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# Energy Consumption Analysis of Sintering Temperature Optimization of Pure Aluminum Powder Metal Compacts Sintered by Using The UHFIS

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**Abstract**

In this study, pure aluminum (Al) powder metal (PM) compacts are sintered conventional or induction systems. PM compacts are sintered by furnace at 600ºC in 60 minutes in the conventional sintering process. In the other process, PM compacts are sintered by induction system at seven different sintering temperatures from 550°C to 610°C in 4 minutes. 2.8 kW, 900 kHz ultra-high frequency induction system (UHFIS) used for heating application of induction sintering process. Densities and hardness values are investigated for both processes. During these sintering processes, all energy consumption results are measured and calculated, then compared with each other. The effects of the sintering time increase in the induction sintering process on energy cost have been analyzed. Optimum sintering temperature of the induction sintering process is determined. It has been seen that the cheaper energy cost is obtained by the induction system for sintering application.

**Key Words**

"Aluminum, PM, Induction, Energy cost, Energy consumption."

## 1. Introduction

Powder metallurgy (PM) (Amirjan et al., 2013), (Sedlak et al., 2015) is a form of production, which facilitates the manufacture of particularly complex parts, made by mixing pure or alloyed powders of suitable specifications with a mixer, compressing them in a suitable mold with the desired shape to be mixed, and heating them to a temperature below the melting temperature (Angelo,2008).

Sintering (Pozzoli et al., 2015), (Caliman et al.,2015) is the most important production process of powder metallurgy. It is the process of increasing the grain size of the powder particles by increasing the strength of the particles and the strength of the powder components by heating them at a temperature below the melting temperature (Kang,2004).

PM based compacts are sintered by atmosphere controlled furnace, ultra-high frequency induction system (UHFIS) (Çavdar,2014), (Xun et al., 2014), (Gökozan et al.,2016), (Çavdar & Çavdar, 2015).

Induction system could be using different processes like; forging (Çavdar, 2015), heat treatment (Taştan et al.,2015), welding (Çavdar & Kusoglu, 2014), (Çavdar & Gulsahin, 2014) or casting. Also PM based compacts are sintered by microwave sintering (Baghani et al., 2015), (Reddy et al., 2016) spark plasma sintering (Mackie et al., 2016), (Dutel et al., 2017), laser sintering (Wudy et al., 2016), (Yasa et al., 2016) and conventional Sintering (Sharma & Majumdar, 2016), (Lemke et al., 2017)

In the study of Bisht et al (Bist et al., 2017) Al-GNP alloy (Graphene nanoplatelets) was sintered at 550 ° C for 40 min. In the study of Guo et al (Guo et al., 2017) Al-CNTs alloy (carbon nanotubes (CNTs) were sintered at 590-630 ° C for 30 min under argon. In the study of Ghasali et al (Ghasali et al., 2016) Al-VC (vanadium carbide) alloy was sintered by conventional sputter plasma sintering at 600 ° C for 60 minutes at 600 ° C and at 450 ° C for 60 minutes. In the study of Cooke et al (Cooke et al., 2016) Al-Sc alloy was sintered at 400, 450, 500 or 550 ° C for 2 min. In the study of Durowoju et al (Durowoju et al., 2015) Gr-Al (graphite aluminum) alloy was sintered at 500, 550 and 580 ° C for 10 min. In the study of Firestein et al (Firestein et al., 2017) aluminum-based BN, AlB2 and AlN doped alloys were sintered at 600 ° C for 60 min. In the study of Sweet et al (Sweet et al., 2014) in commercial purity and 0.4 wt% magnesium-doped aluminum powders were sintered at 400-600 ° C for 30s, 120s, and 300s.

Taskin and Gokozan (Taskin&Gokozan, 2011) used current and voltage data from a three-phase induction motor.In their work, Ozdemir and Tastan (Özdemir&Taştan, 2014) used the power furnace of the arc furnace used in metal melting processes in the industry using the LabVIEW based measurement system used in this study.

In this study, pure Al PM samples were sintered using conventional method or induction. The results obtained are compared among themselves and the optimum sintering temperature is found by induction. In addition, energy consumption and energy cost analysis were performed as a result of induction and conventional sintering of Al PM samples.

## 2. Materials and Methods

In the study, pure Al PM samples were separated into 2 different groups, some sintered in batch type furnace and the other part in induction system. The image of the induction system used in the sintering process is given in Figure 1.

In order to obtain a homogeneous mixture, Al powders were mixed with a V-type mixer at 20 rpm for 30 minutes and then produced by single-axis single-acting hydropar press with 300 MPa cold pressing method. The resulting PM compacts have a diameter of 18 mm and a height of 2 mm. The sizes of the aluminum powders are 45-106 μm.

**Figure 1: Image of induction system**

The first group of samples was sintered using an induction system with a 900 kHz ultra-high frequency and a power of 2.8 kW. The induction temperature is measured and controlled without contact with the infrared thermometer in the system. Al PM compacts were sintered with UHFIS aid at 7 different temperatures between 550-610°C for 4 minutes dwell time in $10^{-1}$ thoor vacuum environment. PM compacts are cooled naturally.

The image of the sample for the induction sintering is given in Figure 2. Sintered images of the sample at three different sintering temperatures with induction are given in Figure 3.

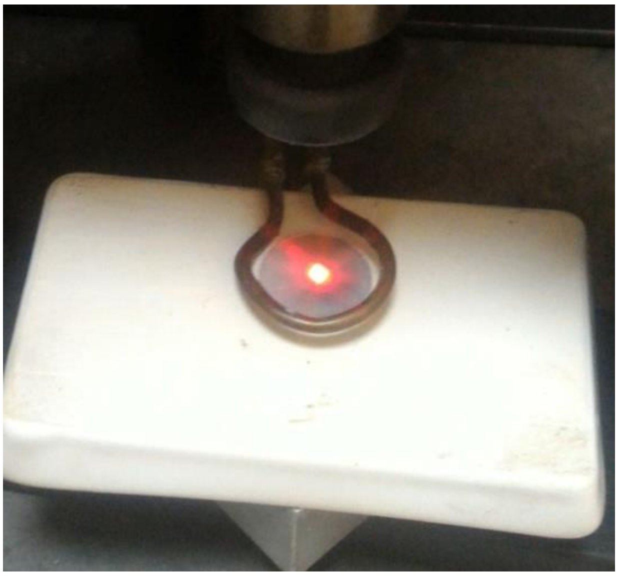

**Figure 2 (a)**

(b)

**Figure 2(Cont) a) Induction sintering process b) Sintering in a vacuum environment**

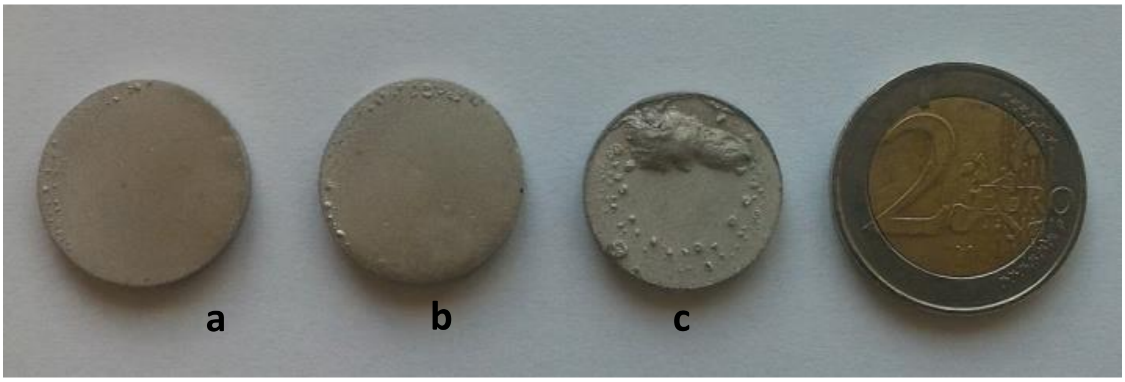


**Figure 3: a) 550°C b) 600°C c) 610°C specimens sintered by induction.**

The second group of samples was sintered in an open atmosphere at 600°C for 60 minutes using Proterm brand Chember Furnace at 2 kW power. PM compacts are cooled naturally. Figure 4-a shows the sintered Al PM sample in the furnace. All the operations of the presented work are given in Figure 5.

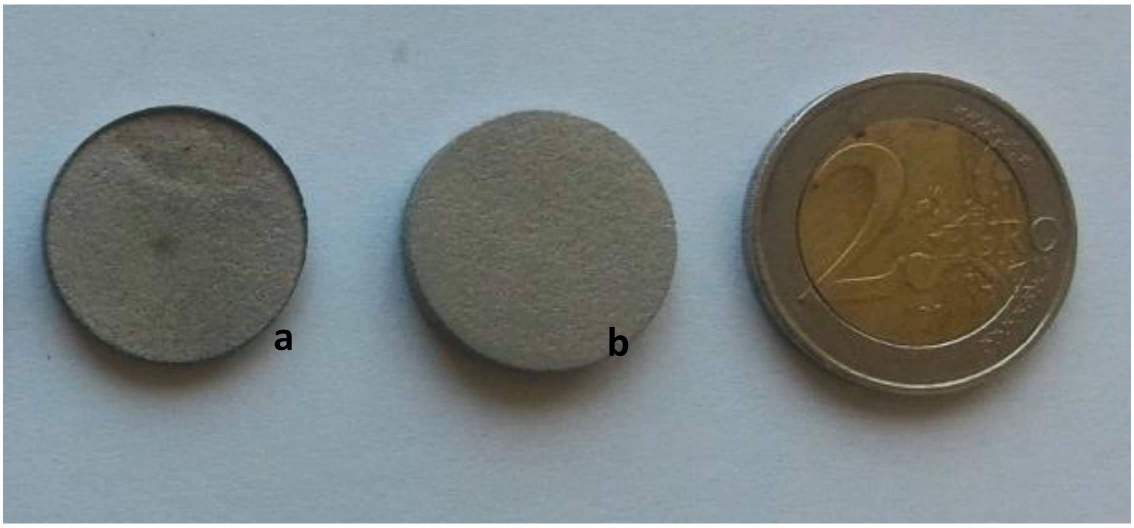


**Figure 4: a) Sintered Al PM sample in furnace b) Non-sintered Al PM sample**

The hardness measurements of the samples were made with the TIME TH-140 Digital Hardness tester. The hardness values were taken from 5 different points of each sample and the results were found by calculating the average hardness values.

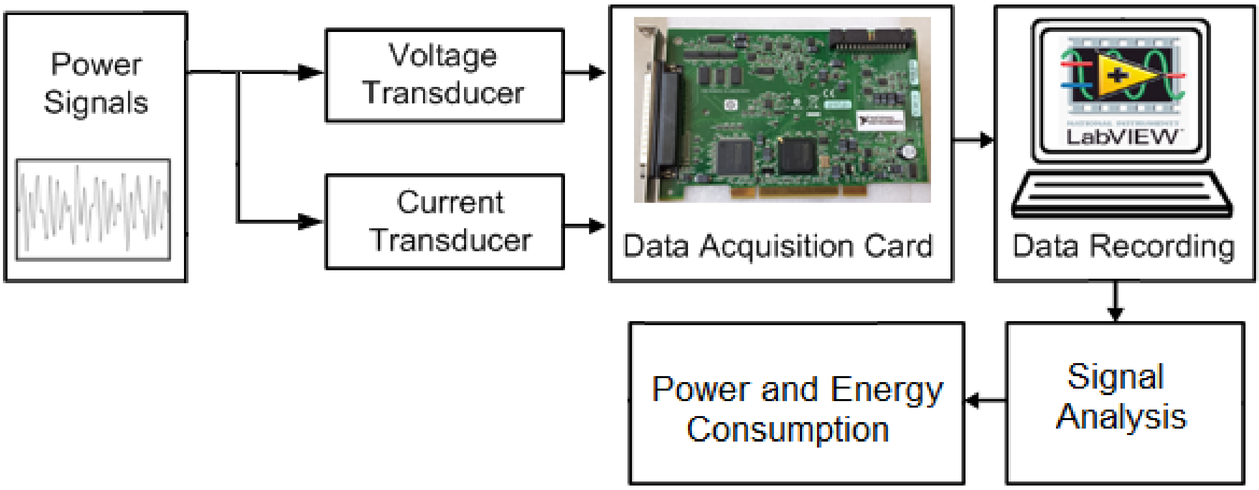


**Figure 6: The block structure of the LabVIEW-based data acquisition and recording system.**

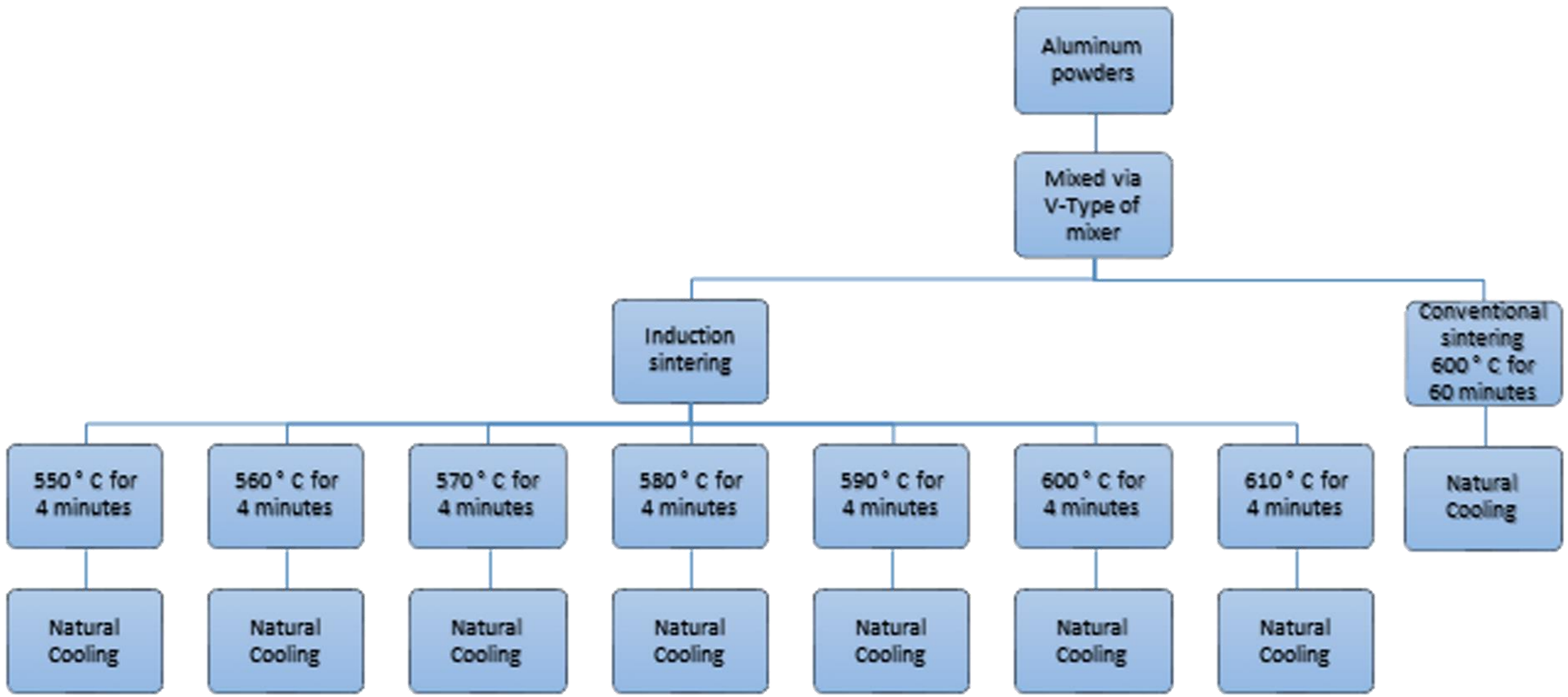


**Figure 5: Flow chart of all processes.**

Figure 6 shows the structure of the data acquisition and recording system based on LabVIEW. Electrical data such as current, voltage, and power factor for the experimental runs were recorded with the LabVIEW 8.5 graphical interface program on a National Instruments data acquisition card in accordance with the relevant IEC standards via current and voltage sensors. By using these power parameters obtained with this data collection system, necessary power calculations (Taskin&Gokozan,2011), (Özdemir&Taştan, 2014) have been made.

### 3. Results and Discussion

Figure 7 shows the change of the current graph of induction sintering of Al PM at 600°C for the first 20 seconds. It is seen that the current value decreases as the sample set temperature reaches about 4 seconds after sintering starts. An average current of approximately 16 A was drawn from the system until the sample set reached temperature. The system has continued to operate with a current of around 5 A after the set temperature has been reached.

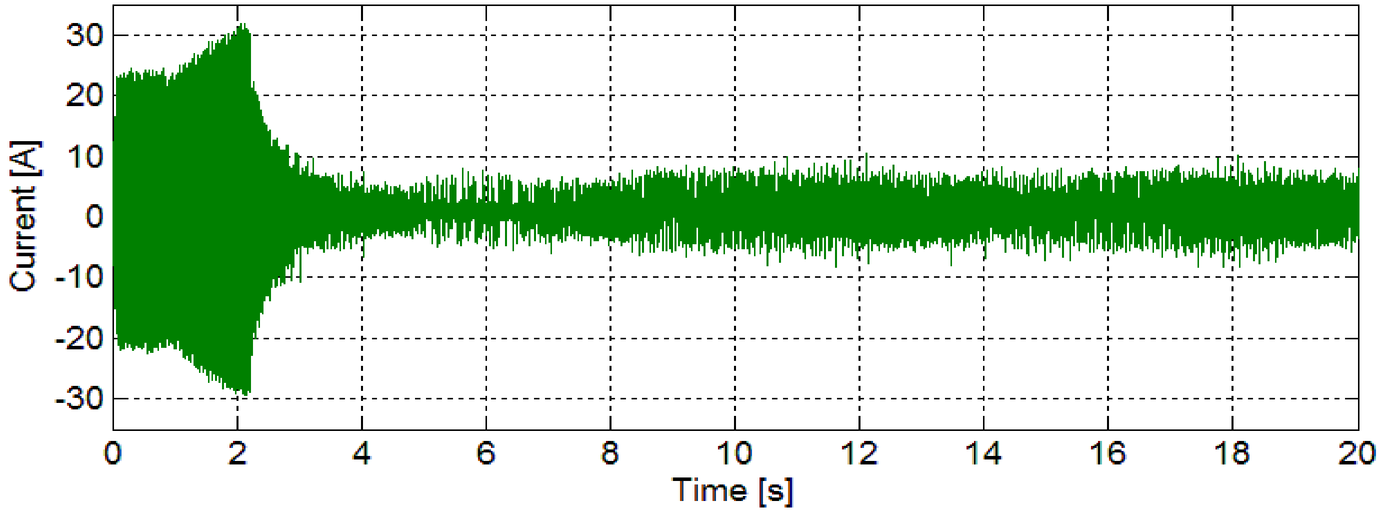


**Figure 7: Current graph of the sintering process at 600°C temperature.**

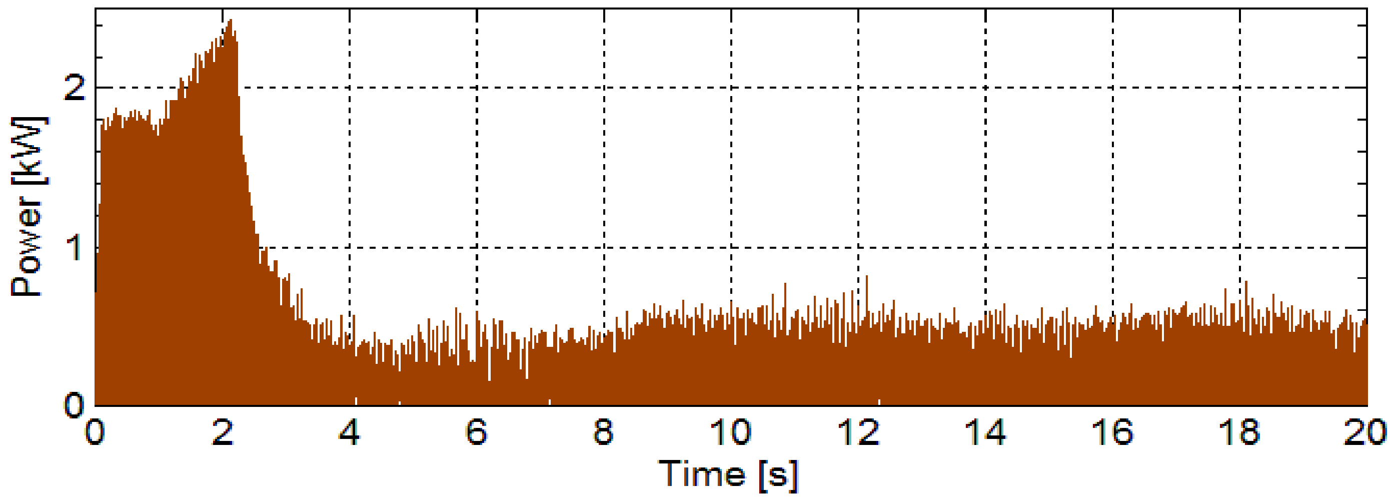


**Figure 8: Power change graph of the sintering process at 600°C temperature.**

Figure 8 shows the time-dependent power change graph of the induction sintering process of the Al PM specimen at a temperature of 600°C. The graph shows the change of the first 20 s. The sample reaches the set temperature within approximately 4 s and the average instantaneous power consumption during this time ranges from 1 to 1.5 kW. After the sample reaches the set temperature, the system continues to operate with an average of 0.3-0.4 kW instantaneous power consumption.

**Table 1: HB hardness and density values of aluminum samples**

| Al PM Compacts | Induction Sintering (4 minutes) | | | | | | | Conventional Sintering |
|---|---|---|---|---|---|---|---|---|
| | 550 °C | 560 °C | 570 °C | 580 °C | 590 °C | 600 °C | 610 °C | 600°C ( 60 min.) |
| Hardness (HB) | 24 | 25 | 27 | 30 | 32 | 34 | 42 | 35 |
| Density($g/cm^3$) | 2,239 | 2,271 | 2,309 | 2,388 | 2,426 | 2,450 | 2,610 | 2,475 |
| % Density | 82,6 | 83,8 | 85,2 | 88,1 | 89,5 | 90,4 | 96,3 | 91,3 |

PM The hardness and density values of aluminum materials after both sintering methods are given in Table 1. The PM compacts were found to have a hardness of 35 HB hardness and a density of 2,475 g / cm3 in a furnace at 600°C for 600 minutes in an argon atmosphere using a conventional method. The same hardness and density values were achieved in 4 minutes sintering time under vacuum using UHFIS. It is seen that the hardness and density values increase with the increase of the induction sintering temperature.

When the values are examined, it can be seen that at the temperature of 550-580°C during induction sintering, the samples are not sinterable enough and cannot form bonds. Although hardness and dense values at 610°C are the best results, it is seen that the eruptions occur in the sample as shown in Figure 3-c. It has therefore been determined that temperatures above 600°C are too high for sintering for Al PM samples. Compared with conventional sintering and induction sintering methods, the optimum sintering temperature was determined to be 600°C. When induction and conventional sintering times are compared, it is seen that the conventional sintering time is 15 times higher.

**Table 2: Energy consumption and energy cost values of aluminum samples as a result of induction and conventional sintering.**

| Al PM compacts | Induction Sintering (4 minutes) | | | | | | | Conventional Sintering (60 minutes) |
|---|---|---|---|---|---|---|---|---|
| | 550°C | 560°C | 570°C | 580°C | 590°C | 600°C | 610°C | 600°C |
| Energy Consumption ($kWh.kg^{-1}$) | 4.987 | 5.030 | 5.087 | 5.134 | 5.227 | 5.254 | 5.324 | 2.053 |
| Cost ($\$.kg^{-1}$) | 0.4883 | 0.4925 | 0.4981 | 0.5029 | 0.5118 | 0.5144 | 0.5212 | 0.2011 |

Table 2 shows the energy consumption and energy cost values of Al PM samples for induction and conventional sintering processes. Sintering with induction at 600°C for 4 minutes resulted in a cost of 0.5144 $\$.kg^{-1}$ for energy consumption of 5.254 $Wh.kg^{-1}$. Conventional sintering at 600°C for 1 hour resulted in a cost of 0.2011 $\$. Kg^{-1}$ for energy consumption of 2.053 $kWh.kg^{-1}$.

## 4. Conclusions

In the work done, pure Al PM wastes were sintered UFIHS or conventionally. The results obtained are given below.

- It has been determined that the increase of the induction-induced sintering temperature increases the production cost and power.
- It has been determined that the optimum sintering temperature of Al PM compacts by induction is 600°C.
- Compared with the conventional sintering and induction sintering processes, Al-based PM samples were found to be sintered in 15 times shorter time using induction. When the hardness and density values are compared, the values are almost the same.
- Compared with induction and conventional sintering, it was found that the induction process cost is about 2.5 times higher than the process cost.

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