Comparative Evaluation of Impact Toughness of Leaf Spring Steel Before and After The Carburizing Process Using Various Natural Carbon Media

Agus Yanto[1]*, Suhardiman[2], Irwan kurniawan[3]

[1]Student of the Applied Bachelor Program in Mechanical Engineering, Production and Maintenance, Department of Mechanical Engineering, Politeknik Negeri Bengkalis, Indonesia
[2,3]Thesis Supervisor, Department of Mechanical Engineering, Politeknik Negeri Bengkalis, Indonesia
Coresponden author:
Email: agusyanto@mhs.polbeng.ac.id

Abstract.
Leaf spring steel is a key component of vehicle suspension systems that operates under dynamic loading and repeated impact loads, requiring adequate impact toughness. This study aims to evaluate the effect of the pack carburizing process on the impact toughness of leaf spring steel using three types of natural carbon media, namely coconut shell charcoal, palm shell charcoal, and mangrove wood charcoal. Carburizing was carried out at a temperature of 920°C with a holding time of 30 minutes, followed by oil quenching. Testing was performed using the Charpy impact test method in accordance with ASTM E23 on specimens before and after carburizing, supported by visual observation of the fracture surfaces. The results show that the specimen before carburizing had the highest average impact value of 0.18 J/mm². After carburizing, all specimens showed a decrease in impact value, with coconut shell charcoal producing the highest value (0.11 J/mm²; a 38.89% decrease), followed by palm shell charcoal (0.05 J/mm²; a 72.22% decrease), while mangrove wood charcoal produced the lowest value (0.03 J/mm²; an 83.33% decrease). Fracture surface observations revealed a shift from ductile fracture before carburizing to a mixed fracture tending toward brittleness after carburizing. Coconut shell charcoal was shown to provide the best balance between increased surface hardness and retained impact toughness of leaf spring steel.
Keywords: *Leaf spring steel; pack carburizing; carbon media; impact toughness and Charpy test..*

I. INTRODUCTION

spring steel is one of the main components of vehicle suspension systems, particularly in trucks, buses, and commercial vehicles that operate under dynamic loading conditions. This component supports the vehicle load, absorbs vibrations caused by uneven road surfaces, and maintains vehicle stability during operation. During service, leaf springs experience cyclic loading and impact loading, which can lead to material fatigue and eventual cracking or fracture if the mechanical properties are inadequate (Callister & Rethwisch, 2020).

One commonly used method to increase the surface hardness of steel is pack carburizing, a process of adding carbon to the surface layer through carbon diffusion at high temperature, followed by quenching to form a martensitic structure (Davis, 2020). Several previous studies have shown that this process effectively increases hardness but may reduce toughness. Ramadhan and Sunyoto (2022) reported an increase in the hardness of EMS 45 steel with increasing pack carburizing temperature, while Ghifari and Mahyoedin (2024) found that the impact absorption energy of AISI 1040 steel changed due to the formation of martensite and cementite distribution after carburizing. Hibatulloh (2025) further confirmed that an excessively long holding time reduces toughness due to the dominance of martensitic structure and increased residual stress, while Darmo et al. (2022) showed that the quenching medium also determines the balance between hardness and toughness.

Although research on pack carburizing has been widely conducted, most studies have focused on low-carbon steel and general structural steel, while specific studies on the effect of natural carbon media on the impact toughness of leaf spring steel remain relatively limited. Leaf spring steel operates under dynamic loading and receives repeated impact loads, making its impact toughness a critical parameter that must be evaluated after surface treatment.

This study aims to evaluate the comparison of impact toughness values of leaf spring steel before and after the pack carburizing process, to analyze the effect of three types of natural carbon media (coconut shell charcoal, palm shell charcoal, and mangrove wood charcoal) on impact toughness, and to determine the carbon medium that produces the best results. Natural carbon media were selected due to their abundant availability, economical cost, and potential for utilizing local biomass waste in Indonesia. The results of this study are expected to provide technical recommendations for the automotive and manufacturing industries in selecting an appropriate carburizing medium for leaf spring components.

II. RESEARCH METHOD

study employed an experimental method, in which direct treatment was applied to the test specimens to determine the effect of the pack carburizing process on the impact toughness of leaf spring steel. The research was conducted at the Materials Testing Laboratory of Politeknik Negeri Bengkalis.

2.1 Materials and Equipment

test material used was leaf spring steel, whose chemical composition was examined beforehand at the Laboratory of the Materials and Engineering Goods Conformity Assessment Management Unit, Department of Industry, Trade, Cooperatives, and Small and Medium Enterprises of DKI Jakarta Province, using the JIS G1253:2002/Amd1:2013 method. The carbon media used in the pack carburizing process consisted of three types: coconut shell charcoal, palm shell charcoal, and mangrove wood charcoal, while oil was used as the quenching medium. The main equipment used included a furnace with a digital temperature controller, a carburizing box, a shaping machine for notching the specimens, a power hacksaw, a Charpy impact testing machine, vernier calipers, a microscope for fracture surface observation, and heat-resistant gloves as personal protective equipment.

2.2 Research Procedure

Leaf spring steel specimens were cut using a power hacksaw and then shaped through a milling process to reach the final dimensions specified by ASTM E23, namely a length of 55 mm, width of 10 mm, and height of 10 mm, with a V-notch. The specimens were divided into four groups: an untreated (control) group and three groups subjected to the pack carburizing process using each carbon medium at a temperature of 920°C with a holding time of 30 minutes. After carburizing, all specimens were rapidly cooled (quenched) using oil to form a martensitic structure in the surface layer. Four specimens were tested for each variation to obtain representative data.

2.3 Charpy Impact Testing

Impact toughness testing was performed using the Charpy method in accordance with ASTM E23, with an initial pendulum swing angle (θ) of 130°, an arm length (L) of 600 mm, and a hammer mass (M) of 8 kg. The parameters recorded included the initial angle (θ), the final angle after specimen fracture (α), notch dimensions (t and b), effective cross-sectional area (A), absorbed energy (E), and impact value (HI). The initial and residual pendulum energies were calculated using equations (1) and (2), while the impact value was calculated using equation (3).

$$E_0 = m \cdot g \cdot (l + l \cdot \sin\theta) \quad (1)$$

$$Er = m \cdot g \cdot (l - l \cdot \cos\alpha) \quad (2)$$

$$HI = E / A, \text{ where } E = E_0 - Er \quad (3)$$

where E_0 is the initial pendulum energy (J), Er is the residual pendulum energy (J), E is the energy absorbed by the specimen (J), A is the effective cross-sectional area at the notch (mm²), and HI is the impact value (J/mm²). The test data were analyzed using a descriptive quantitative approach by comparing the impact toughness values among specimen groups, supported by visual observation of the fracture surfaces to identify the fracture characteristics that occurred.

III. RESULTS AND DISCUSSION

3.1 Chemical Composition of Leaf Spring Steel

The chemical composition test results show that the material is predominantly composed of iron (Fe) at 97.5%, with a carbon (C) content of 0.416%, chromium (Cr) of 0.822%, manganese (Mn) of 0.810%, and silicon (Si) of 0.263%, as shown in Table 1. This carbon content places the material in the medium-carbon steel category, which offers a balance of strength, hardness, and toughness. Chromium and manganese contribute to improved hardenability and impact resistance, while silicon enhances the elastic strength of the material.

Element	C	Si	Mn	Cr	Mo	Ni	Fe	P	S
Content (wt.%)	0.416	0.263	0.810	0.822	0.029	0.0424	97.5	0.0192	0.0042

Table 1. Chemical Composition of Leaf Spring Steel (JIS G1253:2002/Amd1:2013)

3.2 Comparison of Impact Toughness Before and After Carburizing

Charpy impact testing was carried out on four specimens for each treatment variation to obtain representative absorbed energy and impact value (HI) data. The HI value was obtained from the difference between the initial and residual pendulum energy divided by the effective cross-sectional area at the notch, following equations (1)-(3). The average impact values for each specimen group are presented in Table 2 and Figure 1.

No	Specimen Group	Process Condition	Average Impact Value (J/mm²)	Change vs. Initial Specimen
1	Before carburizing	No treatment	0.18	-
2	Carburizing - coconut shell	920°C - 30 min - Oil	0.11	↓ 38.89%
3	Carburizing - palm shell	920°C - 30 min - Oil	0.05	↓ 72.22%
4	Carburizing - mangrove wood	920°C - 30 min - Oil	0.03	↓ 83.33%

Table 2. Comparison of Average Impact Values for Each Specimen Group

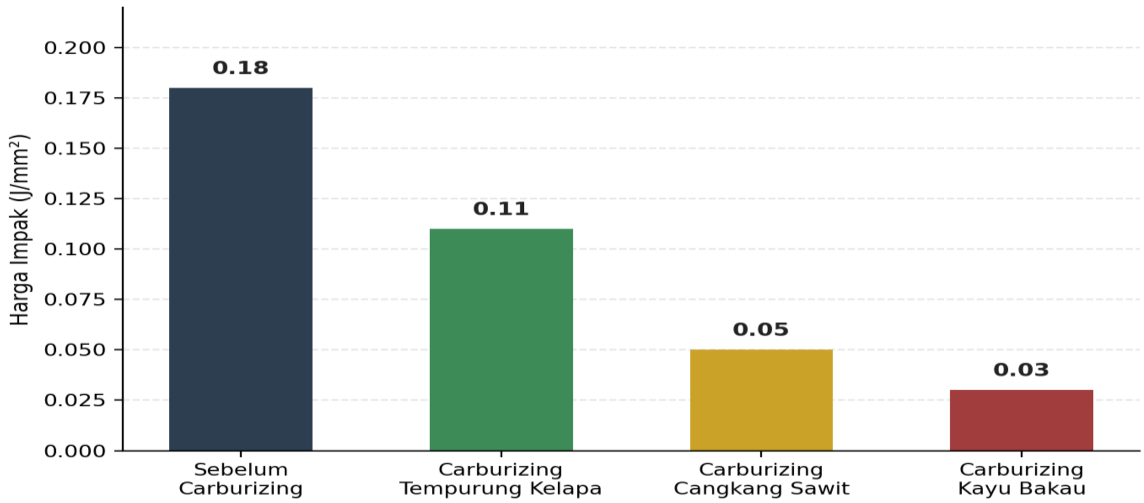

Fig. 1. Comparison Chart of Impact Values of Leaf Spring Steel Before and After Carburizing

Based on Table 2, the specimen before carburizing had the highest average impact value of 0.18 J/mm². After carburizing, all specimen variations showed a decrease in impact value. The specimen carburized with coconut shell charcoal had an average impact value of 0.11 J/mm², a 38.89% decrease compared to the specimen before carburizing. The specimen using palm shell charcoal produced a value of 0.05 J/mm² (a 72.22% decrease), while the lowest value was obtained with mangrove wood charcoal, at 0.03 J/mm² (an 83.33% decrease).

The decrease in impact value indicates that the material's ability to absorb shock energy decreased after the carburizing process. This is due to the diffusion of carbon atoms into the steel surface during carburizing, which forms a high-carbon surface layer. After oil quenching, this layer transforms into a martensitic structure with higher hardness than the original structure, reducing the material's ability to undergo plastic deformation before fracture and thus lowering its impact toughness (Bhadeshia & Honeycombe, 2022).

The difference in impact values across carbon media indicates that the type of carburizing medium influences the outcome of carbon diffusion. Coconut shell charcoal produced the highest impact value among the three media, indicating that the resulting carbon diffusion was able to increase surface hardness without excessively reducing the material's toughness. In contrast, palm shell and mangrove wood charcoal resulted in a greater reduction in toughness, indicating a higher tendency toward brittle fracture in specimens carburized with these two media.

3.3 Fracture Surface Characteristics

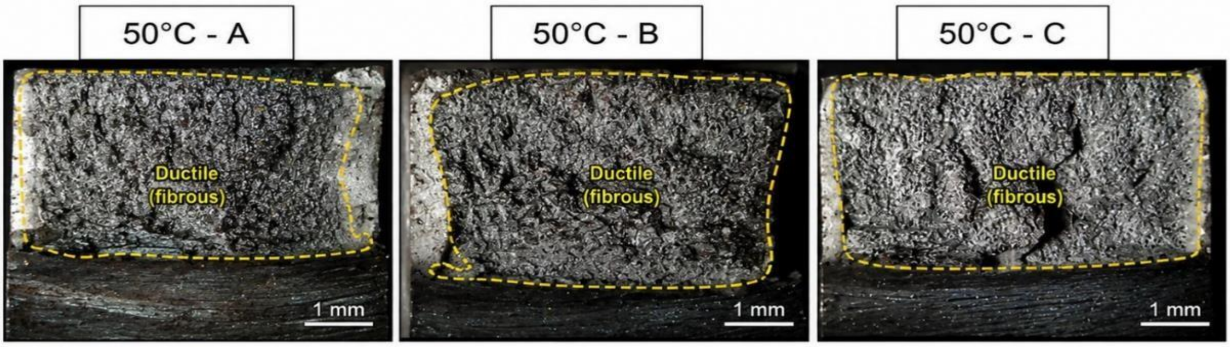

Figure 2. Fracture Surface of Leaf Spring Steel Specimens Before the Carburizing Process

Visual observation of the fracture surfaces supports the impact test results. Specimens before carburizing exhibited fracture surfaces dominated by fibrous regions with a rough, uneven texture, as shown in Figure 2, indicating a ductile fracture mechanism and a relatively high capacity of the material to absorb impact energy before failure.

In contrast, carburized specimens exhibited flatter and denser fracture surfaces compared to the initial specimen, although fibrous regions were still visible in some areas. This condition indicates a mixed fracture mechanism, a combination of ductile and brittle fracture, which is consistent with the decrease in impact values observed in all specimens after carburizing. The lower the impact value of a specimen, the greater the proportion of the flatter fracture surface, indicating an increasing tendency toward brittle fracture.

Overall, the results show that the pack carburizing process using coconut shell, palm shell, and mangrove wood charcoal had different effects on the impact toughness of leaf spring steel. Coconut shell charcoal provided the best performance in maintaining impact toughness after carburizing, while mangrove wood charcoal resulted in the greatest reduction in toughness. These findings confirm that the choice of carbon medium is an important factor in the pack carburizing process, as it affects the balance between increased surface hardness and the material's ability to absorb impact energy before fracture, in line with the findings of Ramadhan and Sunyoto (2022) and Nurharyanto et al. (2019), who reported that the type of carbon medium determines the effectiveness of the diffusion outcome in the pack carburizing process.

IV. CONCLUSION

Based on the research results, it can be concluded that the pack carburizing process affects the reduction of impact toughness of leaf spring steel. The specimen before carburizing had the highest impact toughness value of 0.18 J/mm², which decreased in all specimens after carburizing at 920°C for 30 minutes followed by oil quenching. The type of carbon medium was shown to have different effects on the final results: coconut shell charcoal produced the highest post-carburizing impact toughness (0.11 J/mm²; a 38.89% decrease), followed by palm shell charcoal (0.05 J/mm²; a 72.22% decrease), while mangrove wood charcoal produced the lowest value (0.03 J/mm²; an 83.33% decrease). Fracture surface observations supported these findings, showing a shift from ductile fracture to a mixed fracture tending toward brittleness after carburizing. Coconut shell charcoal proved to be the most effective pack carburizing medium in this study, as it was able to better maintain the impact toughness of leaf spring steel compared to the other two carbon media. Further research is recommended to examine variations in temperature and holding time, and to include hardness testing and microstructural observation (SEM), in order to gain a more comprehensive understanding of the relationship between carbon diffusion, microstructure, and the mechanical properties of leaf spring steel.

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