Revista de Metalurgia 51(3)
July–September 2015, e046
ISSN-L: 0034-8570
doi: http://dx.doi.org/10.3989/revmetalm.046

Comparative energy consumption analyses of an ultra high frequency induction heating system for material processing applications

Mehmet Taştan[a], Hayrettin Gökozan[a], Sezai Taşkin[b], Uğur Çavdar[c,✉]

[a]Celal Bayar University, Turgutlu Vocational School, Department of Electric & Energy, 45400 Manisa, Turkey
[b]Celal Bayar University, Engineering Faculty, Department of Electrical & Electronics Eng., 45140 Manisa, Turkey
[c]Celal Bayar University, Turgutlu Vocational School, Department of Machinery, 45400 Manisa, Turkey
✉Corresponding author: ugur.cavdar@cbu.edu.tr

Submitted: 12 January 2015; Accepted: 29 April 2015; Available On-line: 11 September 2015

ABSTRACT: This study compares an energy consumption results of the TI-6Al-4V based material processing under the 900 kHz induction heating for different cases. By this means, total power consumption and energy consumptions per sample and amount have been analyzed. Experiments have been conducted with 900 kHz, 2.8 kW ultra-high frequency induction system. Two cases are considered in the study. In the first case, TI-6Al-4V samples have been heated up to 900 °C with classical heating method, which is used in industrial applications, and then they have been cooled down by water. Afterwards, the samples have been heated up to 600 °C, 650 °C and 700 °C respectively and stress relieving process has been applied through natural cooling. During these processes, energy consumptions for each defined process have been measured. In the second case, unlike the first study, can be used five different samples have been heated up to the various temperatures between 600 °C and 1120 °C and energy consumptions have been measured for these processes. Thereby, the effect of temperature increase on each sample on energy cost has been analyzed. It has been seen that as a result of heating the titanium bulk materials, which have been used in the experiment, with ultra high frequency induction, temperature increase also increases the energy consumption. But it has been revealed that the increase rate in the energy consumption is more than the increase rate of the temperature.

KEYWORDS: Comparative energy consumption; Comparative energy cost for material processing; Heat treatment; Induction heating; Ti-6Al-4V; Ultra-high frequency

Citation / Cómo citar este artículo: Taştan, M., Gökozan, H., Taşkin, S., Çavdar, U. (2015) "Comparative energy consumption analyses of an ultra high frequency induction heating system for material processing applications". *Rev. Metal.* 51(3): e046. doi: http://dx.doi.org/10.3989/revmetalm.046.

RESUMEN: *Análisis comparativo del consumo energético de un sistema de calentamiento por inducción a alta frecuencia para aplicaciones de procesado de materiales.* En este estudio se comparan los consumos energéticos al procesar Ti-6Al-4V por inducción a 900 kHz. Se ha analizado la potencia total consumida y la energía consumida por muestra. Los experimentos se han realizado en un sistema de inducción de ultra alta frecuencia a 900 kHz, 2,8 kW. Se han considerado dos casos, en el primero se ha calentado Ti-6Al-4V a 900 °C por el método clásico usado en la industria y enfriado en agua; posteriormente las muestras se han calentado a 600, 650 y 700 °C y enfriadas al aire para relajar tensiones. En los tres casos se midió el consumo energético. En el segundo caso, cinco muestras diferentes fueron tratadas a temperaturas entre 660 y 1120 °C, midiendo el consumo energético en todos los casos. Asimismo se analizó el efecto del incremento de temperatura en el consumo energético, observándose que al calentar los materiales de base titanio usados en este trabajo con inducción de alta frecuencia, el consumo energético aumenta al aumentar la temperatura, siendo la velocidad de incremento del consumo energético mayor que la velocidad de incremento de la temperatura.

PALABRAS CLAVE: Calentamiento por inducción; Consumo energético comparativo; Coste energético comparativo para procesado de materiales; Ti-6Al-4V; Tratamiento térmico; Ultra alta frecuencia

1. INTRODUCTION

Titanium has emerged as an important metal for a lots of applications. Ti-6Al-4V is one of the most important titanium alloys in the industry applications. This composition is generally using due to its high specific strength, high operating temperature and corrosion resistance (İbrahim *et al.*, 2013).

Ibrahim *et al.* (2013) reported the effects of the Si-addition as a grain refiner on microstructure and properties of Ti-6Al-4V alloy. Babu and Lindgren (2013) studied dislocation density based model for plastic deformation and globularization of Ti-6Al-4V. Li *et al.* (2013) used Ti-6Al-4V in their work. Their studies about influence of heat treatment of hot continuous rolled titanium based material. In addition to the Ti-6Al-4V studies, Rhaipu (1998) worked about superplastic forming of same titanium alloy.

In several studies induction systems have been used for heating applications of Ti-6Al-4V. Brunelli *et al.* (2009) 450 kHz (high frequency), Markovsky and Semiatin (2010); Markovsky and Semiatin (2011) 400 kHz (high frequency) induction systems were used in their studies. In addition to using high frequency for the heat treated of Ti-6Al-4V materials, in this study same titanium composition heat treated by ultra-high frequency (900 kHz) induction system. In many different applications induction heating systems are being used. For example forging (Çavdar, 2014), medium frequency sintering (Çavdar *et al.*, 2014a; Çavdar *et al.*, 2014b; Çavdar *et al.*, 2014c; Çavdar and Atik, 2014), ultra-high frequency welding (Çavdar and Gulşahin, 2014; Çavdar and Kusoğlu, 2014; Çavdar *et al.*, 2014d), ultra-high frequency sintering (Sarı and Çavdar, 2015) and modelling (Riera and Prado, 2006) applications of the iron and/or iron based materials.

Brunelli *et al.* (2009) investigated the diffusion treatment of Ni-B coatings by using induction heating generator. They were hardened the surface of Ti-6Al-4V alloy via induction. For bulk materials having a complex shape, induction and salt bath, could be used. For example, Semiatin and Sukonnik (1997) used rapid induction heating to form graded microstructures. Titanium alloys were heated by induction and applied by Nishikiori *et al.* (1996) and Benedetti *et al.* (2005). In both of these investigations, it was employed for local heating, but the comparatively long exposure times at high temperatures resulted in relatively coarse-grains and hence poor ductility.

Most of the energy generated in the world is consumed by the industry. One of the most significant prerequisites to be able to compete in the generation industry is to decrease the generation costs. The losses in the raw material, interruptions in the generation lines and excessive energy consumption are among the most important factors that affect the cost (Delgado-Gomes *et al.*, 2013).

Power consumption is an important issue that affects all parts of the life. Hence, power consumption should be taken into consideration during the design of home appliances (Tsai *et al.*, 2013), electronic devices (Han *et al.*, 2014), various communication systems (Hinton *et al.*, 2011; Yu *et al.*, 2012), device and machines used in the industry (especially induction motors). To that end, energy efficiency of the devices, which are used in all parts of the life, should be high.

Taskin and Gokozan (2011) made the harmonic analysis using the power parameters of 75 kW induction motor used in industry. Gokozan *et al.* (2014) made the power quality analysis under different load status of an induction furnace with 350 kVA power and 1 kHz operation frequency used in steel industry. In another study, Ozdemir and Taştan (2014) made the inter-harmonic analysis of the power system using the power data of an arc furnace. In this study; also, energy consumption analysis have been made using the same data collection system (Taskin and Gokozan, 2011; Gokozan *et al.*, 2014; Ozdemir and Taştan, 2014).

Çavdar and Atik (2014) also have made a study covering the energy consumption during the sintering process of iron based powdered metals. Two different sintering processes have been performed within the scope of this study. In a part of the study, sintering process has been made with 12 kW, 50 kHZ induction device and with a medium frequency induction system for the iron based powdered metal materials. In the other part of the study, iron based powdered metal pieces have been sintered using the conventional sintering method which is mostly used in industry. Based on the energy consumed in these two studies, energy consumption per kg has been calculated for each system. Induction sintering process consumes approximately 3.5 times less electrical energy than the conventional process for 1 kg powder compact.

Ultra High Frequency Induction Heat Treatment (UHFIHT) is a rapid heat process. Titanium materials are very important in the automotive, aero-plane, space and biomedical applications. In industrial applications, the most important point is the cost of the application.

In this study, it has been seen that in heating with ultra high frequency induction, the increase in energy consumption is directly linked to the increase in process temperature. Besides, it has been seen that the energy consumption, during the time passed until the samples reach to the desired level, is higher and the energy consumption decreases in the next process.

2. EXPERIMENTAL STUDIES

In this work, two different types of experiment were investigated. One of them is heat treatment of the titanium materials, other one is the heating

Table 1. Average chemical composition of the Ti based materials

% (wt.)						
Al	**V**	**C**	**O**	**F**	**Si**	**Ti**
6.37	4.12	0.02	0.25	0.24	0.02	Balance

durations (from 600 °C to 1120 °C) of the titanium materials. For both experiments, a horizontal titanium based materials and a horizontal coil was used for ultra-high frequency induction heat treatment (UHFIHT) application. The diamination's of the titanium materials are the diameter 16 mm and the height 5 mm. The heat treatment was applied to the samples the coil of the induction system. Diameter of 4 mm and a wall thickness of 0.5 mm of the induction coil was used for heat treatment application. The copper wire was wrapped one making a coil with an inner diameter of 22 mm. Magnetic flux was achieved homogenously due to the centering the titanium materials. Five different bulk materials were used for three different UHFIHT process. The energy costs were the average of the calculations. All bulk materials were heat treated by 2.8 kW, 900 kHz (ultra-high frequency) induction system under atmospheric environment. The temperature of the bulk materials was measured by an infrared thermometer (±5 °C). The heating temperatures were measured and fixed by the infrared laser of the induction system. The chemical composition of Ti-6Al-4V is given in Table 1 as follows.

The numbers are given to the experiments from E1 to E9. The explanations are given in Table 2 and the cycles are given in Fig. 1 and Fig. 2.

2.1. Measurement system

Measurement system was designed by using the NI LabVIEW program. A multi-functional graphical user interface was designed to save power system data.

Table 2. Explanations of the numbered experiments

The Number of Experiments	Explanations of the experiments
E1	E4+E5
E2	E4+E6
E3	E4+E7
E4	T=900 °C in 60 seconds; than fast cooling (sample dropped into a water.)
E5	T=600 °C in 30 seconds; than natural cooling
E6	T=650 °C in 30 seconds; than natural cooling
E7	T=700 °C in 30 seconds; than natural cooling
E8	T=900 °C in 30 seconds; than natural cooling
E9	T=1120 °C in 30 seconds; than natural cooling

Using this interface, the changes in the following characteristics of current and voltage signals can be monitored and recorded in the real time: the waveforms of voltage and current in each phase, changes in the power parameters which are apparent, active and reactive power. The overall block diagram of the measurement system is shown in Fig. 1. It consists of voltage and current transducers, data acquisition card and the software. Figure 2 shows the user interface of the measurement system.

The required calculations have been made using the power parameters obtained with data collection system. The formulas in Eq. (1) and Eq. (2) have been used in the calculations.

$$P = U^{*} I^{*} \cos\varphi \tag{1}$$

were P is the power of the induction heating system (W), U the source voltage (V), I the current drawn by the device (A) and $cos\varphi$ the power factor.

$$W = P^{*} \frac{t}{3600} Wh \tag{2}$$

were W is the consumed energy amount (Wh), P the power of the induction heating system (W) and t the operating time of the device (s)

On the one hand, three different heat treatment processes were applied to the titanium based samples as given in Fig. 3. The all heat treatments were done at 900 °C for 1 minute and then three different quenching temperatures were applied to the Ti based samples from 600 °C to 700 °C for 30 seconds.

On the other hand, for several heating durations from 600 °C to 1120 °C Ti based materials were heated for half minute. For five different heating durations are illustrated in Fig. 4.

Power and energy consumption values calculated with the formula in Eq. (1) and Eq. (2) are given in Table 3.

3. RESULTS AND DISCUSSIONS

From the data collected during the study, Current-Time graph of the induction heating process under 700 °C is given in Fig. 5; Power-Time graph is given in Fig. 6.

When the Fig. 5 and Fig. 6 is reviewed, it is clearly seen that the power consumption is high in first 7 seconds of heating system (Period-I) and it is lower in the following period of time (Period-II). After the material reaches to the desired temperature level, power consumption decreases. This is similar for all temperature levels as seen in Fig. 7.

The power consumption values of the experiments between E5 and E9 means the temperature durations from 600 °C to 1120 °C are given in Fig. 8. All experiments were applied the samples in 30 seconds after

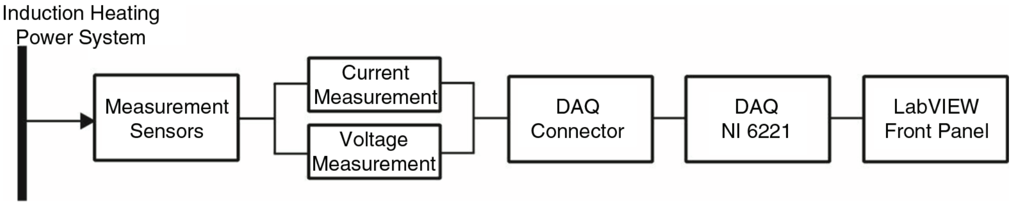

FIGURE 1. Block diagram of the measurement system.

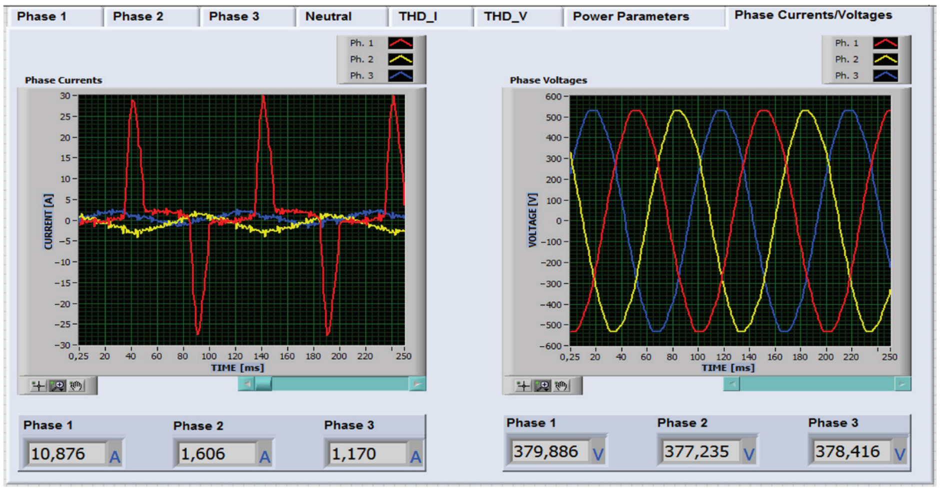

FIGURE 2. The user-interface of the measurement system.

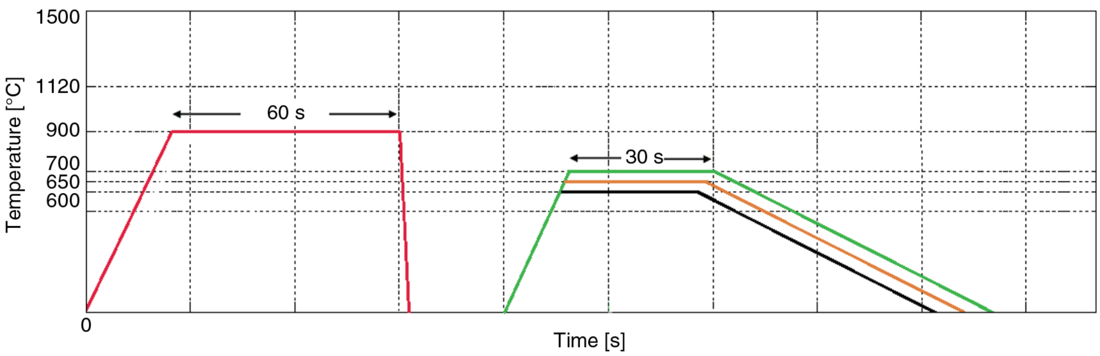

FIGURE 3. Heat treatment cycles of ultra-high frequency induction heating applications (Experiments from E1 to E3).

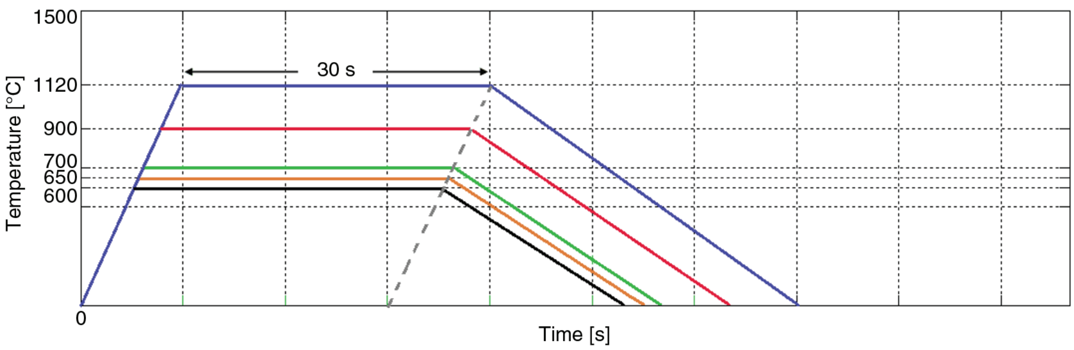

FIGURE 4. Effects of the heating durations between 600 °C and 1120 °C of the ultra-high frequency induction heating application of Ti based bulk materials (Experiments from E5 to E9).

TABLE 3. The power and the energy consumptions of the all experiments

Number of Experiments	The Power Consumption (W)	The Energy Consumption (Wh)
E1	351.38	8.78
E2	370.87	9.27
E3	373.87	9.35
E4	379.67	6.33
E5	294.80	2.46
E6	353.54	2.95
E7	362.26	3.02
E8	487.02	4.06
E9	744.17	6.20

the samples temperatures were grow up to the fixed temperature.

In these experiments which are made under equal process durations and different temperatures, power consumption has increased depending on the temperature. The increase in power consumption is seen in power-temperature graph in Fig. 8, power-time graphs in Fig. 6 and Fig. 7.

Considering the energy consumption values in Eq. (2), energy costs of the processes, energy unit price 0.0861 $/kWh (electrical price was taken from the web page of www.enerjienstitusu.com/elektrik-fiyatlari/) and material weight have been calculated for 2 g. Process costs per material and kg are shown in Table 4.

The total cost of the heat treatment applications is given via bar graph in Fig. 9 as follows.

It is seen on the graph in Fig. 9 that energy costs increase depending on the increase of temperature values in stress relieving processes.

In Fig. 10 energy costs per Kg are seen for the 30 seconds long processes under five different temperatures between 600 °C and 1120 °C.

When the temperature is increased from 600 °C to 900 °C, it is seen that the change in energy consumption is 65.2% while the change in temperature is 50%. When the temperature is increased from 900 °C to 1120 °C, it is seen that the change in energy consumption is 52.77% while the change in temperature is 24.4%. From all these results, it is

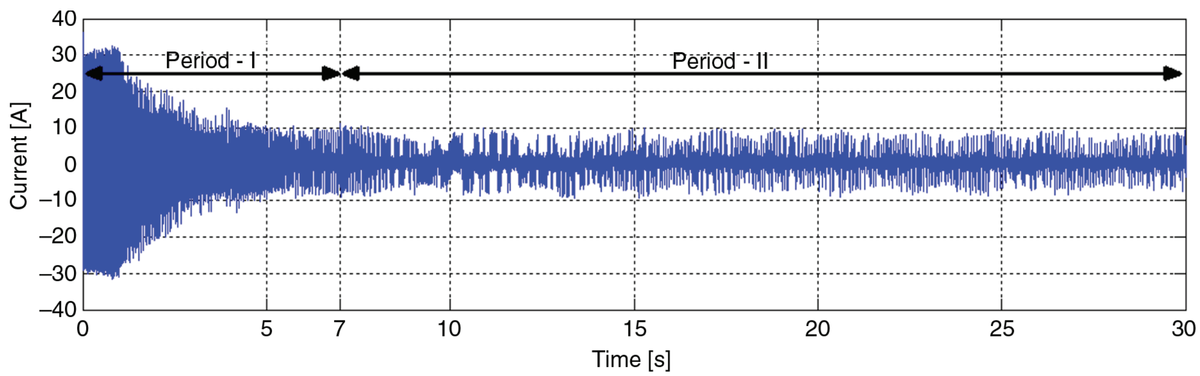

FIGURE 5. Current change of the induction heating system under 700 °C.

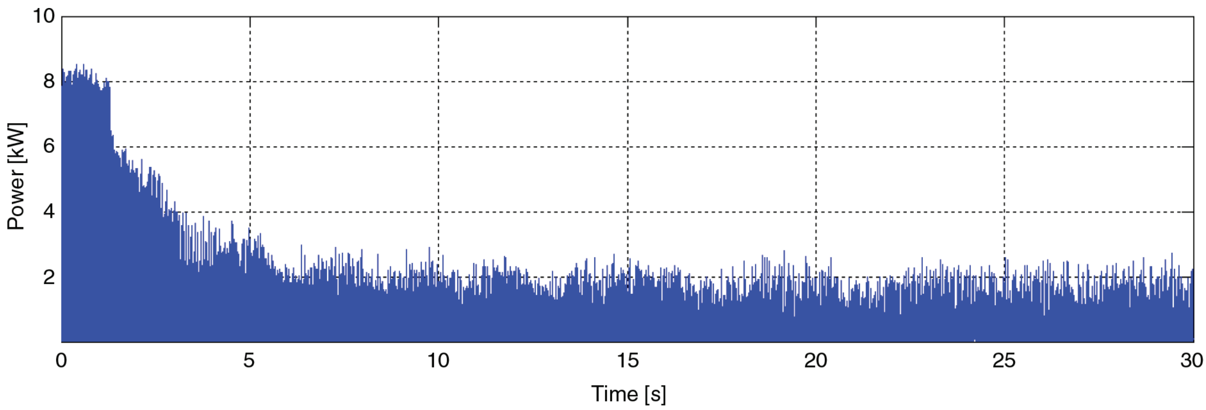

FIGURE 6. Power change of the induction heating system under 700 °C.

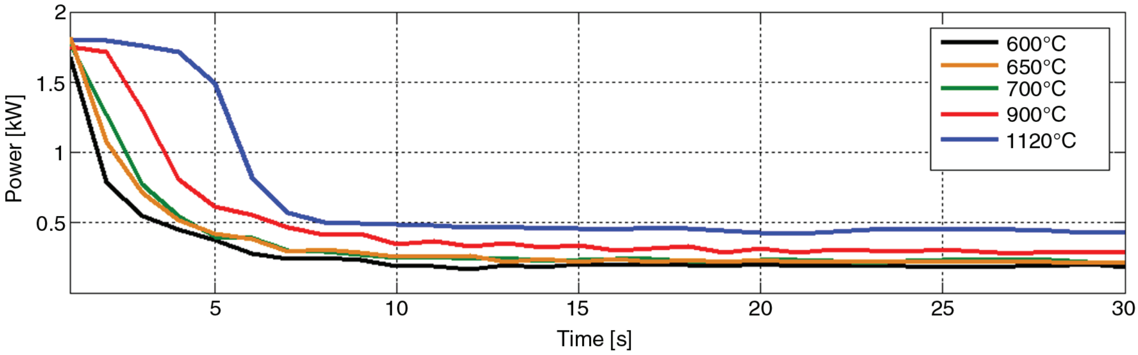

FIGURE 7. Power consumption graph depending on time under different temperatures.

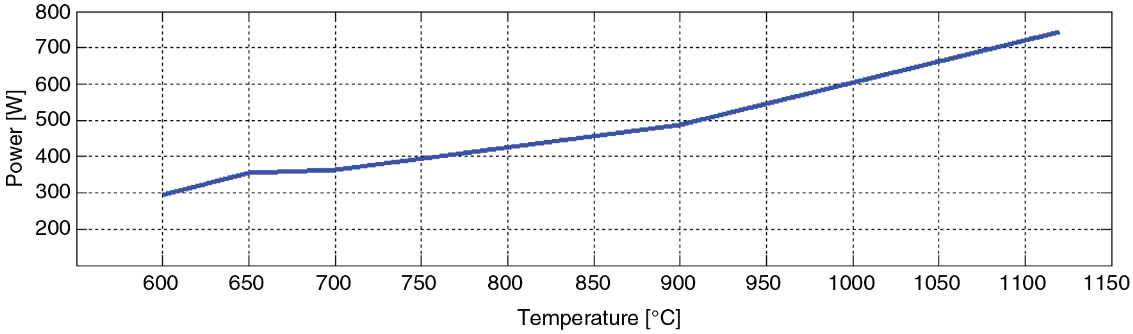

FIGURE 8. The power consumptions graph of the temperature durations.

seen that ratio between the increase in temperature and the cost increase are not same.

In the study of Brunelli *et al*. (2009), they were used 450 kHz high frequency and 100 kW capacity induction generator. They were obtained by immersion in nickel chloride aqueous solutions with sodium borohydride for electroless nickel-boron coatings on Ti-6Al-4V alloy. The diffusion treatments were carried out by induction heating at 1020 °C in 100 seconds. They were compared the induction heating with conventional method.

TABLE 4. The energy cost of the heat treatment applications per samples or per kilogram

Number of Experiments	Energy Cost ($ / Sample)	Energy Cost ($ / Kg)
E1	0.000756	0.3781
E2	0.000798	0.3991
E3	0.000804	0.4022
E5	0.000211	0.1057
E6	0.000254	0.1268
E7	0.000260	0.1299
E8	0.000349	0.1747
E9	0.000534	0.2669

This obtained previously by heat treatments in oven at 800 °C for 40 hours.

Markovsky and Semiatin used 400 kHz high frequency induction generator and variable power level of 3–5 kW for heating the Ti-6Al-4V rapidly (Markovsky and Semiatin, 2010; Markovsky and Semiatin, 2011). They could be control the heating durations within 0.1 seconds.

In contrast to using the high frequency 400 kHz (Brunelli *et al*., 2009) or 450 kHz (Markovsky and Semiatin, 2010; Markovsky and Semiatin, 2011) induction systems, in this study 900 kHz ultra-high frequency induction system was used for heating application of the Ti-6Al-4V alloy. Our heating frequency is approximately two times higher than the other studies on the literature. Induction frequency is the directly proportional with penetration depth of the magnetic field.

As a result of the studies, samples reach to the desired temperature level very fast in the heating with induction. So, energy consumption is higher in this period (Period-I). In the following process (Period-II) energy consumption decreases as the temperature is kept stable. In the processes made for different temperatures, it has been seen that the temperature increase rate and energy consumption increase rates are not same.

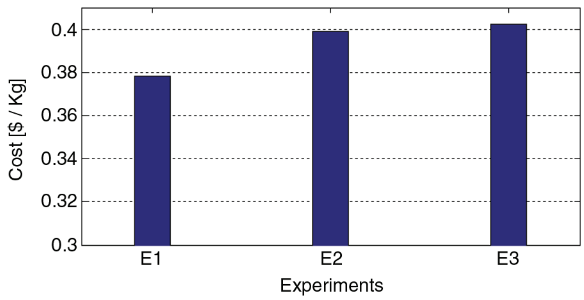

Figure 9. Cost per kg graph for E1, E2, E3 processes.

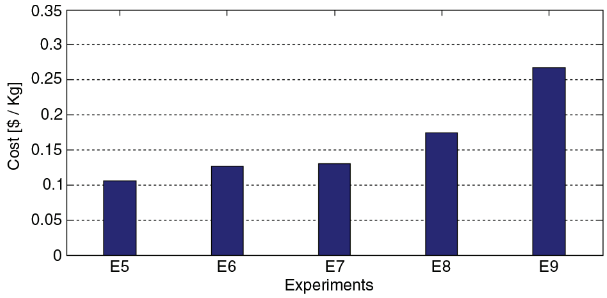

Figure 10. Energy cost graph depending on the temperature.

4. CONCLUSIONS

The conclusions of ultra-high frequency induction heating application of Ti-6Al-4V materials, following results were obtained:

- Titanium based bulk materials were heat treated successfully with the ultra-high frequency induction system.
- Costs of titanium materials E1, E2 and E3 heat treatments are 0.3781 $/Kg, 0.3991 $/Kg and 0.4022 $/Kg.
- As the temperature increases in induction heating process of titanium materials, cost per E5-E9 $/kg have been 0.1057 $/Kg, 0.1268 $/Kg, 0.1299 $/Kg, 0.1747 $/Kg and 0.2669 $/Kg. Increase in the temperature increases the energy cost.
- When the temperature is increased from 600 °C to 1120 °C, it has been seen that while the change in temperature is 86.6%, the increase in energy consumption is 152%. It has been determined that the rate between the temperature increase and cost increase is not same.

ACKNOWLEDGEMENT

The authors present their special thanks to the Celal Bayar University Scientific Research Projects Commission for supporting this study under project numbers 2012-052 and 2012-022.

REFERENCES

Babu, B., Lindgren, L.E. (2013). Dislocation density based model for plastic deformation and globularization of Ti-6Al-4V. *Int. J. Plasticity* 50, 94–108. http://dx.doi.org/10.1016/j.ijplas.2013.04.003.

Benedetti, M., Heidemann, J., Peters, J.O., Lutjering, G. (2005). Influence of sharp microstructural gradients on the fatigue crack growth resistance of α+β and near-α titanium alloys. *Fatigue Fract. Eng. M*. 28 (10), 909–922. http://dx.doi.org/10.1111/j.1460-2695.2005.00932.x.

Brunelli, K., Dabala, M., Dughiero, F., Magrini, M. (2009). Diffusion treatment of Ni-B coatings by induction heating to harden the surface of Ti-6Al-4V alloy. *Mater. Chem. Phys.* 115 (1), 467–472. http://dx.doi.org/10.1016/j.matchemphys.2009.01.016.

Çavdar, U. (2014). Mechanical Properties of Hot Forged ANSI 1050 Steel. *Mater. Test*. 56 (3), 208–212. http://dx.doi.org/10.3139/120.110555.

Çavdar, U., Atik, E. (2014). Investigation of conventional and induction sintered iron and iron based powder metal compacts. *JOM* 66 (6), 1027–1034. http://dx.doi.org/10.1007/s11837-014-0977-0.

Çavdar, U., Gulsahin, I. (2014). Ultra high frequency induction welding of powder metal compacts. *Rev. Metal*. 50 (2), e016. http://dx.doi.org/10.3989/revmetalm.016.

Çavdar, U., Kuşoglu, I.M. (2014). Effects of coil design on induction welding of sintered iron based compacts. *Mater. Test*. 56 (11–12), 973–979. http://dx.doi.org/10.3139/120.110641.

Çavdar, U., Atik, E., Akgul, M.B. (2014a). Magnetic-Thermal Analysis and rapid consolidation of 3 wt.% Cu mixed iron based powder metal compacts sintered by medium frequency induction heated system. *Powder Metall. Met. C*. 53 (3–4), 191–198. http://dx.doi.org/10.1007/s11106-014-9603-5.

Çavdar, U., Atik, E., Ataş, A. (2014b). Mechanical, properties and hardness results of the medium frequency induction sintered iron based powder metal bushing. *Sci. Sinter*. 46 (2), 195–203. http://dx.doi.org/10.2298/SOS1402195C.

Çavdar, U., Unlu, B.S., Atik, E. (2014c). Effect of copper content in iron based powder metal compacts. *Mater. Tehnol*. 48 (6), 977–982. UDK 621.762:621.762.5:669.3.

Çavdar, U., Yalamaç, E., Gulsahin, I. (2014d). Effects of surface finishing on the mechanical properties of induction welded iron based sintered compacts. *Mater. Test*. 56 (10), 852–857. http://dx.doi.org/10.3139/120.110640.

Delgado-Gomes, V., Oliveira-Lima, J.A., Lima, C., Martins, J.F., Jardim-Goncalves, R., Fernao Pires, V. (2013). Energy Consumption Evaluation to Reduce Manufacturing Costs. *POWERENG2013, Fourth International Conference*, Istanbul, pp. 1012–1016. http://dx.doi.org/10.1109/PowerEng.2013.6635749.

Gokozan, H., Taskin, S., Seker, S., Ekiz, H. (2014). Aneural network based approach to estimate of power system harmonics for an induction furnace under the different load conditions. *Electr. Eng*. 96 (4), 79–84. http://dx.doi.org/10.1007/s00202-014-0320-3.

Han, J., Choi, C.S., Park, W.K., Lee, I., Kim, S.H. (2014). PLC-Based Photovoltaic System Management for Smart Home Energy Management System. *IEEE International Conference*, on Consumer Electronics (ICCE), pp. 542–543. Las Vegas, NY. http://dx.doi.org/10.1109/ICCE.2014.6776124.

Hinton, K., Baliga, J., Feng, M., Ayre, R., Tucker, R.S. (2011). Power Consumption and Energy Efficiency in the Internet. *IEEE Network* 25 (2), 6–12. http://dx.doi.org/10.1109/MNET.2011.5730522.

Ibrahim, K.M., Hussein, A.H., Abdelkawy. M. (2013). Effect of Si-addition as a grain refiner on microstructure and properties of Ti-6Al-4V Alloy. *T. Nonferr. Metal. Soc*. 23 (7), 1863–1874. http://dx.doi.org/10.1016/S1003-6326(13)62671-0.

Li, X., Sugui, T., Xianyu, B., Liqing, C. (2013). Influence of heat treatment on microstructure and creep properties of hot continuous rolled Ti-6Al-4V alloy. *Mat. Sci. Eng. A-Struct*. 559, 401–406. http://dx.doi.org/10.1016/j.msea.2012.08.116.

Markovsky, P.E., Semiatin, S.L. (2010). Microstructure and mechanical properties of commercial-purity titanium after rapid (induction) heat treatment. *J. Mater. Process. Tech*. 210 (3), 518–528. http://dx.doi.org/10.1016/j.jmatprotec.2009.10.015.

Markovsky, P.E., Semiatin, S.L. (2011). Tailoring of microstructure and mechanical properties of Ti-6Al-4V with local rapid (induction) heat treatment. *Mat. Sci. Eng. A-Struct*. 528 (7–8), 3079–3089. http://dx.doi.org/10.1016/j.msea.2010.12.002.

Nishikiori, S., Hattori, H., Noda, T., Okabe, M., Isobe, S. (1996). Application of heat resistant titanium-based compressor with dual structure. *Mat. Sci. Eng. A-Struct*. 213 (1–2), 124–127. http://dx.doi.org/10.1016/0921-5093(96)10257-4.

Ozdemir, A., Taştan, M. (2014). PLL Based Digital Adaptive Filter for Detecting Interharmonics. *Math. Probl. Eng*. (ID 501781), 1–10. http://dx.doi.org/10.1155/2014/501781.

Rhaipu, S. (1998). The effect of microstructural gradients on superplastic forming of Ti-6Al-4V. *J. Mater. Process. Tech*. 80–81, 90–95. http://dx.doi.org/10.1016/S0924-0136(98)00179-4.

Riera, M.D., Prado, J.M. (2006). Modelling of the plasticity in cold compaction of metal powders. *Rev. Metal*. 42 (6), 456–462. http://dx.doi.org/10.3989/revmetalm.2006.v42.i6.43.

Sarı Çavdar, P., Çavdar, U. (2015). The evaluation of different environments in ultra-high frequency induction sintered powder metal compacts. *Rev. Metal*. 51 (1), e036. http://dx.doi.org/10.3989/revmetalm.036.

Semiatin, S.L., Sukonnik, I.M. (1997). Rapid heat treatment of titanium alloys. Proc. 7th International Symposium on Physical Simulation of Casting, Hot Rolling and Welding. H.G. Suzuki, *et al*. (Eds.), Dynamic Systems, Inc. Poestenkill, NY, pp. 395–405.

Taskin, S., Gokozan, H. (2011). Determination of the Spectral Properties and Harmonic Levels for Driving an Induction Motor by an Inverter Driver under the Different Load Conditions. *Elektron. Elektrotech*. 108 (2), 75–80. http://dx.doi.org/10.5755/j01.eee.108.2.149.

Tsai, C.H., Bai, Y.W., Lin, M.B., Jhang, R.J.R., Chung, C.Y. (2013). Reduce the Standby Power Consumption of a Microwave Oven. *IEEE Transactions on Consumer Electronics* 59 (1), 54–61. http://dx.doi.org/10.1109/TCE.2013.6490241. www.enerjienstitusu.com/elektrik-fiyatlari/.

Yu, C., Sung, C.H., Kuo, C.H., Yen, M.H., Chen, S.J. (2012). Design and implementation of a low-power OFDM receiver for wireless communications. *IEEE Transactions on Consumer Electronics* 58 (3), 739–745. http://dx.doi.org/10.1109/TCE.2012.6311312.