International Journal of Industrial Innovation and Mechanical Engineering

E-ISSN .: 3047-4515
P-ISSN .: 3047-4507

Research Article

Biomass-Derived Surface Engineering of AISI 1020 Steel for Electromedical Applications

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Abstract: This study investigates biomass-derived surface engineering of AISI 1020 steel for electromedical applications using galam wood charcoal and chicken bone waste as carburizing media. Surface modification is required to improve the mechanical performance of low-carbon steel, particularly in applications that demand high wear resistance and long-term durability. A pack carburizing approach was applied using various ratios of biomass-derived media at a treatment temperature of 800 °C for 2 hours. Chemical composition was analyzed using Optical Emission Spectroscopy (OES), surface hardness was evaluated using Micro Vickers hardness testing, and microstructural characteristics were observed using optical microscopy. The results show a significant increase in surface carbon content with increasing fractions of chicken bone powder, indicating its effectiveness as a carbon donor and diffusion promoter. The surface hardness increased from approximately 150 HV in the untreated condition to a maximum of about 860 HV in the treated specimen. Microstructural observations revealed the formation of a distinct carburized layer with increasing thickness and uniformity, consistent with enhanced carbon diffusion and surface strengthening. These findings demonstrate that biomass-derived surface engineering provides an effective and sustainable approach for improving the surface properties of low-carbon steel. The proposed method offers strong potential for environmentally friendly manufacturing of durable and reliable electromedical components.

Keywords: AISI 1020 Steel, Biomass-Derived Materials, Carburizing, Electromedical Applications, Surface Engineering.

Received: January 12, 2026
Revised: January 28, 2026
Accepted: February 03, 2026
Online Available: February 07, 2026
Curr. Ver.: February 07, 2026

1. Introduction

Electromedical devices require metallic components with adequate mechanical strength, structural stability, and durability to ensure reliable performance during prolonged service and repeated sterilization processes (Lee et al., 2025). In many electromedical systems, structural steels are still utilized in supporting and non-critical components due to their good machinability, availability, and cost efficiency. Among these materials, AISI 1020 steel is widely applied because of its balanced mechanical properties and ease of fabrication (Adawiyah et al., 2024). Nevertheless, the relatively low surface hardness and limited surface durability of untreated AISI 1020 steel restrict its performance in applications that demand enhanced surface properties (Robittah et al., 2025; Ramli et al., 2021; Hassan et al., 2020).

DOI : https://doi.org/10.61132/ijiime.v3i1.387

Surface engineering is an effective strategy to improve the functional performance of metallic materials without significantly altering their bulk characteristics (Lichioiu, 2022). By modifying only the surface layer, improvements in hardness and structural stability can be achieved while maintaining the toughness of the core material (Robittah et al., 2025 ; (Ramli et al., 2021a). Conventional surface treatment techniques often rely on industrial chemicals and energy-intensive processes, which may raise economic and environmental concerns. Consequently, there is increasing interest in developing alternative surface engineering approaches that are both technically effective and environmentally sustainable.

Biomass-derived materials have emerged as promising candidates for sustainable surface engineering applications (Sinarep & Darmo, 2021a). Agricultural and forestry wastes can be processed into carbon-rich or mineral-containing media that are suitable for surface modification processes (Darmo et al., 2021). In Indonesia, biomass resources such as galam wood charcoal and chicken bone waste are abundantly available but remain underutilized. Galam wood charcoal is characterized by its high carbon content, while chicken bone waste contains mineral constituents that may influence surface reactions during thermal treatment. The utilization of these locally available materials offers potential benefits in terms of sustainability, cost reduction, and resource efficiency (Adawiyah et al., 2024; Robittah et al., 2025; Karim et al., 2022).

Several previous studies have reported that biomass-based surface treatments can enhance the surface properties of low-carbon steels by promoting microstructural evolution near the surface (Sinarep & Darmo, 2021; Rafi, 2024; Achmadi et al., 2025). Changes in surface chemistry and thermal exposure during treatment may result in increased hardness and improved structural features. However, most existing studies focus on conventional mechanical characterization or specific treatment methods, while comprehensive evaluations that simultaneously correlate chemical composition, surface hardness, and microstructural characteristics—particularly for electromedical applications—are still limited.

Chemical composition is a fundamental factor governing the response of steel to surface engineering processes (Robittah et al., 2025). Optical Emission Spectroscopy (OES) is commonly employed to verify material composition and ensure conformity with standard specifications prior to and after surface modification. In addition, hardness testing provides quantitative information on the strengthening effects induced at the surface, while microstructural observation using optical microscopy enables direct assessment of structural changes that govern material behavior (Lichioiu, 2022). An integrated evaluation of these parameters is essential to understand the effectiveness of biomass-derived surface engineering on AISI 1020 steel. Therefore, this study aims to investigate biomass-derived surface engineering of AISI 1020 steel for electromedical applications by analyzing its chemical composition, surface hardness, and microstructural characteristics.

2. Literature Review

Biomass-Based Carburizing Media

The utilization of biomass-derived materials as carburizing media has attracted increasing attention due to their environmental sustainability, low cost, and wide availability. Various studies have demonstrated that agricultural and organic wastes, such as coconut shell, eggshell, oyster shell, and animal bone, can serve as effective carbon sources and catalytic agents in pack carburizing processes. Sinarep & Darmo, (2021) reported that chicken eggshell powder, which is rich in calcium carbonate, significantly enhances carbon diffusion and improves the mechanical properties of carburized AISI 9310 steel. Similarly, Rafi, (2024) demonstrated that pearl oyster shell-based nanocatalysts promote surface carbon enrichment and lead to notable improvements in hardness and wear resistance in low-carbon steels.

Animal bone waste has also been widely investigated as a promising carburizing catalyst due to its high calcium oxide (CaO) content after thermal decomposition. Achmadi et al., (2025) showed that mussel shells and peanut shells can accelerate carbon diffusion and promote the formation of fine-grained martensitic structures during the pack carburizing of AISI 1020 steel. The presence of CaO was found to increase surface reactivity and facilitate carbon transport into the steel matrix. Similar findings were reported by Karim et al., (2022), who observed that Na_2CO_3 and $CaCO_3$ catalysts significantly enhance the carburizing efficiency and mechanical performance of AISI 1020 steel.

From a sustainability perspective, the replacement of conventional coal-based carburizing agents with biomass-derived media offers substantial environmental benefits. Biomass materials reduce dependence on fossil-based resources and contribute to waste valorization by transforming organic residues into functional engineering materials (Sinarep & Darmo, 2021; Shell et al., 2022) .These studies collectively indicate that biomass-based carburizing media are not only technically feasible but also environmentally advantageous for surface engineering applications.

Surface Engineering of Low-Carbon Steel

Surface engineering of low-carbon steel has been extensively explored as an effective approach to overcome the inherent limitations of low surface hardness and wear resistance. Traditional techniques such as gas carburizing, plasma carburizing, nitriding, and laser surface treatment have been reported to significantly improve surface properties. For instance, Lichioiu, (2022) demonstrated that pack carburizing treatment enhances the surface hardness and microstructural refinement of 1.7131 steel through carbon diffusion and martensitic transformation. Similarly, Park et al., (2023) reported that carburization improves the microstructure and weldability of stainless steel by modifying near-surface phase characteristics.

In the context of low-carbon steels, Ramli et al., (2021) showed that natural shell powders used in extended carburization processes produce substantial hardness improvements and refined microstructures. Achmadi et al., (2025) further confirmed that organic waste-based carburizing media enhance not only mechanical strength but also corrosion and fatigue performance of AISI 1020 steel. These results indicate that surface engineering plays a critical role in improving the functional performance of low-carbon steels without altering their bulk properties.

However, despite the effectiveness of conventional surface treatments, most existing studies focus primarily on mechanical performance indicators, such as hardness and wear resistance, while neglecting the integrated relationship between chemical composition, microstructural evolution, and surface mechanical behavior. Moreover, many surface engineering studies are conducted in the context of general mechanical or industrial applications, with limited emphasis on specific functional requirements for electromedical components.

3. Materials and Method

Material and Surface Engineering Approach

This study employed AISI 1020 low-carbon steel as the base material due to its widespread use in engineering applications and its suitability for surface modification. The steel specimens were prepared with uniform geometry to ensure consistency during chemical analysis, hardness evaluation, and microstructural observation. Biomass-derived materials, namely galam wood charcoal and chicken bone waste, were utilized as surface engineering media to explore an environmentally sustainable approach to surface modification using locally available resources. The chemical composition of AISI 1020 steel is attached in Table 1.

Tabel 1. Chemical composition of AISI 1020 steel.

Element	C (%)	Mn (%)	P (%)	Si (%)	Fe (%)
AISI 1020	0,18-0.23	0.30-0.60	0.035	0.15-0,35	98

Surface Treatment Conditions

Surface engineering was performed through a pack carburizing process using mixed biomass-derived media. Galam wood charcoal and chicken bone powder were combined at different ratios to investigate their influence on surface modification behavior. The steel specimens were completely embedded in the carburizing media and subjected to thermal treatment at 800 °C for 2 hours. This temperature and holding time were selected to promote surface modification while preserving the bulk properties of the steel. Rapid cooling was applied after the thermal process to retain the modified surface characteristics.

Characterization Techniques

Chemical composition analysis was conducted using Optical Emission Spectroscopy (OES) to evaluate elemental composition and to identify changes associated with the surface engineering process, with particular emphasis on carbon content. Surface mechanical performance was assessed through Micro Vickers hardness testing. Hardness measurements were taken at multiple locations on the treated surface to obtain representative values and to minimize local variation effects. Microstructural characterization was carried out using optical microscopy. Metallographic preparation followed standard procedures to reveal surface-related microstructural features. The microstructural observations focused on identifying morphological changes and phase characteristics induced by the biomass-derived surface engineering process.

The combined results from chemical composition analysis, surface hardness testing, and microstructural observation were systematically analyzed and correlated to evaluate the effectiveness of biomass-derived surface engineering in enhancing the surface characteristics of AISI 1020 steel for electromedical applications.

4. Results and Discussion

Surface Carbon Content

Optical Emission Spectroscopy (OES) analysis indicates that carburizing treatment using galam wood charcoal and chicken bone powder significantly increased the surface carbon content of AISI 1020 steel. The surface carbon composition of AISI 1020 steel is presented in Table 2. The data show that the surface carbon content increases progressively with increasing fractions of chicken bone powder in the carburizing mixture. Specimen A1 (100% galam wood charcoal) exhibited an average surface carbon content of 0.55%, while specimen A2 (90% galam; 10% chicken bone) increased to 0.61%. Furthermore, specimens A3 and A4, containing 20% and 30% chicken bone powder, showed further increases to 0.80% and 0.83%, respectively. This trend indicates that chicken bone powder acts as an effective carbon donor during the carburizing process, enriching the steel surface with carbon required to enhance surface hardness and wear resistance.

Table 2. Surface carbon content of AISI 1020 steel.

Sample Code	**Galam Charcoal (%)**	**Chicen Bone (%)**	**Surface Carbon Content (%)**			**Averege Surface Carbon Content (%)**
A1	100	0	0,56	0,57	0,54	0,55
A2	90	10	0,63	0,61	0,59	0,61
A3	80	20	0,79	0,81	0,81	0,80
A4	70	30	0,84	0,80	0,86	0,83

The obtained results are consistent with the findings of Achmadi et al., (2025), who reported that carbon-rich media and CaO derived from animal bones can accelerate carbon diffusion during the carburizing process and promote the formation of fine-grained martensitic structures. In the present study, the combination of local biomass in the form of galam wood charcoal and chicken bone waste produced surface carbon levels comparable to, or even higher than, those achieved using conventional coal- and calcium carbonate-based carburizing media, as reported by Satria et al., (2019) This advantage indicates that biomass-based media not only have the potential to replace synthetic carburizing agents but also offer improved efficiency and quality of carburizing performance (Sinarep & Darmo, 2021a). In addition, the utilization of local materials such as galam wood and chicken bone waste provides added value in terms of sustainability and cost efficiency.

Surface Hardness Characteristics

Figure 1 shows that carburizing treatment significantly improves the surface hardness of AISI 1020 steel. The initial hardness of the untreated steel (TP) was approximately 150 HV. After carburizing treatment using galam wood charcoal and various fractions of chicken bone powder as a catalyst, the surface hardness increased substantially. The specimen treated without catalyst (0%) exhibited a hardness of approximately 670 HV. The addition of chicken bone powder at 10%, 20%, and 30% resulted in surface hardness values of approximately 740 HV, 790 HV, and a maximum of 860 HV, respectively. This trend clearly indicates that the catalyst fraction has a direct influence on enhancing the effectiveness of the carburizing process. These results are consistent with previous studies emphasizing the role of carbon and CaO in strengthening steel microstructures. Sinarep & Darmo, (2021) reported that carbon and CaO derived from animal bones promote the formation of fine-grained martensitic structures, leading to high hardness values. In addition, Achmadi et al.,(2025) also reported that the use of organic-based carburizing agents produces significant hardness improvement in low-carbon steels.

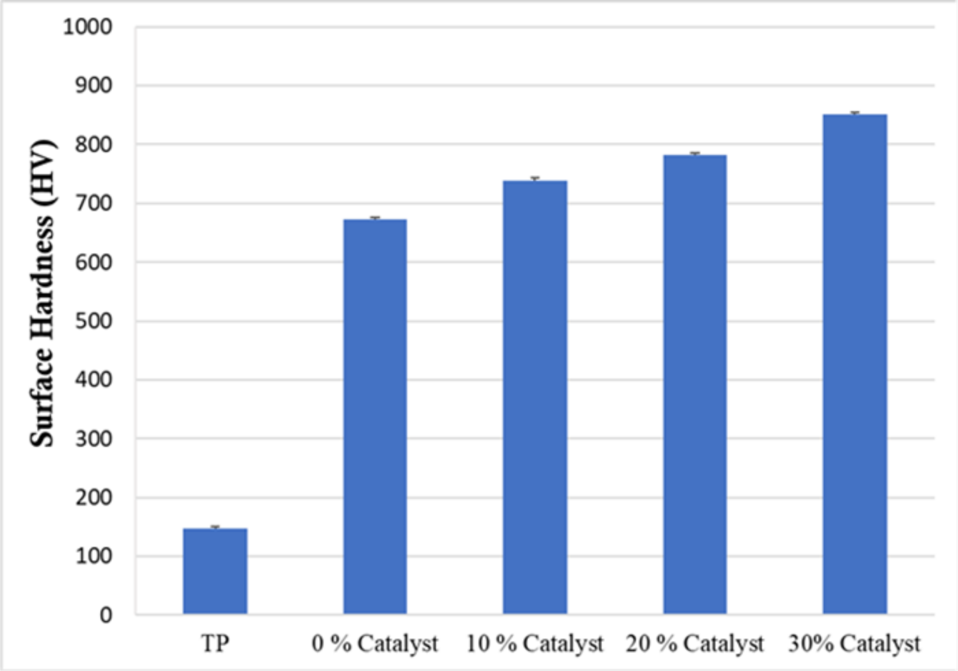

Figure 1. Surface hardness of AISI 1020 steel before and after carburizing treatment.

The more than fivefold increase in surface hardness compared to the untreated condition demonstrates that the combined use of galam wood charcoal and chicken bone waste is not only effective but also offers a sustainable alternative for steel surface engineering. These findings are particularly significant for electromedical component applications, where high surface hardness is required to withstand wear and mechanical stresses under precise and long-term operating conditions.

Microstructural Analysis

Figure 2 presents the cross-sectional microstructures of AISI 1020 steel after carburizing treatment using different ratios of galam wood charcoal and chicken bone powder (A1–A4). The micrographs reveal distinct microstructural variations between the surface region and the interior of the specimens, indicating the occurrence of surface modification induced by the biomass-derived carburizing process.

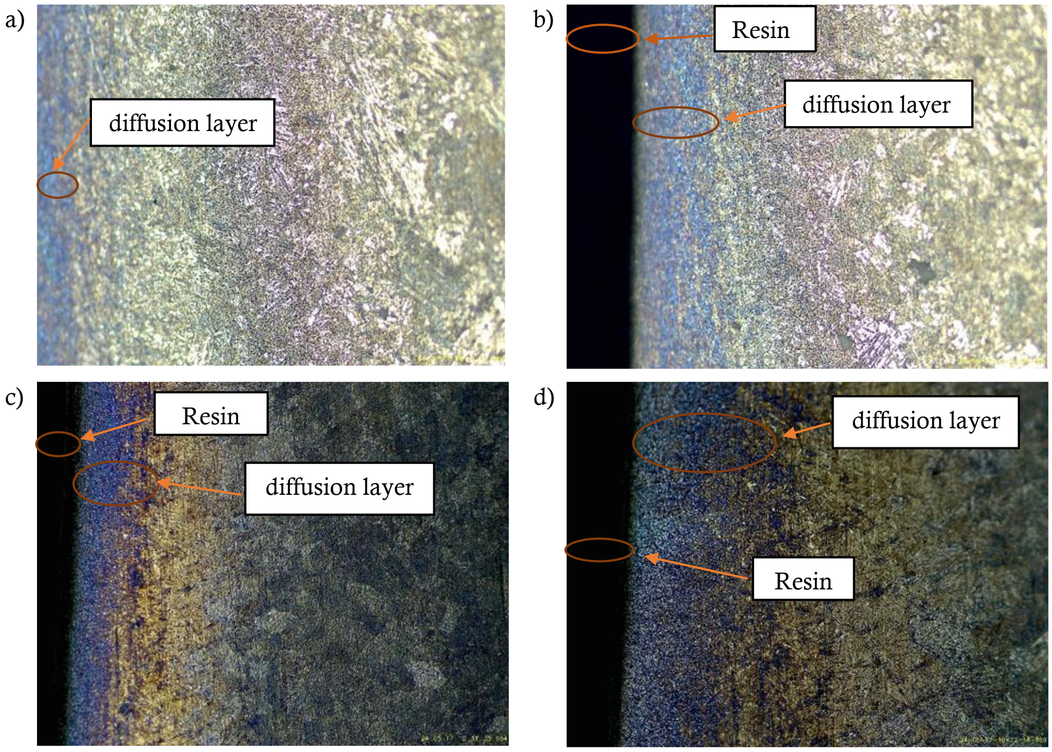

Figure 2. Cross-sectional microstructures of AISI 1020 steel after carburizing treatment using different ratios of galam wood charcoal and chicken bone powder: (a) A1, (b) A2, (c) A3, and (d) A4.

In specimen A1, which was treated using 100% galam wood charcoal, the surface region exhibits a relatively thin modified layer with limited contrast compared to the substrate. The microstructure near the surface shows refinement relative to the core material; however, the transition between the modified surface and the base metal remains gradual. This observation suggests that carbon diffusion occurred but was limited in depth and intensity when galam wood charcoal was used without additional catalytic components (Lichioiu, 2022; Karim et al., 2022). For specimens A2 and A3, which contain increasing fractions of chicken bone powder (10% and 20%, respectively), the surface-modified layer becomes more pronounced. A clearer contrast between the carburized surface zone and the substrate is observed, indicating enhanced carbon diffusion into the steel matrix. The microstructural features near the surface appear denser and more refined, suggesting the formation of harder transformation products as a result of increased carbon availability during the carburizing process (Robittah et al., 2025; Park et al., 2023).

The most significant microstructural modification is observed in specimen A4, treated with 30% chicken bone powder. The cross-sectional micrograph reveals a thicker and more uniform surface-modified layer with a sharp transition boundary relative to the core material. This indicates a more effective diffusion process and a higher degree of surface transformation. The enhanced surface contrast and refinement are consistent with the elevated carbon content and surface hardness measured in this specimen (Achmadi et al., 2025). The observed microstructural evolution across specimens A1–A4 correlates well with the OES and hardness results. The progressive increase in surface carbon content promotes the formation of carbon-enriched microstructures near the surface, which are known to enhance hardness and wear resistance. The presence of calcium-based compounds, such as CaO derived from chicken bone waste, is believed to facilitate carbon diffusion by increasing surface reactivity and promoting carbon transport during the carburizing process.

Overall, the microstructural observations confirm that the combination of galam wood charcoal and chicken bone waste effectively modifies the surface layer of AISI 1020 steel. The formation of a distinct carburized layer with increasing thickness and uniformity supports the significant improvement in surface hardness reported earlier. These microstructural changes are particularly relevant for electromedical applications, where enhanced surface durability is essential to withstand repeated mechanical loading and long-term service conditions.

5. Conclusion

This study demonstrates that biomass-derived surface engineering using galam wood charcoal and chicken bone waste effectively enhances the surface properties of AISI 1020 steel. OES analysis confirmed a significant increase in surface carbon content with increasing fractions of chicken bone powder, indicating its critical role as a carbon donor and diffusion promoter. The carbon enrichment was directly correlated with a substantial improvement in surface hardness, which increased from approximately 150 HV in the untreated steel to a maximum of about 860 HV in the treated specimen. This result indicates that biomass-based carburizing media can provide strengthening performance comparable to, or even exceeding, conventional synthetic carburizing agents. Microstructural observations revealed the formation of a distinct and increasingly uniform carburized layer near the surface, consistent with enhanced carbon diffusion and transformation behavior. These microstructural changes explain the significant improvement in mechanical performance observed after treatment.

Overall, the combination of galam wood charcoal and chicken bone waste offers a sustainable and high-performance approach for surface engineering of low-carbon steel. The proposed method not only improves surface durability but also utilizes locally available biomass and organic waste, making it a promising solution for environmentally friendly manufacturing of electromedical components.

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