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INVESTIGATION OF INDUCTION SINTERABILITY OF POWDER METAL PARTS OF DIFFERENT SHAPES AND SIZES

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Keywords

Powder Metallurgy, Sintering, Induction Sintering, Conventional Sintering

Abstract

Powder metal parts are used in many applications because of widely advantages. Induction sintering is a rapid sintering method, and it is moving towards to an important alternative process of conventional sintering by means of time and energy saving and more improved mechanical properties. In this study, five different commercial component were pressed with dual axis press under 600-800 MPa pressure. The samples were sintered with conventionally and with medium frequency (30 kHz) induction sintering mechanism. The body of the samples was heated directly by induction sintering. Comparison of the mechanical properties and microstructures of samples which produced by conventional and induction sintering methods were carried out. In the tests, compression testing, HRB hardness testing and microstructural examination were used for each component individually or in combination, taking into account customer specifications. As a result of study, although there were differences depending on the alloys and the shape of the powder metal component, when porosity, hardness and compression strength are taken into account, it has been observed that with the induction sintering method, sintering times of 30 minutes could be reduced to 15 minutes, resulting in a time reduction of approximately 50%. While a maximum difference of 11% was observed in the sample with the worst result in the compression test in induction sintering compared to conventional sintering, it was observed that the compression strength obtained with conventional sintering in other samples could be achieved with the induction sintering method. When the hardness and porosity data were examined, it was seen that induction sintering can reach the targeted conventional sintering values. It has been observed that a hardness increases of up to 20 HRB is provided in the best case. When the pre-sintering time is included, an 80 % time advantage is observed compared to conventional sintering.

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FARKLI ŞEKİL VE BOYUTLARDAKİ TOZ METAL PARÇALARIN İNDÜKSİYON İLE SİNTERLENEBİLİRLİĞİNİN ARAŞTIRILMASI

Anahtar Kelimeler

Toz Metalurjisi, Sinterleme, İndüksiyon Sinterleme, Geleneksel Sinterleme

Öz

Toz metal parçalar, yaygın avantajları nedeniyle birçok uygulamada kullanım alanı bulmaktadır. İndüksiyon sinterleme, hızlı bir sinterleme yöntemidir ve zaman ve enerji tasarrufu ve iyileştirilmiş mekanik özellikler sebebiyle geleneksel sinterlemeye önemli bir alternatif olma yolunda ilerlemektedir. Bu çalışmada, beş farklı ticari bileşen 600-800 MPa basınç altında çift eksenli presle preslenmiştir. Numuneler, geleneksel ve orta frekanslı (30 kHz) indüksiyon sinterleme mekanizmasıyla sinterlenmiştir. Numunelerin gövdesi doğrudan indüksiyon sinterleme ile ısıtılmıştır. Geleneksel ve indüksiyon sinterleme yöntemleriyle üretilen numunelerin mekanik özellikleri ve mikro yapıları karşılaştırılmıştır. Testlerde, müşteri spesifikasyonları dikkate alınarak her bir bileşen için ayrı ayrı veya kombinasyon halinde basma testi, HRB sertlik testi ve mikro yapısal inceleme kullanılmıştır. Çalışma sonucunda alaşımlara ve toz metal bileşenin şekline bağlı olarak farklılıklar olmasına rağmen gözeneklilik, sertlik ve basınç dayanımı dikkate alındığında indüksiyon sinterleme yöntemi ile 30 dakikalık sinterleme sürelerinin 15 dakikaya indirilebildiği, bunun sonucunda yaklaşık %50 oranında zaman azalması sağlandığı görülmüştür. İndüksiyon sinterlemede basma testinde en kötü sonuca sahip numunede konvansiyonel sinterlemeye göre maksimum %11'lik fark gözlenirken, diğer numunelerde konvansiyonel sinterleme ile elde edilen basma dayanımının indüksiyon sinterleme yöntemi ile de sağlanabildiği görülmüştür. Sertlik ve gözeneklilik verileri incelendiğinde indüksiyon sinterlemenin hedeflenen konvansiyonel sinterleme değerlerine ulaşabildiği görülmüştür. En iyi durumda 21 HRB'ye kadar sertlik artışı sağlandığı gözlemlenmiştir. Ön sinterleme süresi de eklendiğinde konvansiyonel sinterlemeye göre %80'lik bir zaman avantajı görülmektedir.

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1. Introduction

Due to its many benefits, powder metallurgy is one of the most popular production techniques. Using this technique, powders with varying compositions are crushed and subsequently sintered. One of the most crucial problems in powder metallurgy is sintering, as it greatly increases the resistance of crushed powders. The sintering furnaces are where the sintering process is typically carried out. Both batch furnaces and continuous furnaces are used for this(R.M. German, 1996). An essential substitute for the conventional sintering method is the induction sintering technique. This process's benefit is that it may quickly densify to almost theoretical density and prevent grain development (Shon, Jeong, Ko, Doh, & Woo, 2009). Electromagnetic induction, a heating method for electrically conductive materials such as metals(Zinn, S., Semiatin, 1988). The most important feature of the induction heating system is the rapid heating of material because heating occurs directly on metal parts. In general, induction is used for surface heating of materials. Beside of this, heat transfer is 3,000 times better than other heating systems. This provides much faster completion of the warm-up process and reducing the time spent for this period(Randall M. German, 2005). One of the most effective heating techniques in today's electromagnetic material processing is induction heating, which produces heat that is both energy-efficient and quick to produce (Rapoport & Pleshivtseva, 2006). Induction sintering was generally carried out at the same time as pressing in a high-frequency sintering apparatus (Çivi, Tahrali, & Atik, 2014). High frequency induction sintering (HFIHS) is a new rapid sintering method developed in recent years for ceramic and composite production (H. C. Kim, Shon, Yoon, Doh, & Munir, 2006; H. C. Kim, Shon, Yoon, Lee, & Munir, 2006; H. C. Kim, Yoon, Doh, Ko, & Shon, 2006; S. W. Kim, Cockcroft, Khalil, & Ogi, 2010)Along with high frequency induction sintering studies, medium frequency induction has also been carried out (Uğur Çavdar & Atik, 2014; Çivi & Atik, 2012, 2018; Çivi et al., 2014) in recent years. For applications in powder metallurgy, mixtures of elemental iron and graphite powder are frequently utilized (W. F. Wang, 2005). The difference between this system and high frequency sintering is that sintering is performed after pressing. Since this method is a method between induction and sintering by conventional sintering, it is suitable for serial production and sintering of different shaped parts after pressing.

In this study, iron based different shaped commercial powder metal components were sintered by induction and conventional sintering methods. The suitability of mass production of induction sintering was investigated and sinterability of different shaped powder metal parts was investigated by induction sintering method.

2. Experimental studies

In this study, Iron based Hogenas metal powders was used. The powder contents are listed in Table 1. The chemical compositions and the physical properties of the powder contents specified in Table 1 are given in Tables 2-5. Powder metal components in the specified contents were produced by Sintek Inc. Turkey with a dual axis press under 800 MPa pressure. Conventionally sintering was carried out in sintering furnace for 150 minutes (45 minutes pre-sintering, 30 minutes sintering and 75 minutes cooling). Induction sintering was carried out in medium frequency induction sintering mechanism (30 Khz) for 15 and 30 minutes at 1120°C (Figure 2). Pre sintering was not applied to components and samples were cooled in room temperature environment. Induction sintering was carried out in cupper coil in the heat resistant glass. A laser pyrometer was used to maintain a consistent temperature of 1120°. Measurements and detailed shapes of sintered components are given in Figure 3 (Sample nomenclature was made according to Figure 3). The image of the samples during sintering is shown in figure 4. After the sintering, some mechanical and microstructural analyses were done to samples. The samples are commercially produced and used components in the automotive industry. The mechanical tests carried out on the samples were requested from consumers. Rockwell-B hardness test was applied according to ASTM E18-12. Compression tests were done to some of the samples according to ASTM E9-09. Finally microstructural investigation was done for two samples. Through all these tests, the properties of induction sintered samples were determined, and these values were compared with conventional sintered samples.

Table 1. Chemical Contents of Samples

Sample Name	Content of Metal Powder
Sample a)	% 100 NC 100.24 Pure Iron + % 0,6 Kenolube P11 (% 2.2-% 2.4 Zn)
Sample b)	%100 Distaloy AE (% 4 Ni + % 1,5 Cu + % 0,5 Mo) + % 0,6 Graphite+% 0,6 Kenolube
Sample c)	% 85 NC 100.24 Pure Iron + % 15 Distaloy ACu (% 10,4-11Cu) +% 0,6 Kenolube
Sample d)	% 100 AHC 100.29 Pure Iron+% 0,6 Kenolube
Sample e)	% 80 AHC 100.29+ % 20 Distaloy ACu (% 10,4-11 Cu) (% 99,2)+ % 0,8 Graphite+% 0,4 Kenolube

Chemical compositions, physical properties (apparent density and flowability) and particle size analysis of used metal powders are given in Table 2-5.

Table 2. Högenas NC 100.24 Chemical Compositions, Physical Properties and Particle Size Analysis

Chemical Compositions (%)		Physical Properties		Particle Size Analysis (%)	
H_2	0,15	Apparent Density	2,43 g/cm^3	45 µm<	18,5
Cu	0			45-75 µm	20,5
Mo	0			75-106 µm	25,9
C	0			106µm-150 µm	33,9
O	0,08			150µm-212 µm	2,3
Fe	Balance			180µm-212 µm	0,1
		Flowability	32 s/50 g	>212 µm	0

Table 3. Högenas Distaloy AE Chemical Compositions, Physical Properties and Particle Size Analysis

Chemical Compositions (%)		Physical Properties		Particle Size Analysis (%)	
Ni	4,07	Apparent Density	3,02 g/cm^3	45 µm<	27,1
Cu	1,52			45-75 µm	29,5
Mo	0,50			75-106 µm	20,4
O	0,08			106µm-150 µm	17,2
C	0			150 µm-180 µm	4,7
Fe	Balance			180µ-212 µm	1,1
		Flowability	26 s/50 g	>212 µm	0

Table 4. Högenas AHC 100.29 Chemical Compositions, Physical Properties and Particle Size Analysis

Chemical Compositions (%)		Physical Properties		Particle Size Analysis (%)	
C	0,003	Apparent Density	2,98 g/cm^3	45 µm<	24,9
O	0,13			45-75 µm	28,6
Fe	Balance	Flowability	25 s/50 g	75-106 µm	21,8
				106-150 µm	19,2
				150-212 µm	5,5
				>212 µm	0

Table 5. Högenas Distaloy ACu Chemical Compositions, Physical Properties and Particle Size Analysis

Chemical Compositions (%)		Physical Properties		Particle Size Analysis (%)	
Cu	10,8			45 µm<	22,8
O	0,09	Apparent Density	3,04 g/cm^3	45-75 µm	29
C	0			75-106 µm	20,9
		Flowability		106 µm-150 µm	20,5
				150µm-180 µm	5,8
Fe	Balance			180µm-212 µm	1
		Apparent Density	24 s/50 g	>212 µm	0

All the sintered commercial powder metal parts are given in Figure 1.

Figure 1. Sintered Samples

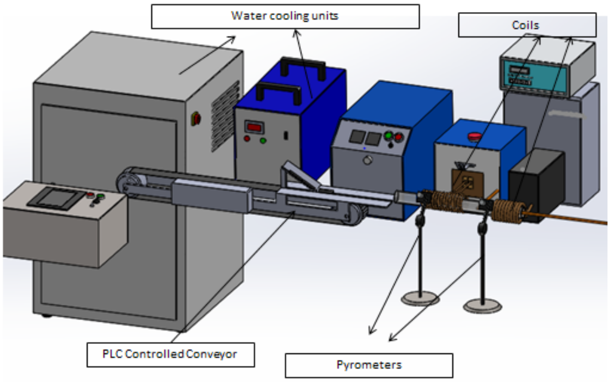

Figure 2. Medium Frequency Induction Sintering Unit

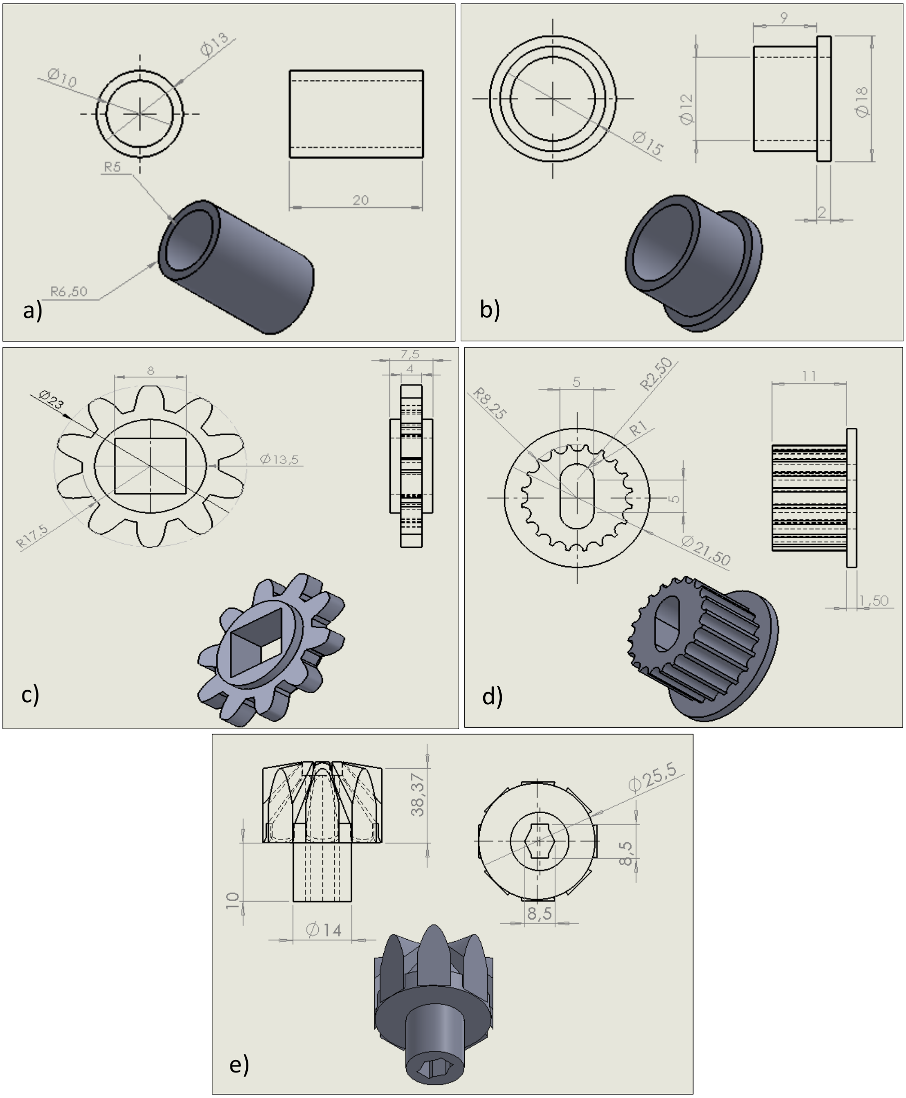

Figure 3. Technical Drawings of All Sintered Components (Dimensions in mm)

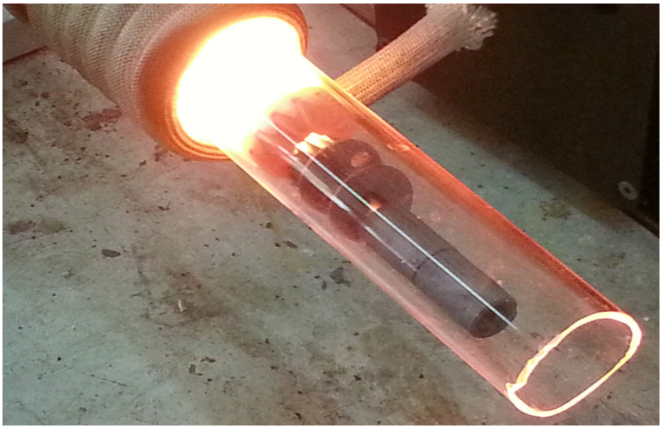

Figure 4. The Image of the Specimens During Sintering

Research and publication ethics were complied with in this study.

3. Results and Discussion

3.1 Sample a)

A compression test was applied to the Sample a (100% pure iron (Högenas NC 100.24) and 0.6% Kenolube lubricant by weight) after the sintering process. Table 6 displays the results of the compression test.

Table 6. Compression Test Results of Sample a.

Sintering duration	Max. Stress (MPa)	Max. Strain (%)
15 min. induction	209,78	10,27
30 min. induction	219,45	12,39
Conventional Sintering	246,94	15,41

In these specimens, the strength values obtained by conventional sintering were not achieved by induction sintering method. Beside of this strength values were increased with sintering duration up to 30 minutes. The increase in sintering time in the induction sintering method naturally resulted in an increase in neck formation and mechanical properties during sintering (Randall M. German, 2005). This is in accordance with the situation determined in the previous study that the mechanical properties in induction sintering of pure iron materials are lower than in conventional sintering. In addition, parallel results were obtained in sample d, which contains pure iron. (Çivi & Atik, 2018). The main advantage of induction sintering is that it is a fast method. Direct heating of the sample makes the method fast and effective. Beside of this Induction heating is based on joule heating. The resistivity of the materials to be heated is critical for this heating method (Rapoport E, 2010). Resistivity of samples containing alloys such as Ni, Mo, Cu, C are much higher before sintering compared to pure iron samples. This supports inductive heating positively (Can Çivi, 2015; Çivi & Atik, 2018). Similar results were obtained for the alloys included in this study (Table 1). These related results are given in the following section.

3.2 Sample b)

The contents of Sample b were 99.4% Distaloy AE (4% Ni + 1.5% Cu + 0.5% Mo) + 0.6 Graphite + 0.6 Kenolube. Compression tests were applied to these samples and microstructure of these specimens were investigated. Table 7 and Figure 5 present the test findings.

Table 7. Compression Test Results of Sample b.

Sintering duration	Max. Stress (MPa)	Max. Strain (%)
15 min. induction	315,21	15,25
30 min. induction	317,32	14,96
Conventional Sintering	316,26	15,10

The strength values obtained by conventional sintering method have been reached in these samples for 15 minutes by induction sintering process. Better results were obtained with induction in iron-based copper alloy samples, in line with the literature (Uğur Çavdar & Atik, 2010). It is known that the addition of Cu and Mo to the alloy in iron-based powder metal parts improves the mechanical properties (R.M. German, 1996; S. Wang et al., 2019). When both methods were compared, similar compression strength properties were obtained in this component. Also, as seen in Figure 5 a and b, porosity decreased as sintering time increased in induction sintering. In addition, porosity analysis results confirm this (Figure 6).

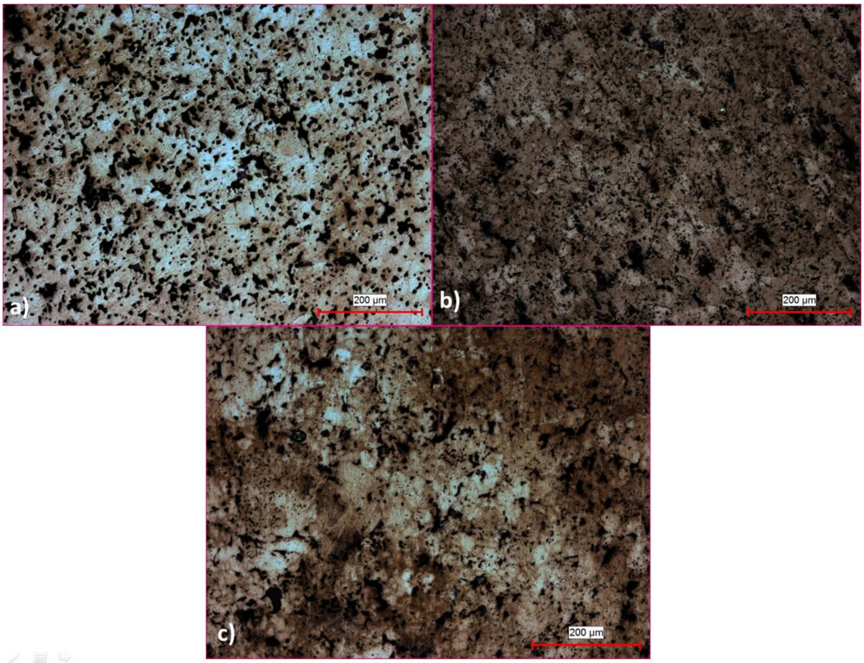

Figure 5. Microstructure Images of Sample b; a)15 Minutes Induction Sintering, b) 30 Minutes Induction Sintering c) Conventional Sintering

Additionally, porosity analyses were done to these samples from microstructure images. Clemex vision lite software was used for porosity analysis. An example analyses were given in Figure 6. Analyses results were given in Table 8.

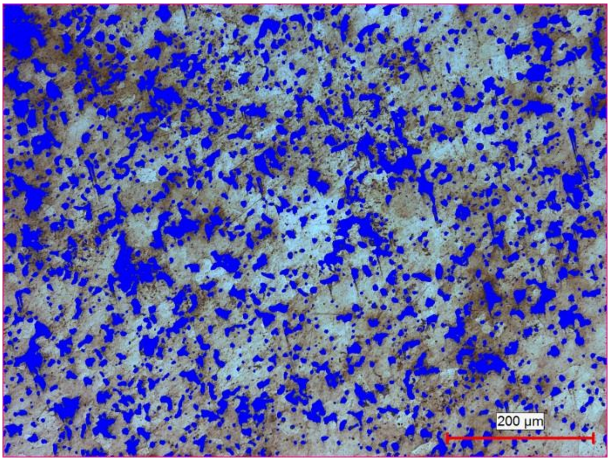

Figure 6. An Example Porosity Analyze İmages

Table 8. Porosity Analyses of Sample b.

Sintering duration	Porosity (%)
15 Minutes Induction	24,59
30 Minutes Induction	20,90
Conventional Sintering	22,19

It is a known fact that density values decrease after sintering in samples containing copper. Similar to the literature, low density values were obtained in this sample containing copper (R.M. German, 1996). In some cases (especially in the bushings used in this study-Sample a and Sample b) porosity is a desired condition for self-lubrication. Oil enters the pores and exits during the first operation, providing lubrication. However, when conventional and induction sintering methods were compared, similar porosity values were observed in this component. Because in this sample the amount of Copper in the Alloy is relatively low compared the other components (Table 1). This also resulted in close strength values (Table 7).

3.3 Sample c)

Sample c have 85% NC 100.24 (Pure Iron Dust) + 15% Distaloy ACu (10,4-11% Cu) +0,6 Kenolube content. Rockwell-B hardness tests were applied to these samples and the microstructure of the samples were examined. As can be seen from the hardness test results, the hardness values obtained by conventional sintering are reached by sintering by induction for 30 minutes.

Table 9 and Figure 7 present the test findings.

Table 9. Rockwell-B Hardness of Sample c.

Sintering Duration	Hardness (HRB)
15 Minutes Induction	45,5
30 Minutes Induction	50,0
Conventional Sintering	49,0

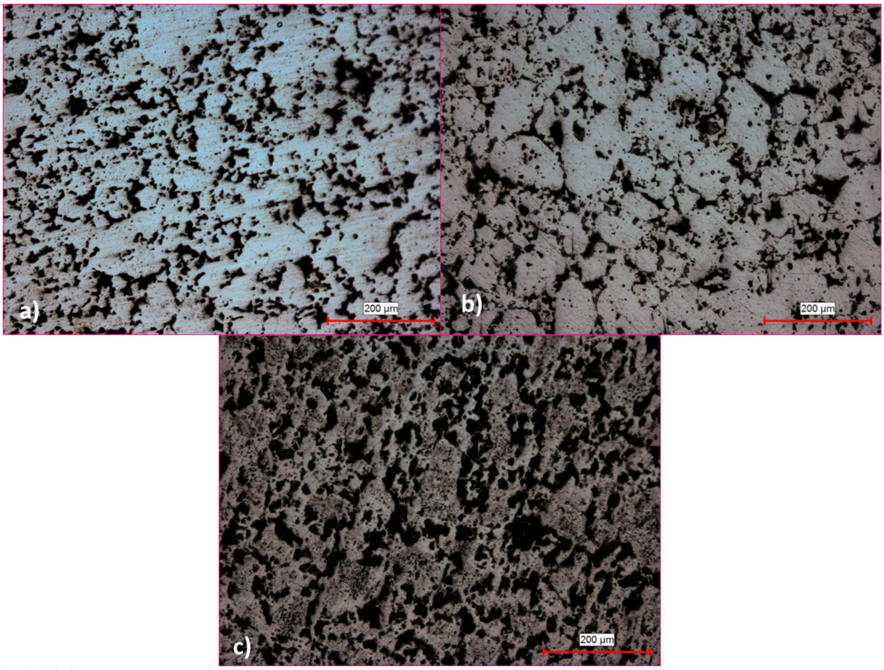

Figure 7. Microstructure Images of Sample c; a)15 Minutes Induction Sintering, b) 30 Minutes Induction Sintering c) Conventional Sintering

Additionally, porosity analyses were done to these samples. Analyses results were given in Table 10.

Table 10. Porosity Analyses of Sample c.

Sintering duration	Porosity (%)
15 Minutes Induction	28,96
30 Minutes Induction	28,24
Conventional Sintering	42,53

Likewise, for this sample, it was observed that better hardness values were obtained after induction sintering (Çivi et al., 2014). Copper supports liquid phase sintering, providing better mechanical strength values. However, the high amount of Copper in the alloy, as mentioned before, leads to increased porosity (Randall M. German, 2005). What is interesting in this sample is the difference in porosity values between the conventional sintered and induction sintered samples (Table 10). It is thought that the hysteresis effect that occurs in direct heating with induction prevents the copper from moving towards the grain boundary. Hysteresis is the effect that expresses the high rate of vibration and displacement of molecules (Zinn, S., Semiatin, 1988).

3.4 Sample d)

Sample d have 100% pure iron (AHC 100.29) and 0.6% kenolube lubricant content. The Rockwell-B hardness test were applied to these samples. Test results were given in Table 11.

Table 11. Rockwell-B Hardness of Sample d.

Sintering duration	Hardness (HRB)
15 Minutes Induction	19,0
30 Minutes Induction	20,0
Conventional Sintering	21,0

The hardness values obtained by conventional sintering were not reached by sintering by induction for 30 minutes (Table 11). Beside of this it has been observed that the hardness values were very close to each other. As stated before, this situation is due to the low resistivity of pure iron samples. The driving force in induction sintering is resistivity (Çivi & Atik, 2018). As a result, it is seen that the induction sintering method is more suitable for alloyed metals rather than pure metals when all components are taken into consideration.

3.5 Sample e)

The contents of Sample e was % 80 AHC 100.29 + 20% Distaloy ACu (% 10,4-11 Cu) mixture (% 99,2) + 0,8% Graphite + 0,4% Kenolube. Rockwell-B hardness tests were applied to these samples. Hardness test results were given in Table 12.

Table 12. Rockwell-B Hardness of Sample f.

Sintering duration	Hardness (HRB)
15 Minutes Induction	48,0
30 Minutes Induction	51,0
Conventional Sintering	30,0

As can be seen from the hardness results, the hardness values obtained by conventional sintering were overcome by induction sintering for 15 minutes and much higher hardness values were obtained. It has been previously demonstrated that the presence of alloying elements in experimental samples leads to intermetallic phases during sintering and improves mechanical properties in induction sintering. Here, parallel results were obtained in the sintering of parts of different sizes and shapes (Can Çivi, 2015). When the results are examined specifically for this alloy, it is seen that induction sintering is very suitable for this alloy. Cu and C in the alloy increase the resistivity, create sintering dynamics and shorten the sintering time. The fact that the hysteresis formed by induction disperses the liquid phase and the graphite content ensures steel formation, and that the alloy production is more effective in the induction method due to rapid heating, has enabled much better hardness values to be achieved on this sample basis (Table 12).

All these experimental results briefly show that induction sintering can be used as a mass manufacturing tool as an alternative to traditional sintering under the right conditions. The additive manufacturing method is a method that is given great importance today and is known to have significant disadvantages as well as important advantages it provides(Pereira, Kennedy, & Potgieter, 2019). For small and cylindrical or homogeneous shaped parts, the induction sintering method can also be an alternative of the additive manufacturing method. Here, the mechanical properties expected from the part to be produced may become important. It has also been shown that both methods can be applied in a hybrid way (Rios, 2018).

4. Conclusions

In the study, sintering of the parts with different shapes and sizes could be carried out by medium frequency induction sintering. Melting or distortion was not occurred on the samples. Mechanical properties of samples were determined parallelly desired mechanical tests from companies that ordered parts. Additionally microstructural analyses were done some of the samples. When porosity, hardness, and compression strength are considered, it has been observed that the induction sintering method can reduce sintering times from 30 minutes to 15 minutes, resulting in a time reduction of approximately 50%. There were variations depending on the alloys and the shape of the powder metal component. The sample that performed the worst in the compression test showed a maximum difference of 11% (246,94-219,45 MPa) between induction and conventional sintering, but other samples showed that the induction sintering method could achieve the same compression strength as conventional sintering. In the best scenario, it has been noted that hardness increases of up to 21 (30 HRB-51 HRB) HRB are given. An 80% time benefit is seen when pre-sintering time is taken into account in comparison to traditional sintering. As a result of this study, it was observed that, induction sintering can be modified serial production and with this method, the production of parts in many different shapes and sizes can be achieved. This method, which is similar to conventional sintering, can be adapted to commercial applications beside scientific studies. In addition, it is thought that the method will be an alternative or complementary to additive manufacturing methods. Future studies will determine this idea.

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