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Effect of Carburizing Media on the Tensile Strength of AISI 1020 Low Carbon Steel under Pack Carburizing Treatment

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ABSTRACT:The demand for sustainable surface engineering has driven the exploration of eco friendly carburizing media as alternatives to conventional carbon sources. This study investigates the effect of biomassderived carburizing media rice husk charcoal and Gigantochloa apus bamboo charcoal on the tensile strength of AISI 1020 low-carbon steel processed through pack carburizing. The specimens were carburized under controlled temperature and soaking time, followed by mechanical testing and microstructural characterization. The results reveal that both carburizing media significantly enhance tensile strength compared to untreated steel, attributed to carbon diffusion and the formation of a hardened surface layer. Among the tested media, Gigantochloa apus bamboo charcoal exhibits superior performance, resulting in higher tensile strength due to its higher carbon activity and more effective diffusion kinetics. Microstructural analysis confirms the transformation from ferrite pearlite to a refined structure with increased pearlite fraction and case hardening depth. This study demonstrates that agricultural waste based carburizing media not only improve mechanical performance but also offer a sustainable and cost effective alternative for surface hardening processes. The findings provide valuable insights into the relationship between biomass carbon potential and mechanical enhancement in low carbon steels.
KEYWORDS: Pack Carburizing,CarburizingMedia, Rice Husk Charcoal, Gigantochloa Apus Bamboo Charcoa, Tensile Strength.

I. INTRODUCTION

The increasing demand for high performance engineering materials has intensified the need for effective surface modification techniques, particularly for low-carbon steels such as AISI 1020 steel. This material is widely utilized in automotive, structural, and mechanical applications due to its good ductility, weldability, and cost-effectiveness; however, its relatively low carbon content limits its tensile strength and wear resistance [1], [2]. Consequently, surface hardening treatments are essential to enhance its mechanical performance and extend service life [3].

Among various surface engineering methods, pack carburizing remains a widely adopted and cost-effective technique for improving surface properties of low-carbon steels [4], [5]. The process involves carbon diffusion into the steel surface at elevated temperatures, leading to the formation of a hardened case layer while maintaining a tough and ductile core [6]. The efficiency of carburizing is strongly influenced by processing parameters such as temperature, soaking time, and carbon potential of the carburizing medium [7], [8]. Conventional carburizing agents are typically derived from fossil-based sources, which raise environmental concerns and sustainability issues [9].

In response to these challenges, recent studies have explored the use of biomass-derived materials as alternative carburizing media due to their renewability, low cost, and high carbon content [10]–[12]. Agricultural wastes such as coconut shell, palm kernel shell, and wood charcoal have demonstrated promising results in improving hardness and wear resistance of carburized steels [13]–[15]. Among these materials, rice husk charcoal has attracted significant attention due to its abundance and unique composition, including silica content that may influence carbon diffusion mechanisms and surface reactions during carburizing [12].

In addition to rice husk, bamboo charcoal has emerged as a potential carburizing medium due to its high fixed carbon content, porous structure, and enhanced reactivity [16], [17]. Bamboo-derived carbon materials, particularly from Gigantochloa apus, are widely available in Southeast Asia and offer favorable physicochemical properties for thermal processing [13]. Previous studies have reported that bamboo charcoal can improve carbon transfer efficiency and enhance surface hardness in carburized steels [15], [16]. Furthermore, the carburizing performance is closely related to carbon activity and diffusion kinetics, which directly affect microstructural evolution during heat treatment [18], [19].

Despite these advancements, the current state of the art indicates that most studies predominantly focus on hardness and wear resistance as primary indicators of carburizing performance [20]–[22]. While these properties are important, tensile strength is a critical parameter for structural applications, yet it remains relatively underexplored in biomass-based carburizing research [23], [24]. In addition, only limited studies have conducted direct comparisons between different biomass-derived carburizing media under identical processing conditions.

Another important gap lies in the insufficient understanding of the relationship between carbon potential of biomass media, diffusion behavior, and the resulting microstructural evolution. The transformation of ferrite pearlite structures, case depth development, and their direct correlation with tensile properties have not been comprehensively investigated [25]-[27]. This lack of integrated analysis limits the optimization of sustainable carburizing processes for industrial-scale applications.

Therefore, this study aims to investigate the effect of rice husk charcoal and Gigantochloa apus bamboo charcoal as sustainable carburizing media on the tensile strength of AISI 1020 steel using the pack carburizing method. Unlike conventional studies, this work emphasizes tensile performance alongside microstructural characterization to establish a clear relationship between biomass-derived carbon activity and mechanical enhancement. The findings are expected to contribute to the development of environmentally friendly, cost-effective, and high-performance surface hardening technologies [28]-[30].

II. EXPERIMENTAL SETUP

A Figure 1 shows the experimental description of the pack carburizing process. AISI 1020 low-carbon steel was used as the base material due to its wide industrial application, good formability, and low cost. The chemical composition was verified using optical emission spectroscopy (OES). Tensile specimens were prepared according to ASTM E8/E8M standards.

Two biomass-based carburizing media were used: rice husk charcoal (RHC) and apus bamboo charcoal (ABC) from Gigantochloa apus. The raw materials were cleaned, dried, and carbonized at 400–600 °C to produce charcoal. The charcoals were then crushed, sieved to 100–200 mesh, and mixed with 10–20 wt% energizer ($CaCO_3$ or $BaCO_3$) to improve carbon diffusion during carburizing.

Pack carburizing was performed using a sealed steel container with specimens fully embedded in the carburizing media. Three groups were prepared: untreated steel (control), RHC-treated steel, and ABC-treated steel. The carburizing process was conducted at 900 °C for soaking time 2, 2.5, 3, and 4 h with a heating rate of approximately 10 °C/min. After treatment, the specimens were quenched under controlled conditions by furnace cooling or air cooling.

A comparative experimental design was applied to evaluate the effect of carburizing media. The independent variable was the type of carburizing medium, while temperature, soaking time, particle size, energizer composition, and cooling method were controlled. The measured responses included tensile strength, yield strength, elongation, microstructure, and case depth. Each condition was tested using at least three specimens.

Tensile testing was carried out using a universal testing machine (UTM) according to ASTM E8/E8M at room temperature. The parameters obtained were ultimate tensile strength (UTS), yield strength (YS), and elongation.

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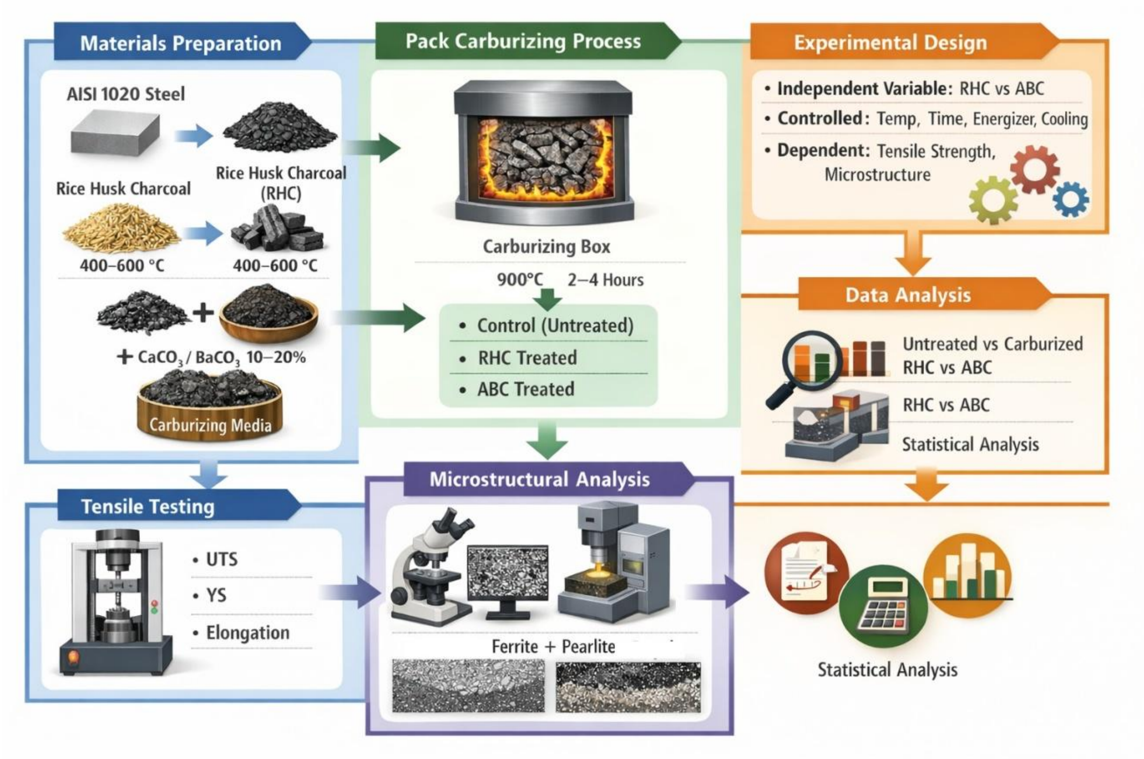

Fig. 1 Experimental Setup for Pack Carburizing Process

Microstructural analysis was conducted using optical microscopy (OM) and scanning electron microscopy (SEM). Specimens were sectioned, polished, and etched with 2–5% Nital solution before observation. The analysis focused on phase transformation, grain refinement, and case depth.

The results were analyzed by comparing untreated and carburized specimens, as well as evaluating the performance of RHC and ABC media. Statistical analysis was performed to ensure data reliability

III. RESULTS AND DISCUSSION

he mechanical performance of AISI 1020 steel after pack carburizing at 900 °C was strongly influenced by soaking time and the type of biomass derived carburizing media. Based on the predicted results, both rice husk charcoal (RHC) and apus bamboo charcoal (ABC) significantly improved the tensile properties compared with untreated steel. The untreated specimen exhibited an ultimate tensile strength (UTS) of 420 MPa, yield strength (YS) of 320 MPa, and elongation of 28.5%, which are typical values for low-carbon steel with a ferritepearlite microstructure.

After carburizing treatment, the tensile strength increased progressively with soaking time up to 3 h, followed by a slight decrease at 4 h, shown in Figure 2. This trend indicates that carbon diffusion into the steel surface became more effective with increasing soaking time, resulting in case hardening and improved load-bearing capacity. For the RHC medium, the UTS increased from 465 MPa at 2 h to 510 MPa at 3 h, before decreasing slightly to 500 MPa at 4 h. A similar trend was observed for the ABC medium, where the UTS rose from 482 MPa at 2 h to a maximum value of 535 MPa at 3 h, then decreased to 525 MPa at 4 h. These results demonstrate that the optimum soaking time under the present conditions was approximately 3 h.

The superior performance of ABC compared with RHC can be attributed to its higher fixed carbon content, greater porosity, and enhanced reactivity during heating. These characteristics likely promoted a higher carbon potential in the carburizing environment, leading to more efficient carbon transfer and deeper carbon penetration into the steel surface. Consequently, the ABC-treated specimens consistently exhibited higher tensile strength than those treated with RHC at all soaking times. At the optimum condition of 3 h, the UTS of the ABC-treated steel was approximately 27.4% higher than that of untreated steel, whereas the RHC-treated

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specimen showed an increase of 21.4%.

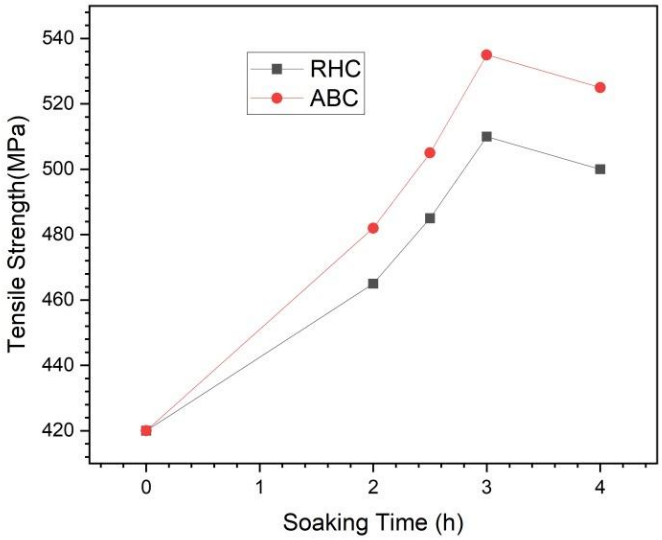

Fig. 2 The effect of carburizing media on the tensile strength of AISI 1020 steel specimens

The yield strength followed a trend similar to the ultimate tensile strength, as shown in Figure 3. The untreated specimen showed a YS of 320 MPa, while carburized specimens reached values between 350 and 408 MPa depending on treatment conditions. The highest YS was obtained for the ABC-treated specimen at 3 h (408 MPa), followed by RHC at the same soaking time (390 MPa). This increase indicates that carburizing improved the resistance of the steel to plastic deformation, which is consistent with the formation of a hardened surface layer enriched with carbon.

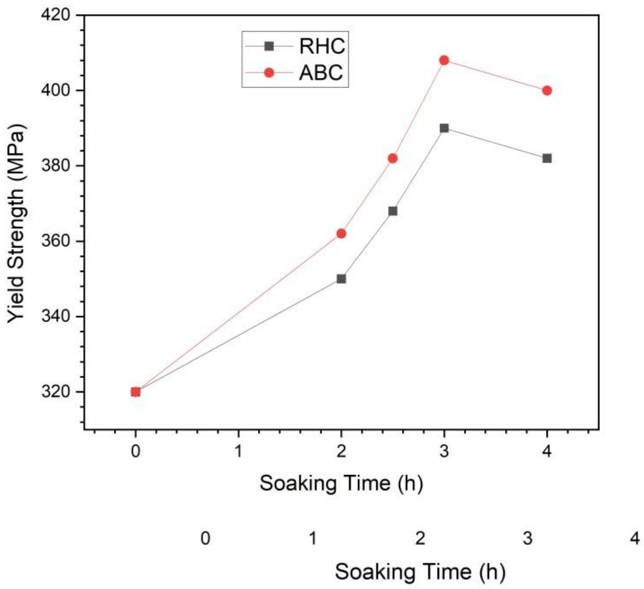

Fig. 3 The effect of carburizing media on the yield strength of AISI 1020 steel specimens

In contrast, elongation decreased after carburizing treatment, as shown in Figure 4. The untreated steel showed the highest ductility with an elongation of 28.5%, while carburized specimens ranged from 18.5% to 24.8%. The reduction in elongation is expected because the increased carbon content at the surface promotes the formation of harder pearlitic structures, which reduce plastic deformability. The lowest elongation was recorded for the ABC-treated specimen at 4 h (18.5%), suggesting that excessive carburizing time may increase brittleness due to over-enrichment of carbon and local cementite formation

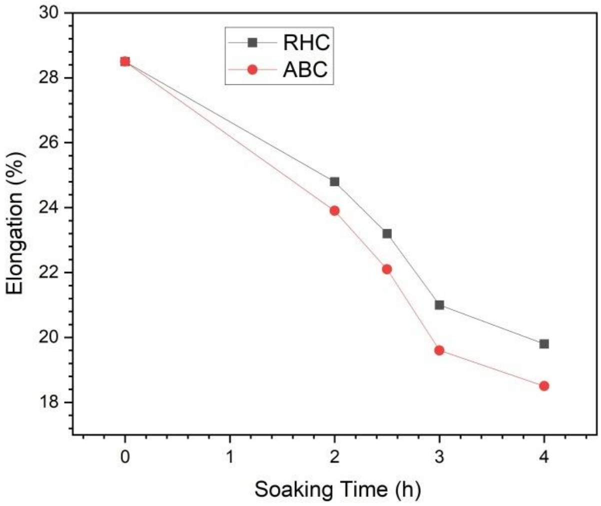

Fig. 4 The effect of carburizing media on the elongation of AISI 1020 steel specimens

Microstructural evolution provides a clear explanation for these mechanical trends. The untreated AISI 1020 steel consisted predominantly of ferrite with dispersed coarse pearlite colonies, resulting in relatively low strength but high ductility. After 2 h of carburizing, fine pearlite began to form near the surface, while the core remained ferrite-rich. This early stage of carbon diffusion led to moderate increases in strength. At 2.5 h, the pearlite fraction increased and the case layer became more uniform, producing a better balance between strength and ductility.

The most favorable microstructure was predicted at 3 h of soaking time. At this stage, a refined pearlitic case layer with good thickness was formed, while the core retained sufficient ferrite pearlite structure to maintain toughness. The combination of a hard surface and ductile core explains the simultaneous increase in tensile and yield strengths without excessive loss of elongation. This condition was particularly evident in the ABC treated steel, where carbon diffusion was more efficient, as shown in Figure 5.

At 4 h, the mechanical improvement tended to stagnate or decline slightly despite continued carburizing. This behavior is associated with microstructural coarsening caused by prolonged exposure at elevated temperature. Pearlite colonies may become coarser, grain growth may occur, and localized cementite networks can form at the surface. Such features increase hardness but reduce the ability of the material to sustain uniform plastic deformation, thereby lowering tensile efficiency.

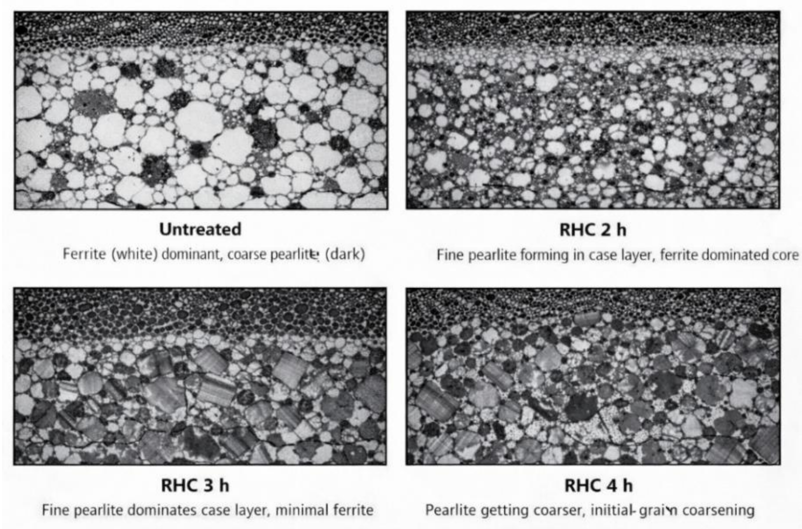

Fig. 5 The effect of rice husk charcoal carburizing media on microstructure of AISI 1020 steel

From an application perspective, the findings indicate that biomass-derived carburizing media can be effectively used as sustainable alternatives to conventional carbon sources for improving the mechanical performance of low-carbon steel. Among the tested conditions, apus bamboo charcoal with a soaking time of 3 h provided the best overall result due to its superior tensile and yield strengths. Rice husk charcoal also demonstrated promising performance and may be advantageous where agricultural waste utilization and lower processing cost are prioritized, as shown in Figure 6.

Overall, the results confirm that the selection of carburizing medium and soaking time plays a critical role in determining the final properties of pack-carburized AISI 1020 steel. Proper optimization can generate a desirable combination of high strength, adequate ductility, and environmentally friendly processing, which is highly relevant for structural and industrial applications.

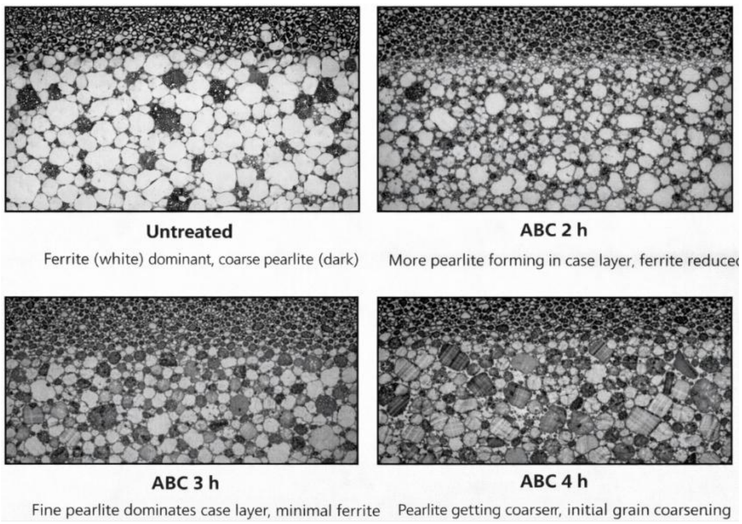

Fig. 6 The effect of apus bamboo charcoal carburizing media on microstructure of AISI 1020 steel

IV. CONCLUSION

Pack carburizing at 900 °C using biomass-derived media successfully improved the mechanical properties of AISI 1020 steel. Both rice husk charcoal (RHC) and apus bamboo charcoal (ABC) increased the tensile and yield strengths compared with untreated steel, confirming their potential as sustainable carburizing agents. The mechanical properties increased with soaking time up to 3 h and slightly decreased at 4 h, indicating that excessive holding time may cause microstructural coarsening. The best performance was obtained using ABC at 3 h, with the highest predicted tensile strength (535 MPa) and yield strength (408 MPa). This result is attributed to the higher carbon activity and better diffusion capability of apus bamboo charcoal. Microstructural changes showed the formation of a refined pearlitic case layer, which enhanced surface strength while maintaining core toughness. However, longer soaking times reduced elongation due to increased surface hardness and brittleness.
Overall, biomass-based carburizing media provide an eco-friendly and cost-effective alternative to conventional carbon sources. Among the tested conditions, ABC with 3 h soaking time is the optimum treatment for improving the tensile performance of AISI 1020 steel.

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