO	HEAT (°C)	TIME (min)	RAW DENSITY (g/cm^3)	SINTERED DENSITY (g/cm^3)	CHANGE (%)
1	600°C	3 min	2.550	2.603	2.054
2	600°C	5 min	2.563	2.621	2.254
3	600°C	10 min	2.543	2.596	2.103
4	650°C	3 min	2.536	2.578	1.644
5	650°C	5 min	2.556	2.593	1.463
6	650°C	10 min	2.521	2.552	1.257
7	700°C	3 min	2.546	2.574	1.103
8	700°C	5 min	2.536	2.562	1.028
9	700°C	10 min	2.583	2.610	1.045

The findings in Table 4 show that the induction sintered sample has a higher density than the raw sample. For example, while the raw density was 2.55 g/cm^3, the final density of the sintered sample in the induction system at 600°C for 3 minutes was 2.60 g/cm^3. Besides, the density of the raw material before the sintering process was 2.53 g/cm^3. After being sintered in the induction system at 700°C for 5 minutes, the final density was measured as 2,56 g/cm^3. This increase was observed in all samples. The error range of the density values in the samples are approximately ±1.5%. Table 5 shows the raw densities and post-sintering density values kept separately at 600°C, 650°C, and 700°C for 1 hour.

Table 5. Density Change Caused by Sintering of Pure Aluminum at Different Temperatures in the Furnace

SAMPLE NO	HEAT (°C)	TIME (min)	RAW DENSITY (g/cm^3)	SINTERED DENSITY (g/cm^3)	CHANGE (%)
10	600°C	60 min	2.581	2.639	2.234
11	650°C	60 min	2.570	2.498	-2.812
12	700°C	60 min	2.556	2.466	-3.501

In Table 5, it is seen that the density of the sample sintered for 1 hour in the furnace at 600°C increased compared to its raw density, while the densities of the samples sintered for 1 hour in the furnaces at 650°C and 700°C decreased after sintering. Melting of the material and loss of mass causes a decrease in density, as shown in Figure 4. While the density increases by 2.23% at 600°C, it decreases by 2.81% at 650°C and 3.50% at 700°C.

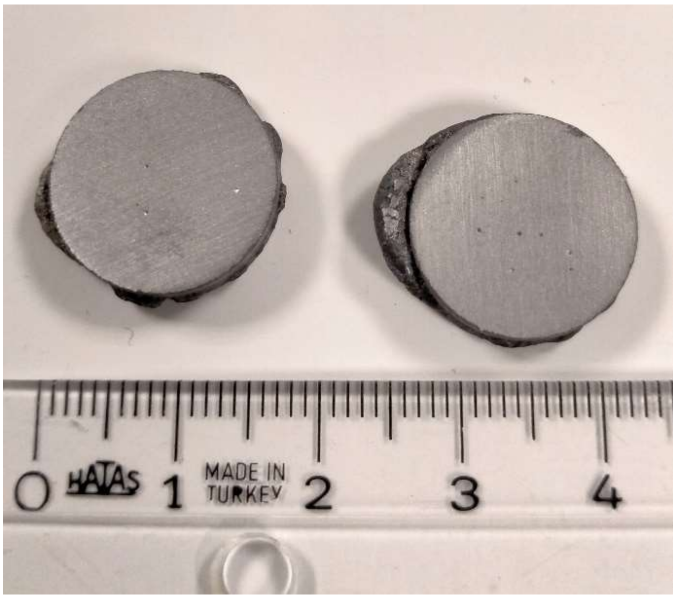


***Figure* 3.** Furnace Sintered at 650°C (Left), Sintered at 700°C (Right) Relatively Molten Pure Aluminum

3.2. Size Change

In Table 6, the raw and post-sintering sizes of the aluminum sintered at different time intervals as 3 minutes, 5 minutes, and 10 minutes operating at 600°C, 650°C, and 700°C, are given.

Table 6. Size Change as a Result of Induction Sintering of Pure Aluminum

SAMPLE NO	HEAT (°C)	TIME (min)	RAW SIZE (mm)	SINTERED SIZE (mm)	CHANGE (%)
1	600°C	3 min	16.15	16.10	-0.309
2	600°C	5 min	16.15	16.10	-0.309
3	600°C	10 min	16.25	16.20	-0.307
4	650°C	3 min	16.25	16.20	-0.307
5	650°C	5 min	16.25	16.20	-0.307
6	650°C	10 min	16.25	16.20	-0.307
7	700°C	3 min	16.20	16.15	-0.308
8	700°C	5 min	16.20	16.15	-0.308
9	700°C	10 min	16.20	16.15	-0.308

Table 6 shows that the diameter dimensions of the samples have decreased. For instance, while the raw size of the sample sintered at 650°C in 10 minutes is 16.25 mm, the size decreases to 16.20 mm after sintering. The error range was measured as max ±3.25%. Table 7 gives the size change values of the material sintered for 1 hour in the furnace at 600°C, 650°C, and 700°C.

Table 7. Size Change Due to Sintering of Pure Aluminum in the Furnace

SAMPLE NO	HEAT (°C)	TIME (min)	RAW SIZE (mm)	SINTERED SIZE (mm)	CHANGE (%)
10	600°C	60 min	16.20	16.20	0.000
11	650°C	60 min	16.15	15.95	-1.238
12	700°C	60 min	16.25	15.95	-1.846

Table 7 shows that while no change is observed at 600°C, a decrease is observed at values close to and above the melting temperature. The reason for the difference in decrease rates depends on the approaching and exceeding the melting temperature in the sintering material, as shown in Figure 4. According to that percentage of change increases which is also seen in the change in porosity values.

3.3. Hardness Results

Hardness values of pure aluminum sintered by ultra-high frequency induction at 600°C, 650°C, and 700°C for 3 minutes, 5 minutes, and 10 minutes are given in Table 8. Hardness was measured by taking the average of the 5 determined points. The determined points were set as the outermost of the circular part (200 µm inside the border), the center (8000 µm inside the border), and the middle of these two points (4000 µm inside the border).

Table 8. Hardness Change of Induction Sintered Pure Aluminum in Time and Temperature Parameters

SAMPLE NO	HEAT (°C)	TIME (min)	HARDNESS OF THE SINTERED EXTERIOR SURFACE (HV) *Distance: 200µm*	HARDNESS OF THE SINTERED MIDDLE SURFACE (HV) *Distance: 4000µm*	HARDNESS OF THE SINTERED INSIDE (HV) *Distance:8000 µm*
1	600°C	3 min	42.5	41.4	40.9
2	600°C	5 min	43.2	42.1	41.5
3	600°C	10 min	41.9	41.2	40.5
4	650°C	3 min	38.1	37.5	36.9
5	650°C	5 min	39.7	39.2	38.7
6	650°C	10 min	38.3	37.8	37.5
7	700°C	3 min	38.0	37.4	36.8
8	700°C	5 min	39.0	38.5	37.8
9	700°C	10 min	38.3	37.6	37.1

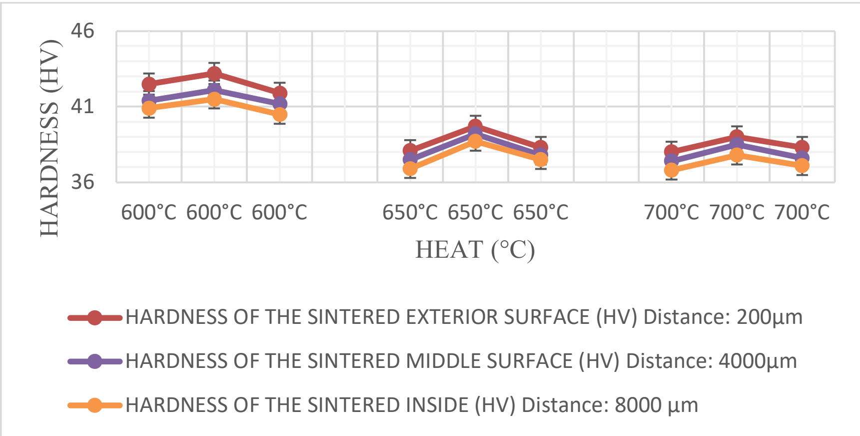


Figure 5. Density Change Caused by Sintering of Pure Aluminum at Different Temperatures in the Furnace

The values that are shown in Table 8 formed the curve as a parabolic curve. The hardness decreases if the time is kept constant and the temperature increases. Besides that, a comparison between 5 and 10 minutes shows that the hardness decreases as the temperature increases. The error range was found as ±2.25%. In Table 9, hardness values of pure aluminum sintered for 1 hour (60 minutes) in the furnace at 600°C, 650°C, and 700°C are given.

Table 9. Hardness Change of Pure Aluminum Sintered in the Furnace for 1 Hour

SAMPLE NO	HEAT (°C)	TIME (min)	HARDNESS OF THE SINTERED EXTERIOR SURFACE (HV) *Distance: 200µm*	HARDNESS OF THE SINTERED MIDDLE SURFACE (HV) *Distance: 4000µm*	HARDNESS OF THE SINTERED INSIDE (HV) *Distance: 8000 µm*
10	600°C	60 min	37.0	35.2	34.0
11	650°C	60 min	35.7	34.1	33.5
12	700°C	60 min	35.2	33.5	33.0

Table 9 shows that if the time is kept constant, the hardness decreases as the temperature increase. While the change in hardness between the sample sintered at 600°C and at 650°C is approximately ±1.3 (distance: 200µm), the change in hardness between the sample sintered at 650°C and at 700°C is ±0.5 (distance: 200µm).

3.4. Porosity Values

Raw porosity and post-sintering porosity values of pure aluminum sintered at 600°C, 650°C, and 700°C are given in Table 10.

Table 10. Raw and Sintered Porosity Values by Sintering Method and Time Parameters

SAMPLE NO	SINTERING METHOD	HEAT (°C)	TIME (min)	RAW POROSITY (g/cm^3)	SINTERED POROSITY (g/cm^3)	CHANGE (%)
1	Inductıon	600°C	3 min	0.056	0.036	-35.714
2	Inductıon	600°C	5 min	0.051	0.030	-41.176
3	Inductıon	600°C	10 min	0.059	0.039	-33.898
4	Inductıon	650°C	3 min	0.061	0.046	-24.590
5	Inductıon	650°C	5 min	0.054	0.040	-25.925
6	Inductıon	650°C	10 min	0.067	0.055	-17.910
7	Inductıon	700°C	3 min	0.058	0.047	-18.965
8	Inductıon	700°C	5 min	0.061	0.051	-16.393
9	Inductıon	700°C	10 min	0.044	0.034	-22.727
10	Furnace	600°C	60 min	0.044	0.023	-47.727
11	Furnace	650°C	60 min	0.048	0.075	56.249
12	Furnace	700°C	60 min	0.054	0.087	61.111

In Table 10, it is seen that the porosity decreases in the samples sintered by induction. Besides, the porosity of samples sintered with the furnace at 600°C decreases, and the final porosity value increases at 650°C and 700°C. While the change between the raw and post-sintering porosity values was approximately ±0.03, the porosity value change was approximately ±0.01 in the sample sintered at 700°C for 5 minutes. The average error range is found as ±1.3%.

In the literature, it is clear that there is a need for further investigation on the sintering of Pure Al powders by ultra-high frequency induction. In this study, it is shown that properties such as hardness can be increased by using faster manufacturing methods of aluminum. In future studies, experiments can be conducted by optimizing the size of Pure Al powders, different powder material additive and applied pressure parameters. Besides, further studies can be conducted to find other optimum conditions by changing other parameters, such as induction coil design, the frequency and the applied power of the induction system [11,17,21,22]. The induction technique can provide better information about the change in the material surface's internal structure and possible hardness increase. The hardness change is proof of surface hardening by heat treatment which is carried out during induction sintering.

4. RESULTS VE DISCUSSION

In this study, 30 Bar pressure was applied to 15 µm Pure Al powders under cold press, and sintering was provided by furnace and induction. Obtained results are presented below.

- In all induction sintered samples, the density after sintering increased compared to the raw density. As a result, the porosity decreased. In addition, as the temperature increases in these samples, the percentage change in density decreases.
- It is found out that using the induction sintering method is more advantageous to obtain a better hardness when different sintering methods are compared.
- Hardness decreased as the sintering temperature increased in all samples. On the other hand, the best hardness value was obtained after 5 minutes of induction and sintering at the specified temperatures.
- An increase in density was detected in sample 10, sintered with a furnace at 600°C. On the other hand, a decrease in density was observed in samples 11 and 12 sintered with a furnace close to and above the melting temperature of aluminum (650°C and 700°C). The melting of the material above the sintering temperature causes a decrease in density.
- Porosity decreased in induction-sintered samples. The decrease in the material's porous structure caused its size to decrease and its density to increase. Accordingly, the hardness values of the material increased.
- Induction-sintered samples are sintered faster than furnace-sintered samples. In this context, it is possible to save time with the induction sintering method.

6. CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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