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Effect of Heat Treatment Temperature on Hardness of Jaw Implant Produced from EDM Die-Sinking Process

Pengaruh Temperatur Perlakuan Panas terhadap Kekerasan Implan Rahang yang Dihasilkan dari Proses Die-Sinking EDM

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Abstract

Hardness is the main problem in making jaw implants using the die-sinking EDM process. Heat treatment can increase the hardness of jaw implants resulting from the EDM process. This research investigates the influence of temperature during the heat treatment process on the hardness of jaw implants produced from the EDM process. Heat treatment uses a quenching process. The quenching temperatures used were 940 °C, 950 °C, and 960 °C, while the holding time was 30 minutes. The aging temperature is 550 °C. The research results show that the greater the quenching temperature, the greater the increase in hardness. The hardness of the white layer reaches 713 VHN when using a temperature of 960 °C. Meanwhile, the hardness of the inner jaw implant reaches 354 VHN.

Keywords: heat treatment, quenching, holding time, jaw implant.

***SDGs*:**

Abstrak

Kekerasan menjadi permasalahan utama dalam pembuatan implan rahang dengan proses die-sinking EDM. Proses heat treatment dapat dijadikan solusi untuk meningkatkan kekerasan implan rahang hasil proses EDM. Penelitian ini menyelidiki pengaruh suhu perlakuan panas terhadap kekerasan implan rahang yang dihasilkan dari proses EDM. Perlakuan panas menggunakan proses quenching. Suhu quenching yang digunakan adalah 940 °C, 950 °C, dan 960 °C, sedangkan waktu penahanannya adalah 30 menit. Suhu penuaan menggunakan 550 °C. Hasil penelitian menunjukkan bahwa semakin besar suhu quenching maka semakin besar peningkatan kekerasannya. Kekerasan lapisan putihnya mencapai 713 VHN bila menggunakan suhu 960 °C. Sedangkan kekerasan implan rahang bagian dalam mencapai 354 VHN.

Kata Kunci: perlakuan panas, *quenching*, *holding time*, implan rahang.

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1. INTRODUCTION

The need for jaw implants is currently increasing, but this is not accompanied by the availability of adequate implants and affordable prices. The release of Republic of Indonesia Minister of Health Regulation Number 17 of 2017 served as a marker for this. To promote the use of domestic pharmaceutical products and medical devices, action plans for the growth of the pharmaceutical and medical device industries are discussed. Currently, jaw implants are still relatively expensive. This is because the current availability of jaw implants must be imported to obtain them. Apart from that, the process of making jaw implants still uses 2 machines, namely electrical discharge machining (EDM) type wire and using μ-milling. To reduce the price of jaw implants, efficiency is required while making jaw implants. One way to streamline the process of making jaw implants is to use one type of machine, namely die-sinking EDM.

Making jaw implants with die-sinking type EDM has been carried out (Kurniawan, Pangarsono, *et al.*, 2022; Kurniawan, Tiyastianto, *et al.*, 2022). However, the results of the research carried out still have weaknesses, namely the hardness of the jaw implants produced is in the range of 131-140 HVN. The hardness value achieved is still below the hardness of jaw implants sold on the market, around 165-170 HVN.

Increasing the hardness of jaw implants can refer to basic material science, where the heat treatment process can be used to increase the hardness of a material (Callister and Wiley, 1980). The effect of the heat treatment process has been widely studied on titanium materials (da Rocha *et al.*, 2006; Venkatesh, Chen and Bhole, 2009; Reda, Nofal and Hussein, 2013; Catherine and Hamid, 2018; Arab, Chen and Guo, 2019; Mpumlwana, Msomi and Fourie, 2021; Jian *et al.*, 2022). Reda, et al., have investigated the effect of single and duplex stage heat treatment (SSHT and DSHT) on the material hardness of the titanium alloy cast (Reda, Nofal and Hussein, 2013). The SSHT process uses quenching (935˚C, 10 min) with water cooling. The DSHT process uses cooling in a furnace from 935˚C after being held for 10 minutes, then to 600-700˚C followed by isothermal holding for 30 minutes and than cooling with water until room temperature. The research results show that the SSHT process is able to increase the hardness by around 21.45% of the initial material. Meanwhile, the DSHT process with temperatures of 600 and 700 ˚C can increase hardness by around 4% and 4.5% respectively. The impact of heat treatment on the mechanical characteristics of the ELI titanium alloy has been studied by Venkatesh et al. (Venkatesh, Chen and Bhole, 2009). The heat treatment variations used are quenching with water cooling and aging and quenching with air cooling and aging. The quenching and aging temperatures used were 950 ˚C and 525 ˚C respectively. The research results show that the quenching process with water cooling and aging can increase the hardness by around 85% of the initial material hardness. Meanwhile, the quenching process using air cooling and aging can increase hardness by around 75%.

Arab, et al. have studied the influence of the heat treatment process on the hardness of TA15 titanium alloy material (Arab, Chen and Guo, 2019). Variations of heat treatment used include quenching with water cooling, quenching with water cooling and aging, quenching with air cooling and aging. The quenching and aging temperatures used are 970 ˚C and 500 ˚C respectively. The research results show that the quenching process by cooling water increases hardness by around 16.3%. The quenching process with water cooling and aging can increase hardness by around 6.3%. Meanwhile, the quenching process with air cooling and aging causes a decrease in the hardness of the TA15 titanium alloy material by around 3%. Rocha, et al., have investigated the hardness of pure titanium cast materials and alloys after applying heat treatment (da Rocha *et al.*, 2006). The first treatment variation (T1) uses heating at 750 ˚C for 2 hours. The second treatment (T2) uses annealing at a temperature of 955 ºC for 1 hour and aging at a temperature of 620ºC for 2 hours. Heating and cooling were carried out in an argon atmosphere furnace. The results of the investigation show that when using T1 and T2 treatment on pure titanium cast material, the hardness increases by approximately 1% and 29%

respectively compared to the initial material. Meanwhile, by applying T1 and T2 treatment to titanium alloy cast materials, the hardness increases by around 3.4% and 8.4%, respectively.

From several existing literature reviews, the quenching process with water cooling and aging can increase hardness the highest compared to other processes. Although quenching by water cooling and aging has been investigated on pure titanium materials. However, the research that has been carried out is still limited to pure titanium material from castings and the optimum temperature for heat treatment is not yet known. The aim of this research is to increase the hardness of jaw implants produced from the EDM die-sinking process with heat treatment. Research has the advantage of producing jaw implants with a hardness level that meets the implant standards on the market. The novelty of this research is that there has been no research investigating the optimum temperature for the heat treatment process of quenching with water cooling and aging of jaw implants resulting from the EDM die-sinking process. Quenching and aging methods use temperature variations above and below research which has succeeded in increasing the hardness of pure titanium.

2. METHODOLOGY

2.1. Material

Pure titanium grade 1 sheet (NILACO Ltd., Tokyo, Japan) with a thickness of 400 μm was used as jaw implant material. CP-Ti sheet has a hardness of about 160 VHN. Jaw implant and electrode materials were selected based on Kurniawan et al. (Kurniawan *et al.*, 2019). The electrode (Figure 1) material uses copper.

Figure 1. Electrode shape (Kurniawan, Pangarsono, *et al.*, 2022).

2.2. Making Jigs

The Jig design used for the EDM die-sinking process contains several components including base jig, clamping, and screw clamp. Base Jig The jig functions as a place or holder for the workpiece. Clamping functions to press the workpiece that is above the base jig. The screw clamp functions to tie or tighten the clamping so that the workpiece on the base jig cannot move or shift. The results of making the jig are shown in Figure 2.

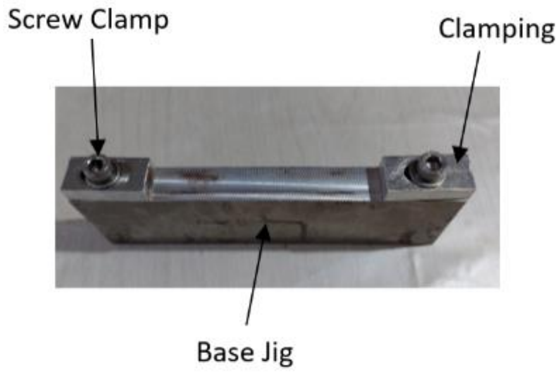

Figure 2. Jig used to hold the workpiece in the EDM process.

2.3. EDM Die-Sinking Process in Making Micro-Plates

The jaw implant manufacturing process uses an EDM die-sinking machine with the type of JOEMARS AZ50 from Taiwan as shown in Figure 3. The EDM die-sinking process parameters use a pulse current of 6A, 24μs for pulse on-time, and 28μs for pulse off-time. The EDM die-sinking machine and the parameters used are based on the optimum parameters from previous research results (Kurniawan *et al.*, 2023).

The die-sinking EDM process succeeded in cutting CP-Ti plate sheets to form micro-plate implants. The micro-plate implant resulting from the EDM die-sinking process is shown in Figure 4. The image shows the cut shape of the micro-plate implant following the shape of the electrode used. The cut side showed that there were no burrs formed on the nine jaw implants made.

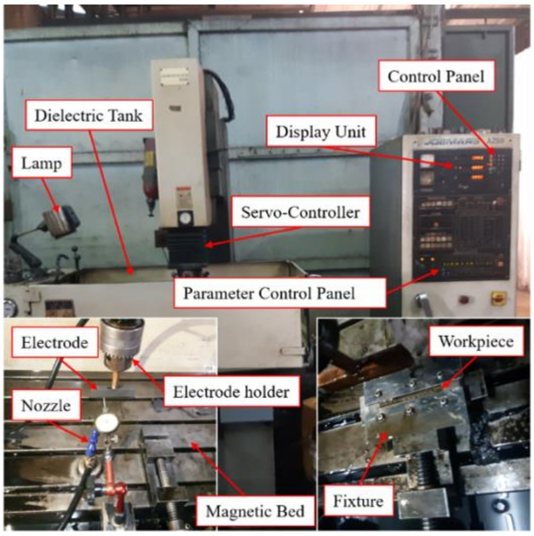

Figure 3. CNC EDM Die-sinking Machine (JOEMARS AZ50) (Kurniawan *et al.*, 2023).

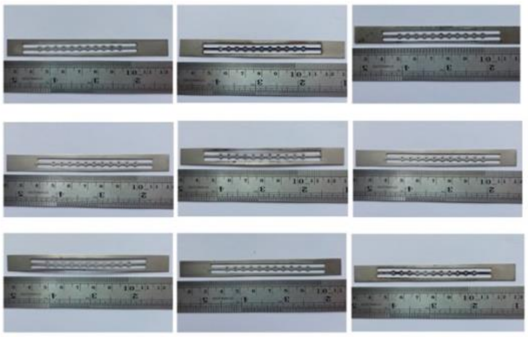

Figure 4. Jaw implants produced by the die-sinking EDM process.

2.4. Heat Treatment Process

The jaw implant heat treatment process uses a quenching method with water cooling and aging. The quenching temperature variations used were 940 °C, 950 °C, and 960 °C, while the holding time was 30 minutes. The aging temperature uses 550 °C. Each process parameter was repeated 3 times with different implants.

The heat treatment process using the quenching method with water cooling and aging was successfully carried out. Figure 5 illustrates the morphology of the jaw implant after it underwent heat treatment.

2.5. Hardness Testing

Testing the hardness of jaw implants using the Vickers microhardness test. Hardness testing uses a 100 gram load with a loading time of 10 s (Kurniawan *et al.*, 2019; Kurniawan, 2021). Hardness measurements were carried out in the white layer area and inside the inner radius, outer radius, and straight sides. White layer hardness measurements were carried out at 50 μm from the side with four measurement points as shown in Figure 6.

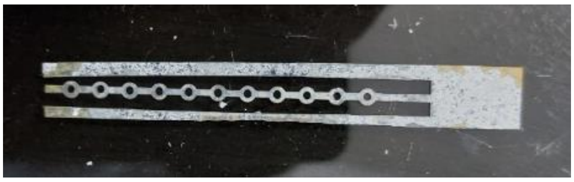

Figure 5. Jaw implants that have been heat treatement.

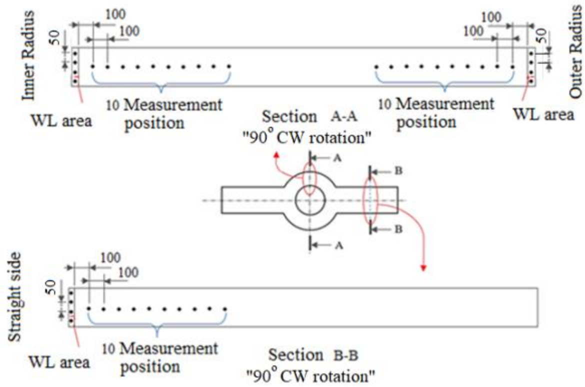

Figure 6. Position of jaw implant hardness measurement.

3. RESULTS AND DISCUSSION

3.1. White Layer (*WL*) Hardness

The hardness value of the ***WL*** after heat treatment using the water quenching and air aging methods is presented in Figure 7, Figure 8 and Figure 9. The hardness value of the ***WL*** at the inner radius (Figure 7) shows an increased hardness value compared to the initial hardness. The increase in violence that occurs in the ***WL*** is not evenly distributed. This is because the initial hardness of the ***WL*** is also uneven. The hardness of the ***WL*** increases with increasing quenching temperature. At a quenching temperature of 940 °C, the average hardness of the ***WL*** increased by around 355 VHN from the initial hardness of the ***WL***. The highest increase in average hardness of the ***WL*** was 494 VHN when using a quenching temperature of 960 °C.

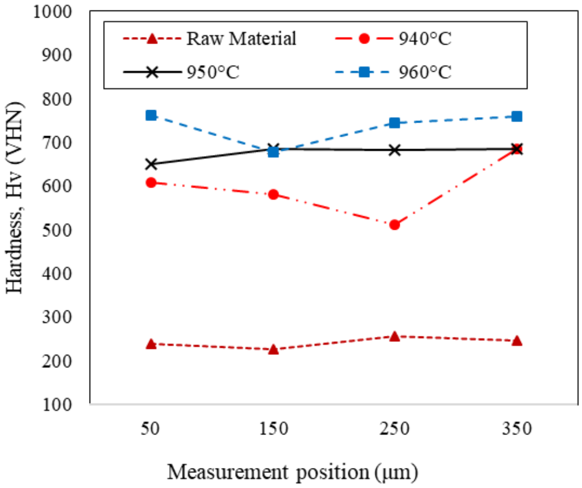

Figure 7. Hardness of the ***WL*** on the inner radius of the jaw implant.

The hardness value of the ***WL*** on the outer radius (Figure 8) shows that the hardness value has increased compared to the initial hardness as happened on the inner radius. The increase in violence that occurs in the ***WL*** is also uneven. This is because the initial hardness of the ***WL*** is uneven. The hardness of the ***WL*** increases with increasing quenching temperature. At a quenching temperature of 940 °C, the average hardness of the ***WL*** increased by around 338 VHN from the initial hardness of the ***WL***. The average hardness again increased to around 436 VHN when using a quenching temperature of 950 °C. The highest increase in average hardness of the ***WL*** was 516 VHN when using a quenching temperature of 960 °C.

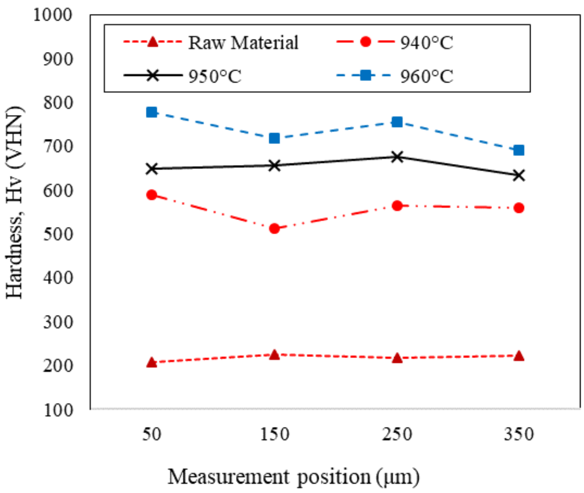

Figure 8. Hardness of the ***WL*** on the outer radius of the jaw implant.

The hardness value of the ***WL*** on the straight side (Figure 9) shows that the hardness value also increases compared to the initial hardness, as occurs on the inner and outer radius. The increase in violence that occurs in the ***WL*** is also uneven. This is because the initial hardness of the ***WL*** is uneven. The hardness of the ***WL*** increases with increasing quenching temperature. At a quenching temperature of 940 °C, the average hardness of the ***WL*** increased by around 350 VHN from the initial hardness of the ***WL***. The average hardness again increased to around 422 VHN when using a quenching temperature of 950 °C. The highest increase in average hardness of the ***WL*** was 484 VHN when using a quenching temperature of 960 °C.

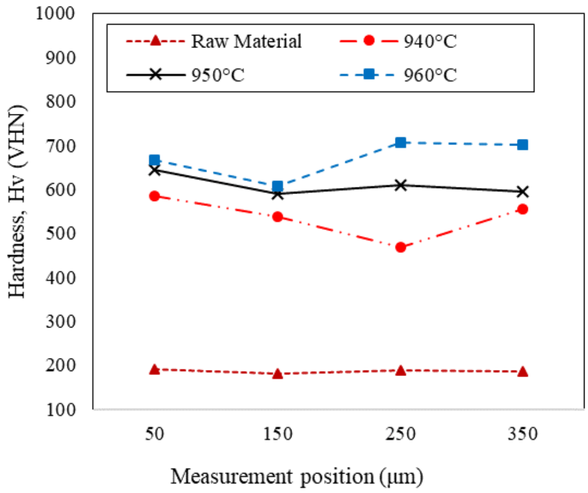

Figure 9. ***WL*** hardness on the straight side of the jaw implant.

3.2. Jaw Implant Hardness

The internal hardness values of jaw implants after heat treatment using the air quenching and air aging methods are presented in Figure 10, Figure 11 and Figure 12. The internal hardness value of the jaw implant at the inner radius (Figure 10) shows that the hardness value has increased compared to the initial hardness. The increase in hardness that occurs on the inside of the implant is uneven. This is because the initial hardness of the inside is also uneven. The uneven initial condition of the implant is caused by the die-singing EDM process reducing hardness with uneven results. At a temperature of 940 °C, the lowest hardness is around 264 VHN at the measurement position of 500 µm. Meanwhile, the highest hardness is around 337 VHN at the measurement position of 1000 µm. At a temperature of 950 °C, the lowest hardness is around 318 VHN at the measurement position of 900 µm. Meanwhile, the highest hardness is around 367 VHN at the measurement position of 600 µm. The lowest hardness at a temperature of 960 °C of around 339 VHN occurs at the measurement position of 100 µm, while the highest hardness of around 399 VHN occurs at the measurement position of 700 µm.

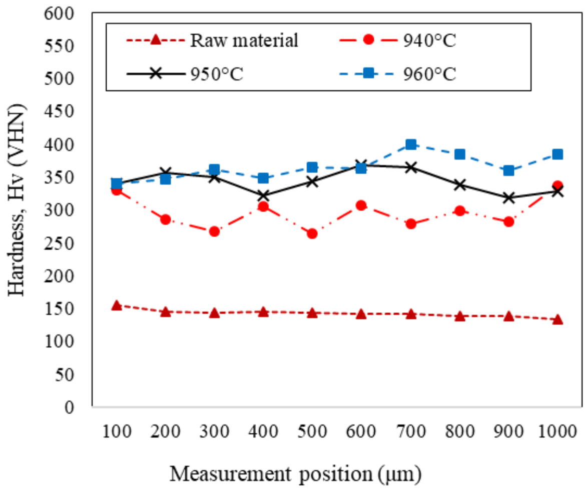

Figure 10. Internal hardness of the jaw implant at the inner radius.

The hardness value of the inside of the jaw implant at the outer radius (Figure 11) shows an increased hardness value compared to the initial hardness that occurred at the inner radius. The increase in hardness that occurs on the inside of the jaw implant on the outer radius is uneven. This is because the initial hardness of the inner part of the outer radius is also uneven. The lowest hardness when using a temperature of 940 °C was around 265 VHN which occurred at the measurement position of 300 µm. Meanwhile, the highest hardness is around 294 VHN at the measurement position of 1000 µm. At a temperature of 950 °C, the lowest hardness is around 275 VHN at the measurement position of 600 µm. Meanwhile, the highest hardness is around 352 VHN at the measurement position of 1000 µm. The lowest hardness at a temperature of 960 °C of around 310 VHN occurred at the measurement position of 200 µm, while the highest hardness of around 379 VHN occurred at the measurement position of 100 µm.

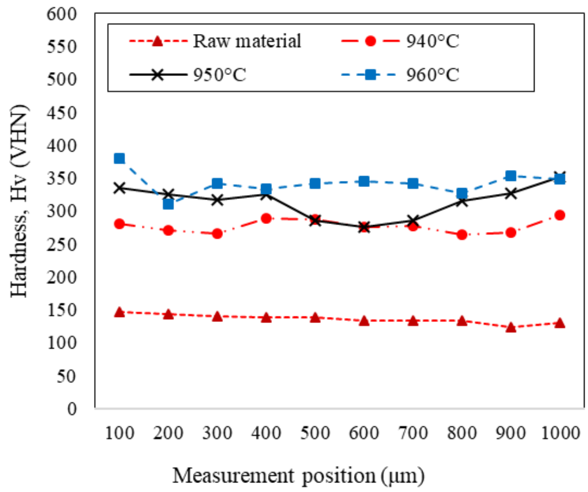

Figure 11. Internal hardness of the jaw implant at the outer radius.

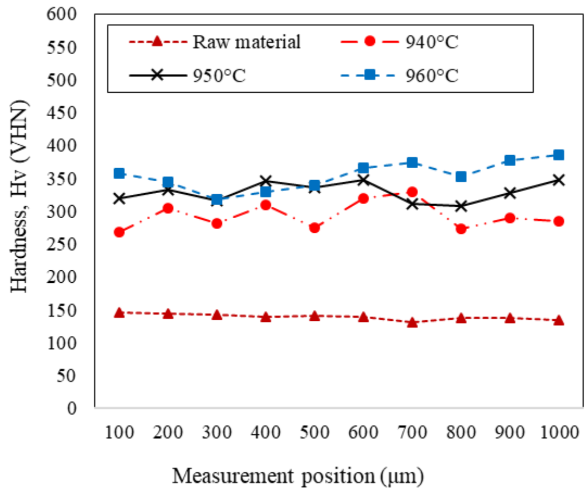

Figure 12. Internal hardness of the jaw implant on the straight side.

The hardness value of the inner part of the jaw implant on the straight side (Figure 12) shows that the hardness value also increases compared to the initial hardness as occurs on the inner and outer radius. The increase in hardness that occurs on the inside of the jaw implant on the straight side is also uneven. This is also caused by the initial hardness of the inside of the jaw implant on the straight side being uneven. At a temperature of 940 °C, the lowest hardness is around 268 VHN at the measurement position of 100 µm. Meanwhile, the highest hardness is around 330 VHN at the measurement position of 700 µm. At a temperature of 950 °C, the lowest hardness is around 308 VHN at the measurement position of 800 µm. Meanwhile, the highest hardness is around 347 VHN at the measurement position of 1000 µm. The lowest hardness at a temperature of 960 °C of around 318 VHN occurs at the measurement position of 300 µm, while the highest hardness of around 385 VHN occurs at the measurement position of 1000 µm.

3.3. Effect of Heat Treatment Temperature on Jaw Implant Hardness

The heat treatment temperature in the quenching method can affect the hardness of the white layer and jaw implants. Increasing the quenching temperature will cause an increase in jaw implants as seen in Figure 13.

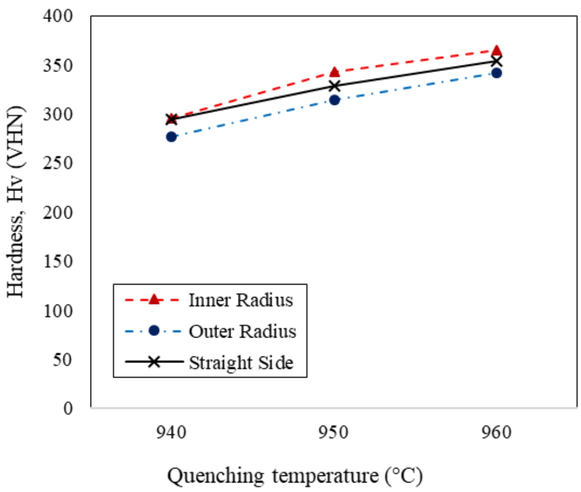

Figure 13. Relationship between quenching temperature and jaw implant hardness.

The greater the quenching temperature causes an increase in jaw implant hardness. At a quenching temperature of 940 °C, the average hardness of the inner part of the jaw implant at the inner radius increased by around 153 VHN from the initial hardness of the inner part of the implant at the inner radius. The increase in the average hardness of the inner part of the implant at the highest inner radius was 223 VHN when using a quenching temperature of 960 °C. The average hardness of the inner part of the jaw implant at the outer radius increased by approximately 144 VHN from the initial hardness of the inner part of the implant at the outer radius. The average hardness again increased to around 178 VHN when using a quenching temperature of 950 °C. The increase in the average hardness of the inside of the implant at the highest outer radius was 206 VHN when using a quenching temperature of 960 °C. The average hardness of the inside of the jaw implant on the straight side increased by approximately 155 VHN from the initial hardness of the inside of the jaw implant on the straight side. The average hardness again increases to around 190 VHN when using a quenching temperature of 950 °C. The increase in average hardness of the inside of jaw implants on the straight side was highest at 215 VHN when using a quenching temperature of 960 °C.

The quenching process can increase hardness because it creates equilibrium between the alpha and beta phases at the temperature during the heat treatment, as well as between these phases' compositions and the martensite's breakdown upon cooling (Fopiano and Hickey, 1973). Regarding the effect of quenching temperature, it can influence an increase in hardness because the CP-Ti microstructure has an alpha phase. After being heated to a temperature above 883°C, there will be a transformation of the HCP crystal structure (alpha phase) into a BCC structure (beta phase) (da Rocha *et al.*, 2006). This greatly raises the hardness of jaw implants, perhaps as a result of modifications to their microstructure. This increase is in line with previous research, where hardness increased with an increase in heat treatment temperature.

4. CONCLUSION

From the results of the experiments that have been carried out, several findings were obtained. The heat treatment process using quenching and aging methods can increase the hardness of jaw implants. The increase in jaw implant hardness is greater when the quenching temperature increases. The hardness of jaw implants is close to standard hardness when using a quenching temperature of 940 °C. An increase in hardness also occurs in the white layer, where the greater the quenching temperature, the harder the white layer is. The hardness of the white layer reaches 562 VHN with a quenching temperature of 940 °C.

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REFERENCES

Arab, A., Chen, P. and Guo, Y. (2019) 'Effects of microstructure on the dynamic properties of TA15 titanium alloy', *Mechanics of Materials*, 137, p. 103121.

Callister, W.D. and Wiley, J. (1980) 'Materials Science', *Science*, 208(4439), pp. 30–30.

Catherine, L.D.K. and Hamid, D.B.A. (2018) 'The effect of heat treatment on the tensile strength and ductility of pure titanium grade 2', *IOP Conference Series: Materials Science and Engineering*, 429(1), p. 012014.

Fopiano, P.J. and Hickey, C.F. (1973) 'Comparison of the Heat Treatment Responses of Three Commercial Titanium Alloys', *Journal of Testing and Evaluation*, 1(6), pp. 514–519.

Jian, S. *et al.* (2022) 'Gradient microstructure and mechanical properties of Ti-6Al-4V titanium alloy fabricated by high-frequency induction quenching treatment', *Materials & Design*, 222, p. 111031.

Kurniawan, Y. *et al.* (2019) 'Effect of Preheating on Punch Force, Sheared Surface and Work Hardening in Cold Punching Process of Commercially Pure Titanium Sheet', *International Review of Mechanical Engineering (IREME)*, 13(9), pp. 504-512.

Kurniawan, Y. (2021) *Proses Punching Lubang Lingkaran Dan Non-Symmetric Pada Pelat Commercially Pure Titanium (Cp-Ti) Sebagai Alternatif Proses Pembuatan Pelat Penyambung Tulang Rahang*. Dissertation. Universitas Gadjah Mada.

Kurniawan, Y., Pangarsono, P.S., *et al.* (2022) 'Effect of Pulse Current and Electrode Material in Producing of Microplate Implant by EDM Die-Sinking', *International Review of Mechanical Engineering (IREME)*, 16(10), pp. 564-572.

Kurniawan, Y., Tiyastianto, S.F., *et al.* (2022) 'Pengaruh Material Elektroda Grafit dan Tembaga terhadap Material Removal Rate (MRR), Electrode Wear Rate (EWR) dan Kekerasan dalam Pembuatan Implan Rahang Menggunakan Dise-sinking EDM', *AME (Aplikasi Mekanika dan Energi): Jurnal Ilmiah Teknik Mesin*, 8(2), pp. 104-109.

Kurniawan, Y. *et al.* (2023) 'Dimensional Accuracy, Surface Roughness and Hardness Properties for Microplate Implants Manufacturing by EDM Die-Sinking Process', *International Journal of Automotive and Mechanical Engineering*, 20(3), pp. 10606-10617.

Mpumlwana, D., Msomi, V. and Fourie, C.J.S. (2021) 'Effect of Heat Treatment on the Mechanical Properties of a 3 mm Commercially Pure Titanium Plate (CP-Ti Grade 2)', *Journal of Engineering*, 2021, p. e6646588.

Reda, R., Nofal, A. and Hussein, A.-H. (2013) 'Effect of Single and Duplex Stage Heat Treatment on the Microstructure and Mechanical Properties of Cast Ti-6Al-4V Alloy', *Metallography, Microstructure, and Analysis*, 2(6), pp. 388-393.

da Rocha, S.S. *et al.* (2006) 'Vickers hardness of cast commercially pure titanium and Ti-6Al-4V alloy submitted to heat treatments', *Brazilian Dental Journal*, 17(2), pp. 126–129.

Venkatesh, B.D., Chen, D.L. and Bhole, S.D. (2009) 'Effect of heat treatment on mechanical properties of Ti-6Al-4V ELI alloy', *Materials Science and Engineering: A*, 506(1), pp. 117–124.