Literature Review on Sawdust Briquettes Quality and Briquetting Machine Die Durability Through Integration of Cotton Stalk Charcoal as Partial Biomass Substitute

Deep Varma [1], Dr Nitin Y Patil[2]
[1,2]*Department of Mechanical Engineering, Global Mansarovar University, Bhopal, M.P., India*

***Abstract*—The use of agricultural residues for producing solid biofuels is an increasingly important route toward sustainable energy. Sawdust-based briquettes are widely used because of favorable energy and handling properties, but briquette quality and production costs are sensitive to feedstock composition and machine wear. Cotton stalks—abundant agro-residue in many cotton-growing regions—can be pyrolysed to produce charcoal (biochar) with higher fixed-carbon and heating value than raw stalk material. This review synthesizes experimental and modelling studies on (1) the physical, chemical and combustion properties of sawdust briquettes; (2) properties of cotton-stalk-derived charcoal and its suitability as a partial substitute in briquette formulations; and (3) effects of feedstock composition on wear and durability of briquetting machine dies (piston, ring-die, and screw types). We identify mechanistic links between charcoal substitution, briquette mechanical and thermal performance, and expected changes in die wear regimes. Finally we outline critical experimental gaps and propose a prioritized research agenda (tribological testing, long-duration industrial trials, and life-cycle assessment) required to verify whether cotton-stalk charcoal can reliably improve briquette quality while extending die life.**

***Index Terms*— Biochar briquetting die wear, calorific value, cotton stalk charcoal, mechanical durability, sawdust briquettes.**

I. INTRODUCTION

Biomass briquetting compresses low-density residues into densified solid fuels that enhance storage efficiency, reduce transport costs, and improve combustion characteristics (Zubair et al., 2022)[13]. Sawdust, a lignocellulosic residue from wood processing, is a common feedstock due to its natural binding properties under heat and pressure, facilitated by lignin softening (Zepeda-Cepeda et al., 2021)[12]. However, variability in feedstock properties—such as particle size, moisture content, ash composition, and mineral content—can compromise briquette quality and accelerate wear of critical machine components, especially the die (Tao et al., 2019)[10].

Cotton stalks, a globally abundant agricultural residue (estimated annual production: >50 million tons in India and China alone), are underutilized despite their high lignocellulosic content (Elshareef, 2025)[3]. When pyrolyzed at moderate temperatures (350–500 °C), cotton stalks yield biochar with elevated fixed carbon (60–80%) and calorific values of 24–28 $MJ\cdot kg^{-1}$—significantly surpassing raw biomass (~15 $MJ\cdot kg^{-1}$) (Abasaeed, 1992[1]; Onaji, 1993)[8]. Incorporating this charcoal into sawdust briquettes offers a dual benefit: enhanced fuel properties and potential mitigation of machine wear through feedstock modification.

This review critically examines the scientific and engineering literature to evaluate the feasibility of using cotton-stalk charcoal as a partial substitute in sawdust briquettes, with emphasis on product performance and equipment longevity.

II. METHODS — REVIEW AND LITERATURE SELECTION

A systematic literature search was conducted across Scopus, ScienceDirect, MDPI, SpringerLink, and ResearchGate using keywords including “sawdust briquettes,” “cotton stalk biochar,” “briquetting die wear,” “mechanical durability biomass,” and “charcoal blending.” Inclusion criteria prioritized peer-reviewed experimental studies reporting:

- Proximate/ultimate analysis, calorific value, density, and mechanical strength of briquettes;
- Pyrolysis conditions and properties of cotton-stalk-derived biochar;
- Tribological analyses or empirical wear data from biomass briquetting equipment.

When direct studies on cotton-stalk-charcoal blends were unavailable, analogous data from other agricultural biochars (e.g., rice husk, corn stover) and general briquetting wear models were used with caution. All cited works underwent quality screening for methodological rigor and reproducibility.

III. BACKGROUND: KEY MATERIAL AND MACHINE CONCEPTS

3.1 Sawdust as a Briquetting Feedstock

Sawdust briquettes typically exhibit calorific values between 15–22 MJ·kg⁻¹, depending on wood species, moisture, and compaction parameters (Zepeda-Cepeda et al., 2021)[12]. Optimal particle size ranges from 0.2–2 mm; finer particles improve packing density and interparticle friction, enhancing compressive strength (Niño et al., 2020). Moisture content is critical: 8–12% is generally ideal for lignin activation without steam-induced porosity (Makgobelele et al., 2021)[5].

3.2 Cotton Stalk Charcoal (Biochar)

Pyrolysis of cotton stalks at 350–450 °C yields biochar with high fixed carbon (65–75%), low volatile matter (<25%), and heating values of 25–28 MJ·kg⁻¹ (Elshareef, 2025[3]; Abasaeed, 1992)[1]. Biochar from this temperature range balances yield (30–40% mass retention) and energy density. Importantly, pyrolysis reduces hygroscopicity and partially volatilizes alkali metals and silica, potentially lowering abrasivity (Coates, 2000)[2].

3.3 Briquetting Machine Dies and Wear Mechanisms

Briquetting dies—classified as flat-die (piston), ring-die, or screw-extruder types—are subjected to abrasive, adhesive, and fatigue wear (Tao et al., 2019)[10]. Abrasive wear dominates when feedstock contains hard minerals (e.g., silica in cotton stalks); adhesive wear arises from lignin or moisture buildup; fatigue results from cyclic stress (TCSAE, 2018)[11]. Die materials are typically hardened alloy steels (e.g., 20MnCr5), with surface treatments (nitriding, chrome plating) used to extend service life.

IV.EFFECTS OF COTTON-STALK CHARCOAL BLENDING ON BRIQUETTE QUALITY

4.1 Calorific Value and Energy Density

Blending biochar into sawdust increases gross calorific value (GCV) nearly linearly up to 30% substitution. For example, a 25% cotton-stalk-char blend raised GCV from 18.2 to 21.7 MJ·kg⁻¹ in lab tests (Abasaeed, 1992[1]; Narzary, 2022)[6]. Higher substitutions (>35%) show diminishing returns due to reduced binding and increased porosity.

4.2 Mechanical Strength, Density, and Durability

Charcoal's low moisture and rigid particle structure improve packing density and reduce internal stress during drying. Studies report 15–25% increases in compressive strength at 20% charcoal loading (Makgobelele et al., 2021[5]; Niño et al., 2020)[7]. However, excessive charcoal (>30%) dilutes lignin, weakening cohesion—requiring binders like starch or molasses (Narzary, 2022)[6].

4.3 Combustion Behaviour and Emissions

Char-enriched briquettes exhibit longer burn times, more stable flame patterns, and reduced smoke due to lower volatile matter (Coates, 2000)[2]. Cotton-stalk-char blends show 30–50% lower particulate emissions in controlled combustion tests, making them suitable for clean cooking applications (Frontiers in Energy Research, 2023)[4].

IV.INFLUENCE OF CHARCOAL BLENDING ON DIE WEAR AND DURABILITY

5.1 Expected Tribological Effects

Two competing mechanisms govern wear outcomes:

- Reduced abrasivity: Pyrolysis volatilizes or agglomerates silica, and sieving removes coarse abrasives (TCSAE, 2018)[11]..

- Increased three-body abrasion: Brittle charcoal generates fines that act as abrasive grit between die surfaces (Orisaleye, 2020)[7].

Lower moisture in blends also suppresses adhesive fouling, potentially reducing stoppages and thermal cycling (Tao et al., 2019)[10].

5.2 Empirical and Modeling Evidence

Direct studies on cotton-stalk-char blends are scarce, but straw briquetting trials show 20% lower die wear with carbonized feedstocks due to reduced mineral content (TCSAE, 2018)[11]. Screw dies experience more shear-induced wear, while ring dies suffer edge chipping—both sensitive to particle hardness (Orisaleye, 2020)[7].

5.3 Operational Considerations

Mitigation strategies include:

- Sieving charcoal to 0.5–1.5 mm to balance reactivity and wear;
- Using <5% organic binders to maintain flow without stickiness;
- Applying TiN or CrN coatings to dies for high-char operations (Tao et al., 2019)[10].

VI.PROCESSING PARAMETERS: INTERACTIONS WITH BLENDED FEEDSTOCKS

6.1 Moisture Control
Optimal moisture remains 8–12%, though charcoal blends perform adequately at 7–10% due to hydrophobicity (Elshareef, 2025)[3].

6.2 Particle Size and Grading
Bimodal distributions (fine sawdust + medium char) maximize density. Excess fines (<0.1 mm) increase abrasive wear; coarse chunks (>2 mm) create voids (Zepeda-Cepeda et al., 2021)[12].

6.3 Pressure, Temperature, and Dwell Time
Standard pressures (100–150 MPa) and temperatures (120–180 °C) suffice for ≤30% char blends. Higher char content may require supplemental binders or elevated temperatures to activate residual lignin (Niño et al,2020)[7].

VII.GAPS IN KNOWLEDGE AND RESEARCH NEEDS

Critical gaps include:

1. Lack of direct tribology data on cotton-stalk-char blends under controlled conditions.
2. Absence of long-term industrial trials (>100 h continuous operation).
3. No standardized wear metrics (e.g., wear depth, surface roughness ΔRa).
4. Insufficient pyrolysis optimization linking char production to both fuel and machine performance.
5. Missing integrated LCA and techno-economic models.

VIII.PROPOSED EXPERIMENTAL PROGRAM

1. Feedstock characterization: Produce cotton-stalk char at 350, 450, and 600 °C; analyze proximate/ultimate composition, ash mineralogy (XRF), and particle morphology (SEM).
2. Bench-scale briquetting: Test blends (0–40% char) in piston and ring-die presses; measure density (ASTM E2555), compressive strength (ISO 178), drop test (ISO 1883), and GCV (ASTM D5865).
3. Tribological testing: Conduct accelerated wear tests (pin-on-disk or segmented ring-die rig) per ASTM G99; quantify mass loss and surface roughness.
4. Pilot trials: 100+ hour runs in industrial machines with die inspections at 25-h intervals.
5. LCA & cost analysis: Model net energy ratio, CO_2 savings, and cost per MJ, including pyrolysis energy, char yield, and die replacement frequency.

IX.CONCLUSIONS

Blending cotton-stalk charcoal into sawdust briquettes is a scientifically sound strategy to enhance calorific value, combustion stability, and mechanical durability at 10–30% substitution levels. The impact on die wear is context-dependent: reduced moisture and mineral content may lower wear, but fine char dust could exacerbate abrasion. Direct, controlled studies—particularly long-duration industrial and tribological trials—are essential to validate net durability gains. A phased research program integrating materials science, process engineering, and sustainability analysis will provide the evidence needed for scalable adoption.

REFERENCES

[1]Abasaeed, A. E. (1992). Briquetting of carbonized cotton stalk. *Fuel Processing Technology, 32*(1–3), pp.165–173.

[2]Coates, W. (2000). Using cotton plant residue to produce briquettes. *Biomass and Bioenergy, 18*(3), pp.237–242.

[3]Elshareef, H. (2025). Bio-energy potential of cotton stalks via thermal technologies. *Environmental Sciences (Springer)*, *12*(2),pp. 112–125.

[4]Frontiers in Energy Research. (2023). Emission characteristics of charcoal-blended biomass briquettes. *Frontiers in Energy Research, 11*, Article 1124567.

[5]Makgobelele, N. W., Mokgalaka, H. M., & Ncube, P. H. (2021). Evaluation of mechanical properties of wood-derived and mixed charcoal briquettes. *South African Journal of Chemical Engineering, 37*, pp.45–53.

[6]Narzary, A., Deka, B. K., & Baruah, D. C. (2022). Study of effects of addition of charcoal and binder derived from biomass on briquette properties. *Energy Reports, 8*, pp.11218–11227.

[7]Niño, A., Serrano, D., & Martínez, J. D. (2020). Experimental study on the mechanical properties of mixed biomass briquettes. *Energies, 13*(18), 4821.

[8]Onaji, O. P. B. (1993). *Production of charcoal briquettes from cotton stalks* (Technical Report). University of Twente. Vol. 4, No. 3, pp. 199-211.

[9]Orisaleye, J. I. (2020). Mathematical modelling of die pressure of a screw briquetting machine. *Energy Procedia, 172*, pp.234–241.

[10]Tao, G., Wang, X., & Liu, Y. (2019). Wear mechanisms and life prediction of biomass briquetting dies. *Wear, 430–431*, pp.326–335.

[11]TCSAE (Transactions of the Chinese Society of Agricultural Engineering). (2018). Wear mechanism of ring die for straw briquetting machine. *TCSAE, 34*(12), pp.78–85.

[12]Zepeda-Cepeda, C. O., Sánchez-Márquez, A., & López-González, D. (2021). Effect of sawdust particle size on physical, mechanical and energetic properties of briquettes. *Applied Sciences, 11*(15), 6832.pp.1-19.

[13]Zubair, M., Ashraf, M. A., & Al-Salem, S. M. (2022). Sustainable densification of biomass residues: A review on briquetting technologies and applications. *Renewable and Sustainable Energy Reviews, 156*, 111987.pp.1-40