The effect of different types of quenching methods on the burr zone characteristics on Ti-6Al-4V material

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Abstract. Heat treatment is a process that aimed to increase the ductility, reduce internal strain, smoothen the crystallite, increase the tensile strength, improve the Carbon (C) atom components, and increase the hardness. This research aimed to find the heat treated results using carburizing and quenching in blanking tool with low-carbon steel in the form of hardness level growth using carbon charcoal media mixed with BaCo3 energizer in pack carburizing process at 900°C temperature for 120 minutes holding time. This is continued with quenching process using oil, saltwater, and water. The blanking tool was tested in blanking experiment with 2.5% clearance, 3000 mm min⁻¹ cutting speed using Ti-6Al-4V sheet metal with 0.6 mm thickness. The result parameter from the experiment was the burr zone level measurement of the product. Heat treatment process increased Carbon (C) atom component in the blanking tool. The raw material had a 0.17% component, and the quench media of oil, saltwater, and water had 0.19%, 0.22%, and 0.3% carbon components respectively. The hardness value also increases using oil, salt water, and water as the quenching media, resulted in 283.7, 423.8, and 462.4 HV respectively. The burr zone level was also obtained using the quench media of oil, salt water, and water with the results of 0.218, 0.206, and 0.119 mm.

Keywords: heat treatment, hardness, blanking, burr zone

1. Introduction
Heat treatment is often associated with increasing ductility, reducing the internal strain, smoothening the crystallite, increase the hardness, improve the metal’s tensile strength, and others. Hardening is one of many heat treatment for steel, it heats the steel up to or above the critical temperature area and continues with rapid cooling or quench. Tool life can be improved using high-quality steel and heat treatment that is applied during metal forming such as stamping, punching, and blanking [1]. Blanking process is a process of cutting metal by pressing it with a specific load on the workpiece so that it reaches the point of fracture with the sheet metal between the punch and dies [2]. Blanking can produce several components in one operation, which is very beneficial because it speeds up production time and has the advantage of economic costs in mass production [3,4].

Blanking process produces many appliances in many fields. For example, in automotive, it provides engine drive component such as ring/washer, gasket, or relay control phase (RCP) in the electric field. The medical field uses the blanking process to produce keychain cranioPlasty plate as an implant plate to knit the head bones. The material and quality of the keychain cranioPlasty
plate influence the fracture healing process in the head bones. Furthermore, the duration and fracture level also affect the recovery process [5].

Research on the implant production process in the form of keychain cranioplasty using blanking machine was also conducted by Lubis and Mahardika [6]. In the previous research that observed about the clearance variations in making the hole on the keychain cranioplasty plate. The results of the study showed a clearance value of 2.5% and a flat-shaped tool has the best sheared edge characteristics. Research by Jiang et al. [7] as well as Roy and Sundararajan [8] emphasized particularly on the various heat treatments after carburizing process on the microstructure and mechanical property on the steel, few studies have checked out the evolution of microstructure in carburizing process. In this present study, blanking tool was given heat treatment process using pack carburizing method at 900 and 120 minutes holding time and then the quenching process is carried out with different quench media: oil, salt water, and water. The heat treatment process influenced the carbon atom content, microstructure, and the hardness level. The processed blanking tool then tested with blanking process test with 2.5% clearance and 3000 mm min⁻¹ cutting speed using Ti-6Al-4V sheet metal material.

2. Methods and materials
The objective of this research was the tool quality effect after the heat treatment process, which is carburizing and quenching, in several quench media: oil, saltwater, and water. The raw material used is low-carbon steel material which has a punch tip profile in the form of a keychain cranioplasty plate with a length of 12 mm, and a circle diameter of 2 mm as a blanking tool (Figure 1a) with an initial carbon content of 0.19% wt. Titanium alloy (Ti-6Al-4V) sheet was used as the specimen material with 0.6 mm thickness. The mechanical properties are used as shown in Table 1.

Table 1. Mechanical properties of Ti-6Al-4V material

| No | Properties            | Value |
|----|-----------------------|-------|
| 1  | Poisson's Ratio       | 0.37  |
| 2  | Modulus Young (GPa)   | 119   |
| 3  | Density (g cm⁻³)      | 4.51  |
| 4  | Yield Strength (MPa)  | 925   |

Figure 1. (a) Half section view of keychain cranioplasty plate, (b) sheared edge characteristics

The addition of carbon to the surface of low-carbon steels was wood charcoal mixed with BaCo₃ energizer in 90%:10% ratio of about 900 °C furnace temperature and 120 minutes
carburizing holding time. The experiment was performed at 3000 mm min\(^{-1}\) cutting speed and 2.5% clearance between tool punch and die. The experiment was conducted three times to obtain valid data.

Experiments conducted to find out high-quality blanking products by observing the characteristics of the cutting edge of the product. The cut edge characteristics were divided into four: rollover zone (Zr), shear zone (Zs), fracture zone (Zf), and burr zone (Zb) as shown in Figure 1b. The optimum products can be seen based on conditions that can produce a sheared edge quality in proportion to the smoothest shear zone (Zs) and the smallest rough side fracture zone (Zf) and burr zone (Zb). The sheared edge characteristics were determined based on the average results from measurements in selected zones using Image-J. Then an analysis was performed to assess the effect of variations in the level of hardness of blanking tool, and in this case, only the burr zone (Zb) was observed.

3. Result and discussion

3.1 Hardness test results (Vickers) of blanking tool

Figure 2 displays the heat treatment and material morphology results on blanking tool. The smallest Vickers hardness test is 125.8 HV in the blanking tool without heat treatment (normal tool), whereas the highest is 479.6 HV in blanking tool with heat treatment with water quench media. The average Vickers hardness test on blanking tool without heat treatment process is 128.96 HV, oil as the quench media is 283.7 HV, saltwater is 423.88 HV, and lastly, with water is 462.46 HV. There was a 28% increase of hardness in water as the quench media as the most significant growth compared with before heat treatment.

![Figure 2](image-url)

**Figure 2.** a) Normal blanking tool morphology, b) Using quench media of oil, c) Salt water and d) Water
The value of steel hardness can be found using the carbon content in the steel surface. Carbon content on steel surface is 0.88% wt, or a maximum of 0.9% wt resulted in a hardness value of 780 HV or maximum of 824 HV \cite{9,10}. Theoretically, the carbon content without carburizing is 0.19% wt, the hardness should be between 280-290 HV. Meanwhile, the steel after carburizing and quenching with water had 0.3% wt carbon atom; thus, the hardness would be 425-440 HV. The theories explained before are in accordance with the results of present research that sought a value above 462.46 HV.

![Figure 3. Micro Vickers hardness test result](image)

The hardness in steel with low-carbon can be increased by carburizing using pack carburizing method (Figure 3). Carburizing process was performed at 900 °C temperature that exceeds the austenite temperature for mild steel, then slowly cooled by turning off the furnace and waited for the temperature to reach 350 °C. Carburizing process also changes the microstructure from the specimen. Initially, the sample was dominated by ferrite crystal than perlite crystal. Because perlite crystal is harder than ferrite crystal, it resulted in low hardness. Meanwhile, after carburizing carbon diffusion occurred in the microstructure that caused the domination of the perlite phase due to the commingling of a carbon atom with crystal perlite and made it appeared larger. The high level of hardness induced by water quenching followed the research of Kowser and Motalleb A \cite{11} because water cooling rate is higher than oil and saltwater. The microstructure that was formed during the carburizing process using oil quench media consisted of low perlite phase and dominated by the ferrite phase. Meanwhile, in the water as quench media, the dominated phase was perlite phase up to 80% of the sample’s surface that influences the hardness. That means quicker cooling increased the hardness level.

3.2 Units burr zone length of blanking process test results
Burr zone length was measured from the results of the blanking experiment in the form of keychain cranioplasty that was carburized and quenched beforehand using quench media of oil, saltwater, and water as displayed in Figure 4. Whereas, the burr zone length on keychain cranioplasty in each blanking tool can be seen in Figure 5 below. The average burr zone length on keychain cranioplasty product with oil quenching with the value of 0.218 mm, the average value in
saltwater is 0.205 mm, while for quench water has the smallest burr height of 0.119 mm. It can be said that higher burr follows the lower level of the tool’s hardness. Thus, higher hardness created lower burr zone. Appropriate blanking product criteria should at least have 75% shear zone (Zs) composition. The smallest burr zone (Zb) in the experiment was found in the specimen with water quenching media with the value of 0.119 mm from 0.66 material thickness. The Zb value was 19.83% which meant the Zs, Zr, Zf values was 80.17%. According to [12], burr zone level was also influenced by wear radius. From this research, the greatest influence of the burr zone was wear rate because a higher wear rate resulted in increasing the burr zone value. Therefore, the minimum wear rate should be used.

![Figure 4](image1.png)

**Figure 4.** Burr zone characteristic examples on keychain cranioplasty product using blanking tool with quenching media of (a) Oil, (b) Saltwater, and (c) Water

![Figure 5](image2.png)

**Figure 5.** Result the burr zone length on keychain cranioplasty in each blanking tool

4. **Conclusion**

Variation of quench media (oil, saltwater, and water) during carburizing process influenced the burr height in keychain cranioplasty product that resulted in 0.218 mm, 0.206 mm and 0.119 mm burr heights respectively.

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