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The Effect of Carburizing Media on the Hardness of Low Carbon Steel Treated with Pack Carburizing

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ABSTRACT: *The effect of various carburizing media on the hardness of ST 37 steel processed using the pack carburizing method has been investigated. The carburizing media used were corn cob charcoal and coconut tree charcoal, as well as $BaCO_3$ energizer. Pack carburizing treatment was carried out at a temperature of 900°C with soaking times varying between 60, 90, and 120 minutes. Hardness testing using the Vickers method referred to ASTM E 384 and SAE J423 standards. The results of the study showed that the surface hardness of specimens in pack carburizing was influenced by the use of carburizing media and soaking time. Longer soaking times tended to increase the surface hardness in the pack carburizing of ST 37 steel specimens with variations in carburizing media, namely corn cob charcoal and palm tree charcoal. Palm tree charcoal was more effective in increasing surface hardness than corn cob charcoal under all soaking time conditions. Palm treel charcoal is superior to corn cob charcoal as a carburizing media because it has a higher carbon content and lower oxygen, nitrogen, and sulphur content, which means better calorific value and lower pollutant emissions. Corn cob charcoal is still suitable for use, but its higher oxygen content makes it slightly less energy efficient than palm tree charcoal*

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I. INTRODUCTION

The pack carburizing treatment is essential for enhancing the mechanical properties of low-carbon steel, particularly in applications requiring improved hardness and wear resistance. This study investigates the effect of various carburizing media, including charcoal and Pinctada maxima shell powder, on the pack carburizing process's ability to achieve the desired mechanical properties. The findings will provide insights into optimizing carburizing media for enhanced performance of low-carbon steel in industrial applications. The results are expected to demonstrate how different media influence the carbon enrichment and mechanical characteristics of low-carbon steel, potentially leading to better performance in engineering applications. The study will also explore the relationship between carburizing temperature and the resulting hardness, aiming to identify optimal conditions for effective treatment.

Carburizing is a heat treatment process that significantly alters the microstructure of low-carbon steel, enhancing its hardness and wear resistance through carbon diffusion. The process parameters, including carburizing temperature and media composition, play a crucial role in determining the effectiveness of carbon enrichment and the resultant mechanical properties of low-carbon steel Bontong et al., [1]. The optimal carburizing temperature for low-carbon steel typically ranges from 850°C to 950°C, with higher temperatures generally yielding improved hardness and wear resistance Panda et al., [2]. The choice of carburizing media, such as Buffalo Bone Charcoal, can significantly influence the carbon content and mechanical properties of low-carbon steel during the carburizing process. Understanding these interactions is vital for optimizing treatment conditions to achieve superior hardness and wear resistance. The study will also assess the impact of varying media ratios on the carbon enrichment of low-carbon steel, aiming to establish a correlation between media composition and mechanical performance. The findings will highlight the importance of selecting appropriate carburizing media and temperatures, as these factors critically influence the hardness and wear resistance of low-carbon steel. The results will contribute to the existing knowledge on carburizing techniques and their impact on the mechanical properties of low-carbon steel, supporting advancements in material engineering. The anticipated outcomes will provide valuable guidelines for selecting carburizing media and optimizing treatment parameters, ultimately enhancing the performance of low-carbon steel in demanding industrial settings.

Low-carbon steel is widely used in various industries due to its excellent ductility, toughness, and weldability, making it suitable for numerous applications in daily life. However, its inherent low hardness limits its performance in wear-resistant applications, necessitating effective carburizing treatments to enhance its properties, Elzanaty, [3]. Effective carburizing processes can significantly improve the hardness and wear resistance of low-carbon steel, making it more suitable for demanding applications. The study will also evaluate the effectiveness of different carburizing temperatures, specifically between 850°C and 950°C, to determine their impact on hardness and wear resistance in low-carbon steel Ramdan et al., [4] Bontong et al., [1]. The findings will emphasize the critical role of carburizing media and temperature in optimizing the mechanical properties of low-carbon steel for enhanced performance in wear resistant applications.

Research on the potential of alternative carburizing media has been conducted, applying mangrove charcoal to improve the effectiveness of the carburizing process in low-carbon steel. Investigations into alternative carburizing media, such as mangrove charcoal, may reveal additional benefits in improving surface hardness and microstructural changes in low-carbon steel. This study will also analyse the effect of varying heating times during the carburizingprocess, with the aim of identifying the optimal duration that can maximise hardness and improve overall mechanical properties. Research results show that the use of coconut shell charcoal can significantly increase the hardness of low-carbon steel compared to other media, such as mangrove charcoal Kadriadi et al., [7]. Coconut shell charcoal carburizing media is superior to other media in increasing hardness, according to previous studies on the effectiveness of various carburizing materials Istiqlaliyah and Ilham, [5] Kadriadi et al., [7]. The variation in the ratio of coconut shell charcoal and mangrove wood charcoal also affects the hardness and microstructure of low-carbon steel during the carburizingprocess. Precise control of carburizing temperature and media composition is essential to achieve optimal surface hardness in low-carbon steel Adedipe et al., [8]. A comparative study of the effectiveness of various carburizing media, coconut shell charcoal versus mangrove wood charcoal, in achieving maximum hardness levels has been carburizing media medium and temperature can optimise the mechanical properties of low-carbon steel for specific industrial applications.

The pack carburizing process significantly increases the surface hardness and wear resistance of low-carbon steel, making it more suitable for demanding industrial applications Ramdan et al., [4] Panda et al., [2]. The results of the study show that pack carburizing not only increases surface hardness but also affects the microstructural changes in low-carbon steel. This study evaluates how variations in carburizingtemperature between 850°C and 950°C affect the microstructure and mechanical properties of the resulting low-carbon steel. The selection of carburizing media, such as the type of charcoal, can cause varying degrees of surface hardness and carbon diffusion depth in low-carbon steel Istiqlaliyah and Ilham, [5]. In addition, the optimal carburizingtemperature between 850°C and 950°C is very important to achieve the desired mechanical properties Panda et al., [2]. Higher temperatures generally increase hardness and wear resistance Ramdan et al., [4] Panda et al., [2].

This research aims to build on previous findings by systematically comparing the effects of different carburizing media on the mechanical properties of low-carbon steel. The expected results will provide a deeper understanding of how variations in carburizing media and temperature affect the mechanical properties of low carbon steel, potentially leading to optimised industrial applications. The results of this study will provide the best guidance in selecting carburizing media to enhance the performance of low-carbon steel in various industrial applications. The findings of this research will make a significant contribution to the knowledge of carburizing, particularly in understanding the interaction between media and carburizing temperature on the mechanical properties of low carbon steel. Studies conducted to date have not addressed the potential sustainability of alternative carburizing media for future applications. Long-term research on carburizing low-carbon steel using alternative carburizing media such as corn cob charcoal and palm charcoal could provide valuable insights.

II. EXPERIMENTAL SETUP

Figure 1 shows the experimental description of the pack carburizing process. The main piece of equipment used is an electric furnace capable of reaching a heating temperature of 900-950°C. The carburizing box is made of heat-resistant steel plates and serves as a container for specimens that are evenly wrapped with carburizing media. The carburizing media consists of powdered corn cob and palm charcoal as a carbon source. Barium carbonate ($BaCO_3$) was used as an activator to speed up the chemical reaction and release of carbon.

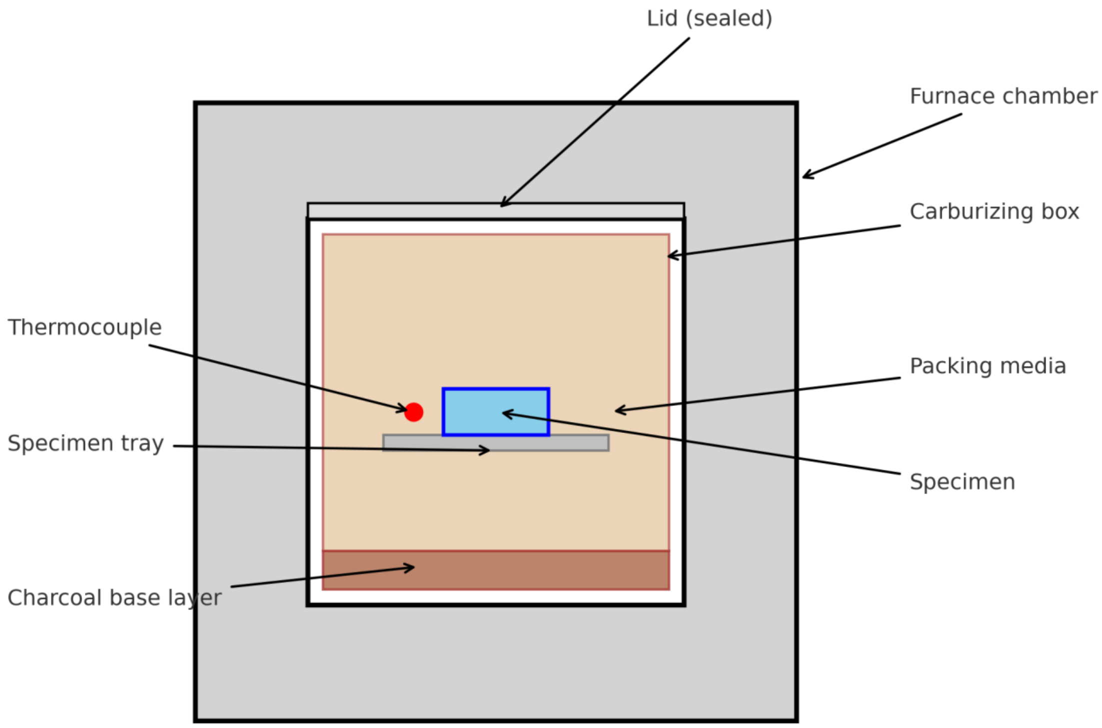

Fig. 1 Experimental setup for pack carburizing process

Pack Carburizing Process, shown in Figure 2. In the preparation stage, the specimen is cleaned from dirt/oil, inserted into the carburizing box with carburizing media (a mixture of charcoal powder and energizer ($BaCO_3$). with a ratio of 70:30 weight

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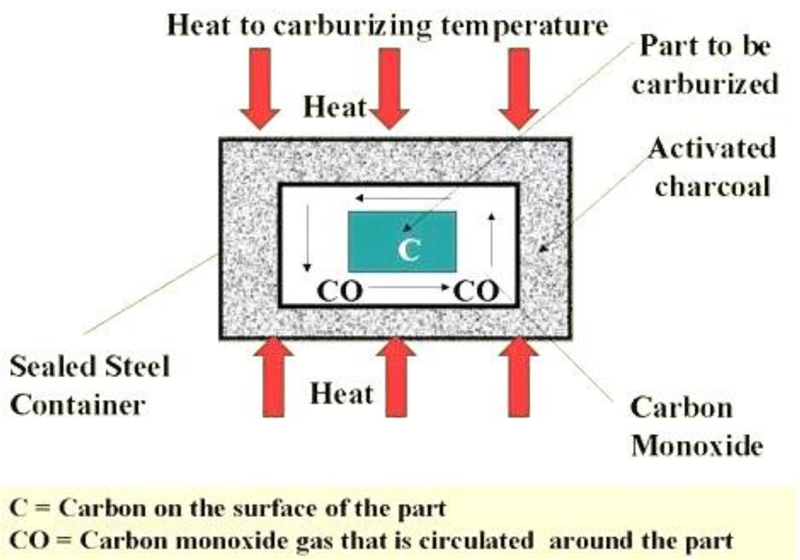

Fig. 2 Pack carburizing process

The specimens, carburizing media and energizer are placed in the carburizing box, sealed tightly and then placed in the electric furnace. Heated at a carburizing temperature of 900°C, with soaking times varying between 60, 90 and 120 minutes. As a result of heating to 900°C, the carburizing media decomposes to form CO gas. The CO gas approaches the surface of the steel and decomposes into C (carbon) + CO_2. Carbon diffuses to the surface of the specimen. The specimen material used in this study was ST 37 low carbon steel plate purchased from Tira Austenite Ltd., located in Surabaya, Indonesia. Chemical composition of the test material: (C) $\leq$ 0.20%, (Fe) 98.0%, (Mn) 0.40–0.65%, (P) $\leq$ 0.045%, (Si) $\leq$ 0.30%, and (S) $\leq$ 0.045%. Mechanical properties: Tensile strength 370–510 MPa, yield strength 235 MPa, elongation 20–25%. Young's modulus 200–210 GPa, density 7.85 g/cm³, surface hardness 130–170 HV.

III. RESULTS AND DISCUSSION

Palm trees and corn cobs as carburizing media must be dry and made into charcoal, as shown in Table 1.

Table 1. Charcoal production process sugar palm trees and corn cobs

Process Stage	Corn Cob	Palm Tree (Enau)
Raw Material	Dried corn cobs (<15% moisture)	Old dried enau trunk (<20% moisture)
Preparation	Cut into ±10–15 cm pieces	Cut into ±20–30 cm pieces
Drying	Sun-dried for 2–3 days	Sun-dried 1–2 weeks / oven-dried
Kiln/Equipment	Simple drum / pyrolysis furnace	Clay kiln / large drum
Carbonization (Pyrolysis)	400–600 °C, 2–4 hours, limited O_2	400–600 °C, 6–12 hours, limited O_2
Cooling	Seal tightly, cool for 12–24 hours	Seal tightly, cool for ±24 hours
Charcoal Characteristics	Lightweight, highly porous, easy to grind	Hard, dense, larger chunks
Advantages	Fast processing, abundant agricultural waste, low cost	Denser & more stable charcoal quality, suitable for carburizing
Disadvantages	Brittle, breaks easily, low density	Longer process, limited raw material availability

To determine the elements contained in palm tree charcoal and corn cobs, an elemental analyser was used. The results of the elemental analyser are shown in Figure 3.

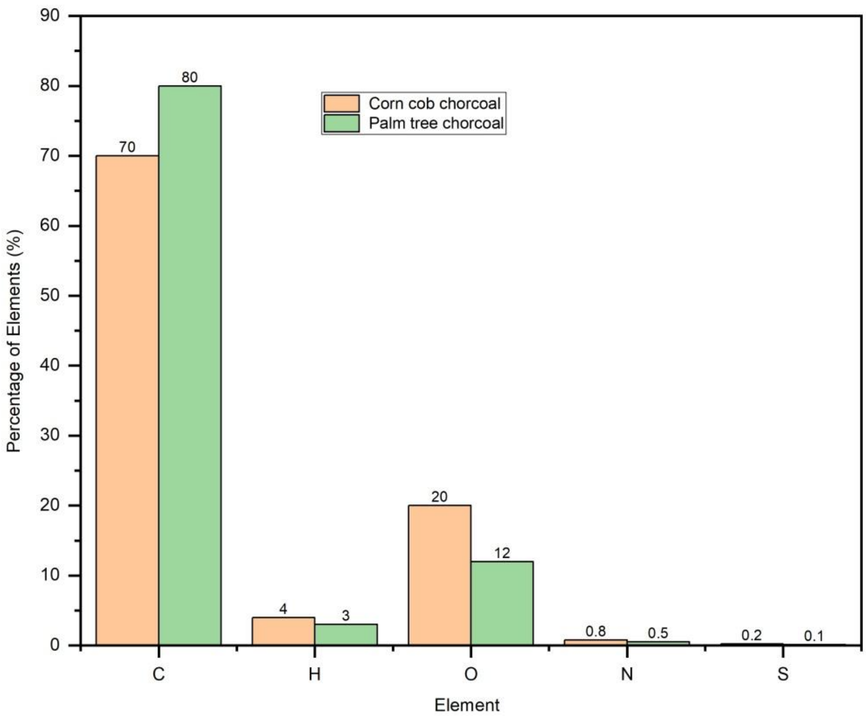

Fig. 3 Elemental content of corn cob charcoal and palm charcoal

Figure 3 illustrates the elemental composition (in weight percent) of two types of charcoal: corn cob charcoal (represented in orange) and palm tree charcoal (shown in green). The elements compared include carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S). Each bar in the graph denotes the percentage of each element present in the two types of charcoal. In terms of carbon content, palm tree charcoal contains a higher percentage (approximately 80%) compared to corn cob charcoal (approximately 70%). Given that carbon is the primary component responsible for energy storage in charcoal, a higher carbon content typically signifies better-quality charcoal. In terms of carbon content, palm charcoal contains approximately 80%, while corn cob charcoal has around 70%. Since carbon is the primary component responsible for energy storage in charcoal, a higher carbon content generally indicates enhanced calorific value and combustion efficiency. Conversely, corn cob charcoal exhibits a significantly higher oxygen content, approximately 20%, compared to palm charcoal, which stands at about 12%. Given that the oxygen bound in charcoal does not contribute to energy production during combustion, a higher oxygen content can reduce the efficiency of charcoal as a fuel source. Both types of charcoal contain relatively low levels of hydrogen, at around 3–4%. Although hydrogen contributes to the calorific value, its impact is minimal and can also lead to steam emissions during combustion. Furthermore, the nitrogen and sulfur content in both types of charcoal is quite low, with nitrogen around 0.5–0.8% and sulfur approximately 0.1–0.2%. This low concentration is advantageous, as elevated levels of these elements can result in pollutant emissions, such as NOx and SO_2.

In this study, Hardness testing using the Vickers method, refers to the ASTM E 384 and SAE J423 standards. The aim is to determine the surface hardness of the specimen after pack carburizing treatment with variations in carburizing media. Surface hardness testing using the Vickers Microhardness Tester Mitutoyo HM-122. The hardness value is obtained by forcing a 10 mm diameter diamond indenter into the surface of the steel sample under static load. The test was repeated three times. The average results of the surface hardness test using the Vickers method after pack carburizing treatment for each variation of carburizing media used are shown in Figure 4.

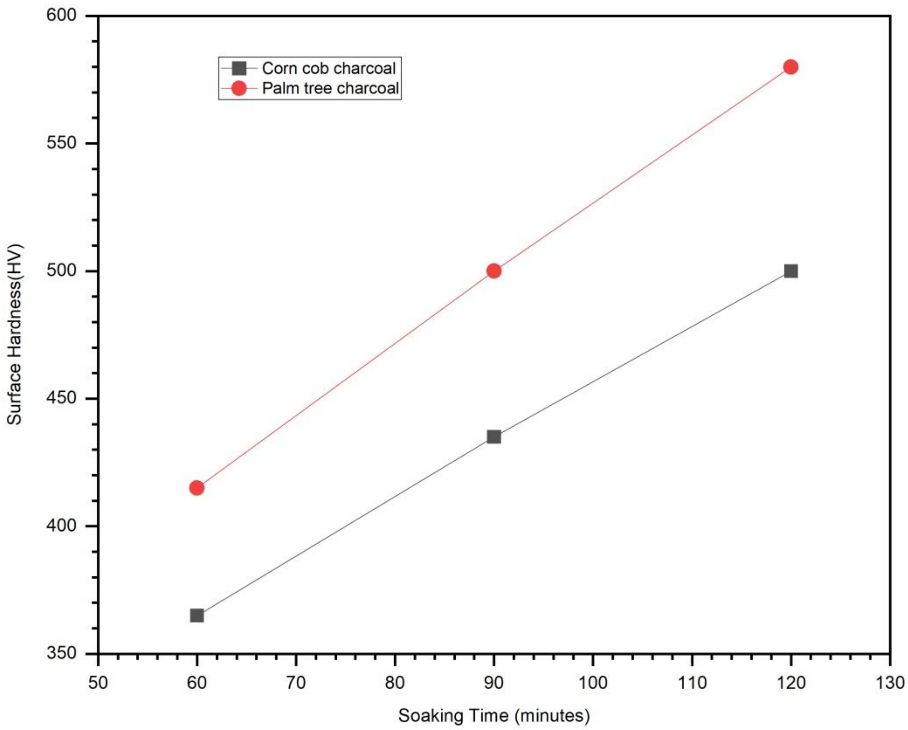

Fig. 4 Effect of carburizing media on surface hardness of ST 37 steel

Figure 4 depicts how the soaking time affected the surface hardness of two types of charcoal, corn cob charcoal and palm tree charcoal. The X-axis represents the soaking time in minutes, while the Y-axis indicates the surface hardness in Vickers hardness (HV). Corn cob charcoal, in Figure 4, presents a situation where the further the soaking time is, the more the surface hardness of the charcoal and vice versa. Just to illustrate, when the soaking time is 60 minutes, the hardness is approximately 400 HV, and at a soaking time of 120 minutes it is nearly 500 HV. The palm tree charcoal also displays the same trend on the graph, with an increase in surface hardness due to a longer soaking time. The palm tree charcoal has the hardness of about 450 HV at the 60-min mark, and it climbs up to around 550 HV at the 120-min mark.

Both kinds of charcoal demonstrated an increase in surface hardness with longer soaking times, although palm cob charcoal was always superior to corn cob charcoal at the same time point regarding surface hardness. It seems that palm cob charcoal is more open to soaking time in terms of plasticity, which might suggest that the palm charcoal's surface structure is more robust or less easily altered than that of corn cob charcoal.

IV. CONCLUSION

The surface hardness of ST 37 steel specimens subjected to pack carburizing treatment is influenced by the use of carburizing media and soaking time. Longer soaking times tend to increase surface hardness in pack carburizing of ST 37 steel specimens with variations in carburizing media, namely corn cob charcoal and palm tree charcoal. Palm tree charcoal is better at increasing surface hardness than corn cob charcoal under all soaking time conditions. Palm tree charcoal is superior to corn cob charcoal as a carburizing medium because it has a higher carbon content and lower oxygen, nitrogen, and sulphur content, which means better calorific value and lower pollutant emissions. Corn cob charcoal is still suitable for use, but its higher oxygen content makes it slightly less energy efficient than palm tree charcoal.

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