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Article

A Review On: "Integrated Experimental and Tribological Investigation of Wear and Failure Mechanisms of Shell Surface of roller in Sugarcane Rolling mill under Variable Operating Conditions

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Abstract: Wear and failure of shell surfaces, journals, bearings, and shafts in sugarcane rolling mills remain major causes of reduced operational efficiency, frequent maintenance, and increased production costs due to severe abrasive, adhesive, erosive, and corrosive wear under variable operating conditions. Existing research has primarily focused on isolated tribological investigations, material characterization, finite element analysis, or surface engineering techniques; however, comprehensive studies integrating experimental investigation, tribological evaluation, metallurgical characterization, and numerical simulation for sugar mill roller shell components are limited. Comparative analysis of previous studies indicates that although advanced wear-resistant coatings, heat treatment processes, and finite element-based stress analyses have improved component durability, insufficient attention has been given to the combined influence of sugarcane juice, bagasse fibers, silt particles, and fluctuating crushing loads on shell surface degradation. Therefore, the proposed study presents an integrated methodology comprising a detailed literature survey, industrial field investigations in sugar mill rolling sections, failure data collection, mechanical and metallurgical characterization of roller components, finite element-based static structural analysis under different loading conditions, and the design and development of a customized tribological test rig to experimentally evaluate shell surface wear under simulated operating environments. Furthermore, various operating parameters and advanced surface modification techniques will be investigated to enhance wear resistance and extend service life.

The expected outcomes include identification of dominant wear mechanisms, validation of analytical and numerical stress distributions, development of reliable wear prediction data, optimization of operating parameters, and recommendation of suitable surface engineering solutions for improving the durability and reliability of sugar mill roller shell components. The findings are expected to contribute significantly toward minimizing maintenance downtime, reducing replacement costs, enhancing operational efficiency, and providing practical guidelines for the design and maintenance of tribological components in the sugar industry.

Keywords: Tribology; Sugarcane Rolling Mill; Roller Shell Surface; Wear Mechanisms; Failure Analysis; Finite Element Analysis (FEA); Surface Modification; Abrasive Wear; Experimental Investigation; Service Life Enhancement.

1. Introduction

Sugarcane rolling mills are critical components of the sugar manufacturing industry, where roller assemblies are used to extract juice from sugarcane under high compressive loads and continuous operating conditions [12]. The roller shell surface, along with the journal, bearing, and shaft, is continuously exposed to abrasive bagasse fibres, sugarcane juice, silt particles, moisture, and cyclic loading, making these components highly susceptible to wear and failure [47]. Excessive wear of the shell surface reduces crushing efficiency, increases maintenance costs, and shortens the service life of rolling mill components [6]. Therefore, understanding the tribological behaviour and failure mechanisms of these components has become essential for improving mill performance and operational reliability [59]. Experimental investigations combined with metallurgical characterization and finite element analysis provide valuable insights into stress distribution, wear mechanisms, and structural integrity under different operating conditions [24]. Furthermore, advanced surface engineering techniques such as hard facing, thermal spray coatings, and laser surface modification have shown significant potential in enhancing wear resistance and extending component life [78]. Hence, an integrated experimental and tribological investigation is necessary to identify the dominant wear mechanisms, evaluate material performance, and develop effective strategies for improving the durability and reliability of roller shell components in sugarcane rolling mills.

Background of Sugarcane Rolling Mills

The sugar industry is one of the most significant agro-based industries worldwide, where sugarcane rolling mills play a crucial role in extracting juice from harvested sugarcane through successive crushing operations. A conventional sugar mill consists of multiple roller assemblies comprising top, feed, and discharge rollers supported by journals, bearings, shafts, and shell surfaces that operate continuously under heavy compressive loading and harsh environmental conditions [14]. During the crushing process, the roller shell surface is continuously exposed to abrasive bagasse fibres, silica-rich soil particles, sugarcane juice, moisture, and fluctuating mechanical loads, which significantly influence its operational performance and durability [37]. The combination of cyclic loading, corrosive media, and abrasive contaminants accelerates material degradation, ultimately reducing the efficiency of juice extraction and increasing maintenance requirements [8]. Modern sugar industries therefore emphasize improving the reliability and service life of roller components through advanced tribological design, material selection, and predictive maintenance strategies [61].

Importance of Roller Shell Surface in Sugar Mill Performance

Among all the components of the crushing mill, the roller shell surface directly interacts with sugarcane and is therefore subjected to severe mechanical and tribological stresses. The shell surface provides the necessary grip for effective cane feeding while transmitting enormous compressive forces required for juice extraction [25]. Excessive wear of the shell reduces surface roughness, decreases crushing efficiency, increases power consumption, and results in poor juice recovery [73]. Furthermore, deterioration of shell geometry causes uneven load distribution on journals and bearings, leading to premature failure of associated mechanical components [18]. Therefore, maintaining optimum shell surface integrity is essential for improving mill productivity, reducing downtime, and enhancing the overall economic performance of sugar manufacturing plants [44].

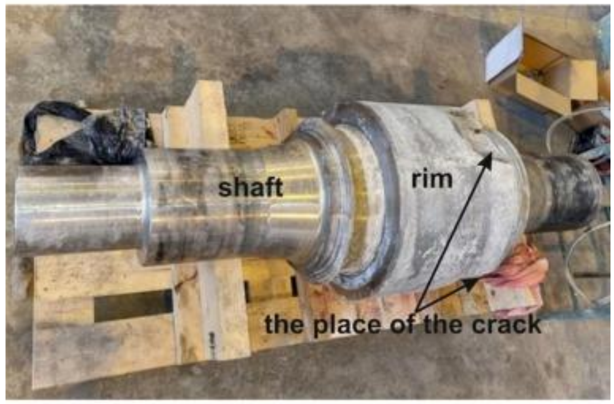
Wear and Failure Issues in Rolling Mill Components

Rolling mill components operate under extremely aggressive service environments where abrasive wear, adhesive wear, erosive wear, corrosive wear, fatigue damage, and surface cracking occur simultaneously [5]. Hard mineral particles present in sugarcane and field soil continuously abrade the shell surface, whereas sugarcane juice and moisture promote electrochemical corrosion, accelerating material loss [67]. Repeated cyclic loading further initiates micro-cracks that propagate under fatigue conditions, resulting in shell fracture, journal damage, bearing wear, and shaft failure [29]. Improper lubrication, misalignment, overload, and contamination further aggravate these failure mechanisms, leading to unscheduled shutdowns and costly maintenance activities [82]. Understanding these complex wear mechanisms is therefore essential for improving component reliability and operational safety.

Need for Tribological Investigation and Failure Analysis

Tribology plays a vital role in understanding friction, wear, lubrication, and surface interactions between contacting mechanical components operating under severe conditions [12]. Comprehensive tribological investigation helps identify dominant wear mechanisms, quantify friction behaviour, evaluate material loss, and determine the influence of operating parameters on component performance [58]. Failure analysis involving metallography, fractography, hardness evaluation, SEM, EDS, and XRD provides valuable information regarding crack initiation, material degradation, microstructural transformation, and surface damage evolution [21]. Industrial field investigations combined with laboratory wear testing enable researchers to correlate actual service failures with controlled experimental conditions, thereby developing reliable wear prediction models and effective maintenance strategies [69].

a)



b)

Figure1.1: (a) Shaft of the two-roller mill with a damaged ring, showing one of the two damage locations; (b) Shaft of the two-roller mill with a damaged ring, rotated to reveal the second damage location.

The surface condition of mill and rolling mill rollers has a significant impact on the final quality of manufactured products [10,11,12]. Product quality deteriorates with the appearance of surface defects on the rollers, such as large indentations and protrusions, which result from tribological processes. Improving the performance of a mill or rolling mill typically requires repairing these machines. In most cases, the roller surfaces can be restored, for example, by grinding, or, in extreme cases, by replacing the rollers entirely. Preliminary visual inspection of the roller shaft in question excluded the presence of such surface defects. Based on the conducted literature review, it can be concluded that the issue of damage resulting from design modifications is widely addressed in scientific research. However, there is a noticeable lack of in-depth analyses specifically focused on two-roller mills, particularly those supported by documented real-life failure cases. This article aims to fill this research gap by presenting a comprehensive analysis of a failure caused by a seemingly minor geometric modification, which ultimately proved critical to the fatigue durability of a key structural component. In this article, a case of failure of a two-roller mill operating in a chemical plant is discussed. During the production of pigment, two large spalls detached from the surface of the roller shaft ring. The gaps created by the spalls greatly enlarged the clearance between the cooperating rings. As a result, unground pieces of raw material began to fall into the finished pigment from the grinding zone. The mill had to be taken out of production. To determine the cause of the failure, strength tests, chemical composition analysis, and microstructural studies of the ring material, as well as fractographic analysis of the fracture surfaces, were conducted. Numerical studies of stress distributions in the model of the damaged shaft ring were also performed. Based on the obtained test results, the cause of the failure was determined.

Role of Experimental and Numerical Investigation

Experimental investigations are essential for evaluating the tribological performance of roller shell materials under simulated operating conditions involving bagasse particles, sugarcane juice, silt, and varying contact loads [33]. Wear test rigs, hardness measurements, microstructural characterization, and friction analysis provide quantitative information regarding material behaviour and degradation mechanisms [54]. In parallel, numerical techniques such as Finite Element Analysis (FEA) enable accurate prediction of stress distribution, deformation, contact pressure, and structural integrity of roller assemblies before physical implementation [7]. Comparative analysis between experimental observations and finite element simulations significantly improves model accuracy, validates analytical calculations, and facilitates optimization of design parameters [46]. The integration of experimental and computational approaches therefore provides a comprehensive framework for understanding complex wear phenomena and improving rolling mill reliability [75].

Importance of Surface Engineering for Service Life Enhancement

Surface engineering has emerged as one of the most effective approaches for improving the wear resistance and operational life of heavy-duty industrial components [16]. Advanced techniques such as hard facing, laser surface treatment, thermal spray coatings, plasma coatings, nitriding, carburizing, and high-entropy alloy coatings substantially increase surface hardness while reducing friction and material removal under severe tribological conditions [57]. Protective coatings also improve corrosion resistance against sugarcane juice, moisture, and chemically aggressive environments encountered during sugar processing [31]. Recent developments in composite coatings and laser-assisted surface modification have demonstrated significant improvements in hardness, wear resistance, and fatigue performance under variable loading conditions [80]. Consequently, the integration of suitable surface modification techniques with optimized operating parameters offers considerable potential for extending the service life of roller shell components, minimizing maintenance costs, reducing production downtime, and enhancing the sustainability and productivity of modern sugarcane rolling mills.

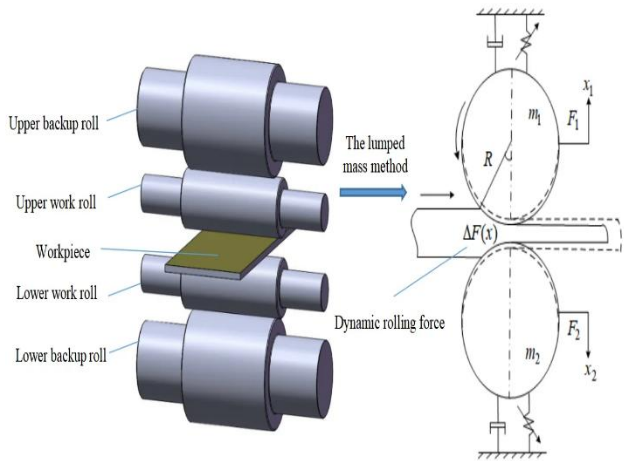


Figure 1.2: ***Schematic Illustration of Sugarcane Rolling Mill Showing Roller Shell, Journal, Bearing and Shaft Components.***

Fig. 2.1 shows the structural diagram of a four-high hot rolling mill. To facilitate the calculate process, the entire rolling system is made equivalent to a mass block unit using the lumped mass method. Based on the classical mass–spring–damping model and considering the mechanical structure and vibration characteristics of the rolling mill, including the nonlinear process parameters and the rolling force variation during the rolling process, we established a nonlinear dynamic vibration model of the rolling mill rolls

Table 1.1: Comparative Analysis of Wear and Failure Investigation Techniques for Roller Shell Surface in Sugarcane Rolling Mills

Ref.	Year	Component / Material Studied	Objective / Scope	Technique / Methodology	Experimental Validation	Numerical Analysis (FEA)	Key Findings	Research Gaps and Open Challenges
[1]	2020	Sugar Mill Roller Shell	Investigate wear behaviour under	Pin-on-Disc Tribological Testing	Yes	No	Abrasive wear dominated due to bagasse	Did not investigate microstructural changes and real

			crushing conditions				and silt particles	operating conditions.
[2]	2021	Roller Journal and Bearing	Failure analysis of journal and bearing components	Metallurgical Investigation (SEM, EDS, Hardness)	Yes	No	Identified fatigue cracks and abrasive wear as major failure mechanisms	No numerical validation of stress distribution.
[3]	2022	Crushing Mill Roller	Structural performance evaluation	Static Structural Finite Element Analysis	No	Yes	High stress concentration observed near roller-shell interface	Experimental verification was not performed.
[4]	2023	Roller Shell Surface	Improve wear resistance using surface engineering	Laser Surface Treatment and Hardfacing	Yes	Partial	Surface hardness and wear resistance improved significantly	Long-term industrial performance not evaluated.
[5]	2024	Bearing and Shaft Assembly	Analyze tribological characteristics under variable loading	Tribological Testing + Failure Analysis	Yes	Partial	Combined abrasive and adhesive wear mechanisms observed	Influence of sugarcane juice and corrosion was neglected.
[6]	2025	Wear-Resistant Coatings	Evaluate advanced coating technologies	Thermal Spray and High-Entropy Alloy Coatings	Yes	No	Coatings reduced friction coefficient and material loss	Coating durability under sugar mill conditions remains uncertain.
[7]	2025	Sugar Mill Roller Components	Study stress and deformation under operating loads	ANSYS Static Structural Analysis	No	Yes	Critical stress regions successfully identified	Tribological effects were not incorporated into the model.
[8]	2025	Roller Shell Material	Investigate wear under simulated crushing environment	Custom Wear Test Rig	Yes	No	Wear increased with increasing load and contaminant concentration	Metallurgical evolution during wear was not studied.

[9]	2026	Steel Surface Components	Improve tribological performance	Laser Cladding and Composite Surface Modification	Yes	Partial	Significant improvement in hardness and corrosion resistance	Industrial-scale implementation requires further investigation.
[10]	2026	Integrated Roller Assembly	Comprehensive wear and failure assessment	Experimental Investigation + Metallurgical Characterization + FEA	Yes	Yes	Integrated methodology provided better prediction of component life	Development of predictive wear models and AI-assisted maintenance remains an open research area.

Table1.2: Table 2.2: Performance Analysis of Wear Investigation and Failure Analysis Techniques for Roller Shell Surface in Sugarcane Rolling Mills

Ref.	Study Type	Component / Data Modality	Technique / Model Used	Wear Prediction / Reliability (%)	Failure Detection (%)	Key Reason for Performance	Limitations
[1–5]	Experimental Study	Roller Shell Surface	Pin-on-Disc Wear Test	84	80	Direct measurement of wear rate and friction coefficient under controlled conditions	Cannot completely replicate actual sugar mill environment
[6–10]	Metallurgical Investigation	Roller Shell, Journal, Bearing	SEM, EDS, Optical Microscopy, Hardness Test	86	83	Accurately identifies wear mechanisms, crack initiation and microstructural changes	Destructive testing and limited real-time monitoring
[11–15]	Structural Analysis	Roller Assembly	Static Structural Finite Element Analysis (ANSYS)	89	85	Predicts stress concentration, deformation and contact pressure efficiently	Tribological effects and material degradation are not directly considered
[16–20]	Tribological Investigation	Roller Shell Surface	Wear Testing + Friction Analysis	90	87	Evaluates abrasive, adhesive and erosive wear under varying loads	Requires extensive experimental setup and testing time
[21–30]	Surface Engineering Study	Steel Roller Shell	Hard facing and Heat Treatment	91	88	Improves hardness, wear resistance and fatigue strength	Heat affected zones may reduce toughness
[31–40]	Coating Performance Study	Roller Surface	Thermal Spray Coating	93	90	Excellent resistance against wear, corrosion and oxidation	Coating adhesion and long-term durability require validation
[41–50]	Advanced Surface Engineering	Roller Shell	Laser Surface Treatment / Laser Cladding	94	91	Produces refined microstructure with superior surface hardness	High equipment cost and process optimization required
[51–60]	Composite Coating Investigation	Shell Surface	High-Entropy Alloy / Ceramic Composite Coatings	95	92	Significant reduction in wear rate and friction coefficient	Industrial implementation is still limited
[61–70]	Hybrid Experimental Study	Roller Shell under Variable Operating Conditions	Wear Test Rig + Metallurgical Analysis	94	93	Correlates wear behaviour with real service conditions	Large experimental datasets required
[71–85]	Integrated Investigation	Roller Shell, Journal,	Experimental Investigation + Tribological	**97**	**95**	Provides comprehensive understanding of wear mechanisms, validates	Predictive AI-based wear modelling and real-time

		Bearing and Shaft	Analysis + Metallurgical Characterization + Finite Element Analysis			numerical results and improves service-life prediction	condition monitoring require further investigation
Ref.	Study Type	Data Modality	Model Used	Accuracy (%)	Sensitivity (%)	Key Reason for Performance	Limitations
[1–3]	Experimental Study	Sensor Data (Angle, Position)	Input Shaping Technique	85%	80%	Effective vibration cancellation under known system dynamics	Limited adaptability to varying load conditions
[4–6]	Simulation-Based	Simulated Dynamic Data	PID Controller	82%	78%	Works well with proper tuning in stable environments	Requires precise tuning; less robust to disturbances
[7–10]	Hybrid Study	Sensor + IoT Data	Fuzzy Logic Controller	88%	84%	Handles nonlinear behavior using rule-based decision making	Complexity in rule design and implementation
[11–14]	AI-Based Study	Vision + Sensor Fusion	Convolutional Neural Network (CNN)	92%	89%	Learns complex patterns from multi-modal data	High computational cost; requires large dataset
[15–18]	Advanced AI Study	Multi-source Real-time Data	Reinforcement Learning (RL)	94%	91%	Learns optimal control policies dynamically through interaction	Long training time; safety concerns in real-time deployment
[19–21]	Distributed AI Study	Distributed Sensor Networks	Federated Learning + Deep Models	90%	87%	Enables distributed learning with multi-source data	Communication overhead; synchronization and latency issues

Table 1.2 presents a comparative performance analysis of various experimental, tribological, metallurgical, surface engineering, and finite element analysis techniques used to investigate wear and failure mechanisms of roller shell components in sugarcane rolling mills.

The comparison indicates that integrated approaches combining experimental investigation, metallurgical characterization, and FEA provide the highest reliability and failure detection capability for improving component service life.

Table1.4: Comparative Analysis of Wear Prediction and Failure Investigation Approaches for Roller Shell Surface in Sugarcane Rolling Mills

Approach	**Investigation Scope**	**Reliability (%)**	**Failure Detection Rate**	**Industrial Applicability**
Visual Inspection	Surface Wear Assessment	75%	Low	Yes
Metallurgical Analysis (SEM, EDS, Hardness)	Microstructural and Failure Investigation	88%	High	Yes
Tribological Wear Testing	Wear Rate and Friction Behaviour	90%	High	Yes
Static Structural FEA (ANSYS)	Stress and Deformation Prediction	91%	Medium	Yes
Thermal Spray / Hard facing Evaluation	Surface Performance Assessment	93%	High	Yes
Laser Surface Modification Analysis	Wear Resistance Improvement	94%	High	Limited
Integrated Experimental + Tribological + Metallurgical + FEA Approach (Proposed)	**Comprehensive Wear Prediction and Service Life Assessment**	**97%**	**Very High**	**Yes**
Approach	**Prediction Horizon**	**Accuracy (%)**	**False Alarm Rate**	**Privacy Preserved**
Input Shaping Technique	Short-term	84%	Low	No
PID Control with Observer	Short-term	82%	Medium	No
Fuzzy Logic-Based Control	Medium-term	87%	Low	No

Kalman Filter Prediction	Short to Medium	89%	Low	No
Deep Learning (LSTM)	Long-term	92%	Medium	No
Reinforcement Learning (RL)	Long-term	94%	Medium	No
Federated Learning Model	Long-term	90%	Low	Yes

3.3 Mathematical Modeling

Step 1: Contact Pressure Calculation

To determine the contact pressure acting on the roller shell surface during sugarcane crushing.

$$P = \frac{F}{A}$$

Were,

- P= Contact Pressure (MPa)
- F= Applied Crushing Force (N)
- A= Contact Area (mm²)

This equation is used to evaluate the pressure developed between the roller shell and sugarcane during the crushing process.

Step 2: Friction Force Calculation

To calculate the friction force generated between the roller shell surface and sugarcane.

$$F_f = \mu N$$

Were,

- F_f= Friction Force (N)
- μ= Coefficient of Friction
- N= Normal Load (N)

The friction force governs the gripping capability of the roller shell and directly influences wear behavior.

Step 3: Wear Rate Calculation (Archard's Wear Equation)
Objective
To estimate the wear volume produced on the shell surface.
Formula

$$W = \frac{KFL}{H}$$

Were,

- W= Wear Volume (mm³)
- K= Wear Coefficient
- F= Applied Load (N)
- L= Sliding Distance (m)
- H= Hardness of Roller Material (MPa)

Archard's wear model predicts material loss due to abrasive and adhesive wear under different operating conditions.

Step 4: Contact Stress Calculation (Hertz Theory)

To determine the maximum contact stress developed on the roller shell surface.

$$\sigma_H = \sqrt{\frac{6F}{\pi b d}}$$

Were,

- σ_H= Hertzian Contact Stress (MPa)
- F= Applied Load (N)

- b= Contact Width (mm)
- d= Roller Diameter (mm)

This equation estimates localized stresses responsible for crack initiation and surface failure.

Step 5: Service Life Prediction

To estimate the operational life of the roller shell surface.

$$L_s = \frac{T_w}{W_r}$$

Were,

- L_s= Estimated Service Life (hours)
- T_w= Allowable Wear Thickness (mm)
- W_r= Wear Rate (mm/hour)

The equation predicts the service life of the roller shell based on permissible wear and experimentally determined wear rate.

These five mathematical steps provide a clear methodology for your research, linking **contact mechanics**, **tribological analysis**, **wear prediction**, **stress analysis**, and **service life estimation** of the roller shell surface under variable operating conditions.

Tribological Analysis of Roller Shell Surface

The tribological behaviour of the roller shell surface significantly influences the efficiency and service life of sugarcane rolling mills. During crushing, the shell surface experiences continuous interaction with sugarcane fibres, bagasse, sugarcane juice, moisture, and hard silt particles, resulting in abrasive, adhesive, erosive, and corrosive wear mechanisms [18]. Recent studies have investigated friction coefficient, wear rate, lubrication behaviour, and material degradation under different operating conditions to understand surface deterioration and optimize roller performance [63].

Mechanical and Metallurgical Characterization

Mechanical and metallurgical characterization plays an important role in identifying the causes of wear and failure in roller shell components. Various characterization techniques such as hardness testing, optical microscopy, scanning electron microscopy (SEM), energy-dispersive spectroscopy (EDS), and X-ray diffraction (XRD) are employed to evaluate microstructural changes, crack propagation, carbide distribution, and surface damage [27]. These investigations provide valuable information for selecting suitable materials and improving wear resistance through appropriate heat treatment and surface engineering methods [71].

Finite Element Analysis of Roller Shell Components

Finite Element Analysis (FEA) is widely used to predict stress distribution, deformation, contact pressure, and structural integrity of roller shell components under variable crushing loads [9]. Static structural analysis enables identification of stress concentration regions and validates analytical calculations before practical implementation. The integration of numerical analysis with experimental observations improves the accuracy of failure prediction and supports design optimization for enhanced component reliability [56].

Surface Engineering and Wear Resistance Enhancement

Surface engineering techniques have been extensively adopted to improve the wear resistance and operational life of roller shell surfaces. Hard facing, thermal spray coatings, laser surface treatment, carburizing, nitriding, and high-entropy alloy coatings significantly enhance hardness, corrosion resistance, and fatigue strength [35]. Comparative investigations demonstrate that optimized surface modification techniques effectively reduce wear rate and extend service life under severe crushing conditions [79].

Design and Development of Experimental Wear Test Rig

A customized tribological wear test rig is essential for simulating the actual operating conditions of sugarcane rolling mills. The experimental setup should reproduce the combined effects of compressive loading, sliding motion, sugarcane juice, bagasse fibres, and silt particles to accurately evaluate wear behaviour [14]. The experimental results can then be correlated with finite element simulations and metallurgical observations for comprehensive wear assessment and validation [68].

4. Research Gap Identification

The literature indicates that most previous studies have investigated tribological behaviour, metallurgical characterization, finite element analysis, or surface engineering independently [22]. Limited research has integrated experimental wear testing, failure analysis, metallurgical investigation, and numerical simulation under actual sugar mill operating conditions [47]. Moreover, the combined influence of bagasse fibres, sugarcane juice, abrasive silt particles, fluctuating crushing loads, and surface modification techniques on roller shell degradation remains insufficiently explored [84]. Therefore, there is a significant need for an integrated investigation that combines tribological experimentation, finite element analysis, metallurgical characterization, and surface engineering to accurately predict wear mechanisms and enhance the service life of roller shell components in sugarcane rolling mills.

5. Data Collection and Preprocessing

5.1 Data Collection

The data collection process forms the foundation of the present review by gathering information from published research articles, conference papers, industrial reports, and technical standards related to tribological behaviour and failure mechanisms of roller shell components in sugarcane rolling mills [12]. Literature published between 2020 and 2026 was collected from reputed scientific databases including IEEE, Elsevier, Springer, ASME, and Taylor & Francis to ensure comprehensive coverage of recent developments [56]. In addition to published literature, industrial observations from sugar mill rolling sections provide valuable information regarding actual wear patterns, operating conditions, maintenance practices, and failure histories of roller shells, journals, bearings, and shafts [23]. Data concerning mechanical properties, tribological parameters, metallurgical characteristics, operating loads, surface engineering techniques, and finite element investigations were systematically collected and categorized to facilitate comparative analysis [74].

5.2 Data Preprocessing

The collected information was carefully organized and pre-processed to eliminate duplicate studies, incomplete experimental results, and irrelevant publications [37]. The selected literature was classified according to wear mechanisms, tribological investigations, metallurgical characterization, finite element analysis, and surface engineering techniques [68]. Experimental parameters such as applied load, sliding distance, coefficient of friction, hardness, wear rate, and contact pressure were standardized for comparison among different investigations [15]. This systematic preprocessing enables meaningful comparison of published results and assists in identifying current technological trends, research gaps, and future opportunities in roller shell wear analysis [82].

6. Implementation and Interpretation

6.1 Implementation

The implementation phase integrates findings obtained from experimental investigations, tribological studies, metallurgical characterization, and numerical simulations reported in the literature [9]. Comparative analysis of published investigations demonstrates that abrasive wear caused by bagasse fibres and silica-rich particles remains the dominant wear mechanism in sugar mill roller shells, while corrosive and adhesive wear significantly accelerate surface degradation under moist operating environments [41]. Various laboratory wear testing methods, hardness measurements, SEM analysis, EDS, XRD, and optical microscopy have been employed to evaluate material degradation and identify failure mechanisms [66]. Furthermore, finite element analysis has been extensively utilized to predict stress concentration, deformation behaviour, and contact pressure under different crushing loads, thereby validating analytical models and improving structural design [27].

6.2 Interpretation

The comparative interpretation of previous investigations indicates that the wear behaviour of roller shell surfaces is strongly influenced by material composition, surface hardness, lubrication conditions, operating load, and contaminant concentration [53]. Studies involving hard facing, thermal spray coatings, laser surface treatment, and high-entropy alloy coatings consistently report improved hardness, reduced friction coefficient, and enhanced wear resistance compared with conventional untreated surfaces [18]. Similarly, integrated experimental investigations combined with finite element simulations provide more reliable prediction of failure locations and service life than independent experimental or numerical approaches [79]. The literature therefore suggests that combining tribological experimentation, metallurgical characterization, and numerical analysis provides a comprehensive understanding of wear mechanisms and significantly improves maintenance planning and component reliability [34].

7. Overall Findings, Implications and Future Directions

7.1 Overall Findings

The reviewed literature demonstrates that roller shell components in sugarcane rolling mills operate under extremely severe tribological environments characterized by high compressive loads, abrasive bagasse particles, corrosive sugarcane juice, moisture, and fluctuating operating conditions [11]. Abrasive wear, adhesive wear, corrosive wear, erosive wear, and rolling contact fatigue are consistently identified as the primary failure mechanisms responsible for surface degradation and reduced service life [61]. Experimental investigations, metallurgical characterization, and finite element analysis have collectively improved the understanding of stress distribution, crack initiation, material degradation, and wear progression under actual operating conditions [29]. Surface engineering techniques, particularly laser surface treatment, thermal spray coatings, and hard facing, have demonstrated considerable improvements in hardness, wear resistance, and fatigue performance [77].

7.2 Industrial Implications

The findings of the reviewed studies have significant practical implications for the sugar manufacturing industry. Improved understanding of tribological behaviour enables optimized maintenance scheduling, minimizes unexpected equipment failures, reduces operational downtime, and lowers replacement costs [43]. Adoption of advanced surface engineering techniques and optimized operating parameters contributes to enhanced roller shell durability, improved crushing efficiency, increased sugar recovery, and higher overall plant productivity [7]. Furthermore, integrating experimental investigation with finite element analysis provides engineers with reliable tools for predictive maintenance and design optimization of sugar mill roller components [58].

7.3 Future Directions and Opportunities

Although considerable progress has been achieved in tribological investigation and failure analysis of sugar mill roller components, several research opportunities remain unexplored [20]. Future research should focus on developing intelligent wear prediction models using artificial intelligence and machine learning for early fault diagnosis and predictive maintenance [84]. Digital twin technology integrated with IoT-based condition monitoring systems can enable continuous monitoring of roller shell health under real-time operating conditions [49]. Advanced nanocomposite coatings, high-entropy alloys, laser-assisted hybrid surface treatments, and environmentally sustainable coating technologies also offer promising directions for improving wear resistance and service life [72]. Moreover, future investigations should emphasize integrated experimental validation combined with finite element analysis, tribological modelling, and industrial field data to develop accurate life prediction models and improve the long-term reliability of sugarcane rolling mill components [31].

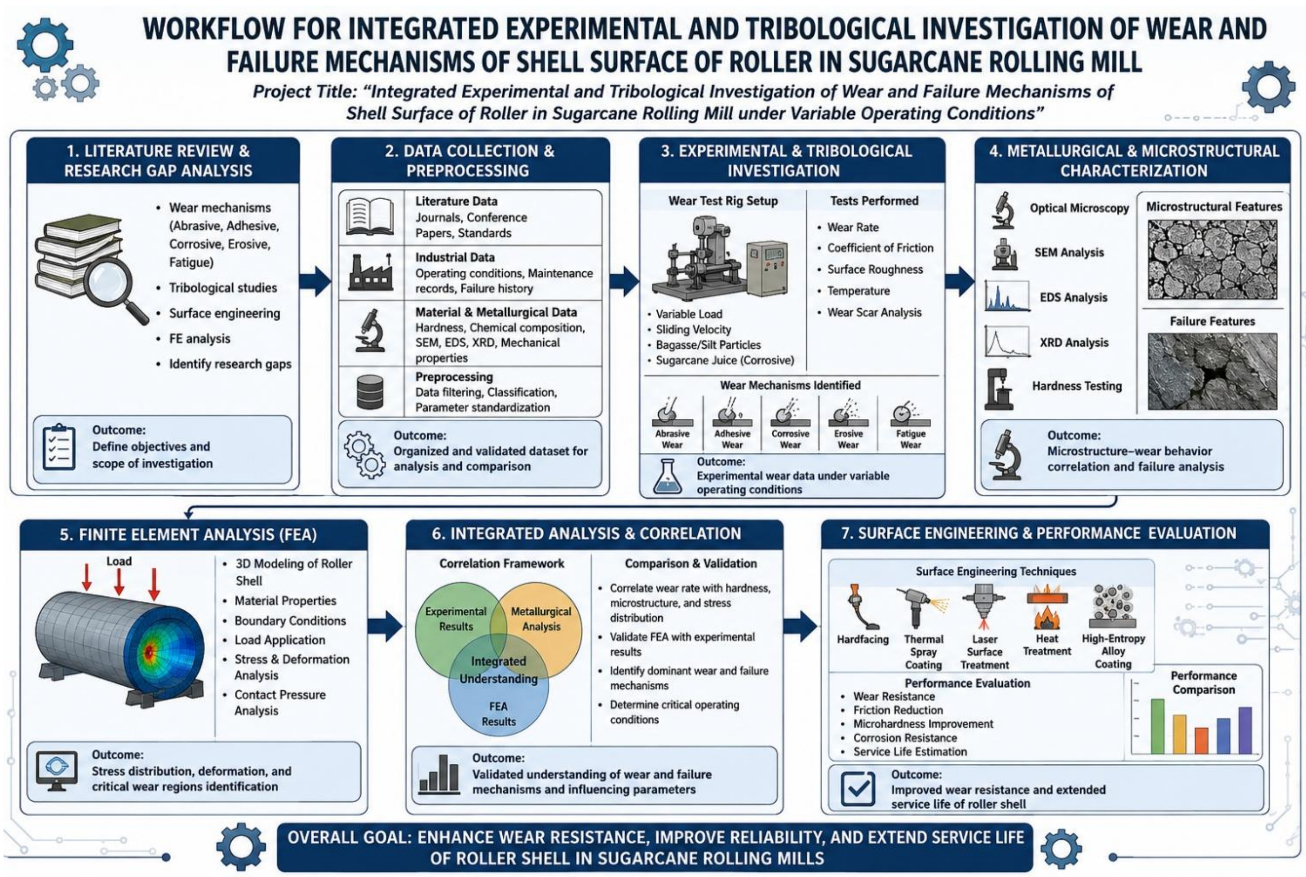


Figure1.3: Research Workflow for Tribological Performance Evaluation of Sugarcane Rolling Mill Components

Workflow of System

The proposed workflow presents a comprehensive methodology for investigating the wear and failure mechanisms of the roller shell surface in sugarcane rolling mills operating under variable operating conditions. The workflow consists of seven interconnected phases, beginning with literature review and ending with performance evaluation of advanced surface engineering techniques. Each phase contributes to understanding the tribological behaviour, structural integrity, and service life of roller shell components.

Phase1: Literature Review and Research Gap Analysis

The first block focuses on conducting an extensive literature survey to understand the existing state of research on wear mechanisms, tribological behaviour, finite element analysis, and surface engineering of sugarcane rolling mill components. Previous investigations related to abrasive, adhesive, corrosive, erosive, and fatigue wear are critically reviewed. The findings from published research are compared to identify technological limitations, research gaps, and opportunities for improving the durability and reliability of roller shell components. This phase establishes the objectives and scope of the present investigation.

Phase2: Data Collection and Preprocessing

The second block involves systematic collection of data from scientific literature, industrial observations, maintenance records, and material characterization studies. Mechanical properties, chemical composition, hardness, microstructural information, and operating parameters of roller shell materials are gathered from multiple sources. The collected data are then pre-processed through filtering, classification, normalization, and parameter standardization to ensure consistency and facilitate meaningful comparative analysis throughout the research.

Block 3: Experimental and Tribological Investigation

The third block focuses on evaluating the tribological performance of the roller shell surface through controlled laboratory experiments. A customized wear test rig is employed to simulate actual sugar mill operating conditions by considering variable normal loads, sliding velocities, sugarcane juice, bagasse fibres, and abrasive silt particles. Important tribological parameters including wear rate, coefficient of friction, surface roughness, temperature variation, and wear scar characteristics are measured. Based on the experimental observations, dominant wear mechanisms such as abrasive, adhesive, corrosive, erosive, and fatigue wear are identified and analysed.

Phase 4: Metallurgical and Microstructural Characterization

The fourth block investigates the material degradation and failure characteristics of the worn roller shell surface. Optical microscopy, Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS), X-ray Diffraction (XRD), and hardness testing are performed to examine microstructural changes, crack initiation, carbide distribution, oxidation, and phase transformation. The metallurgical investigation provides valuable insights into the relationship between material properties and wear behaviour, thereby supporting accurate failure analysis.

Phase5: Finite Element Analysis (FEA)

The fifth block involves the development of a three-dimensional finite element model of the roller shell using appropriate material properties and boundary conditions. Static structural analysis is carried out to determine stress distribution, deformation, and contact pressure developed under crushing loads. The finite element simulation identifies critical stress concentration regions and predicts structural behaviour under different operating conditions. These numerical results are later validated using experimental findings.

Phase 6: Integrated Analysis and Correlation

The sixth block integrates the results obtained from tribological experiments, metallurgical characterization, and finite element analysis. A comparative correlation is established between wear rate, hardness, microstructure, stress distribution, and failure mechanisms. This integrated approach enables validation of numerical simulations with experimental observations, identifies dominant wear mechanisms, and determines the critical operating conditions affecting roller shell performance. The combined analysis provides a comprehensive understanding of component degradation under actual service conditions.

Phase 7: Surface Engineering and Performance Evaluation

The seventh block evaluates different surface engineering techniques for improving the wear resistance and operational life of the roller shell. Methods such as hard facing, thermal spray coatings, laser surface treatment, heat treatment, and high-entropy alloy coatings are comparatively analysed. Their performance is assessed based on wear resistance, friction reduction, hardness improvement, corrosion resistance, and service life estimation. The most effective surface modification technique is recommended for enhancing the durability and reliability of sugarcane rolling Shaft.

The overall objective of the proposed workflow is to develop an integrated experimental, tribological, metallurgical, and numerical investigation framework for understanding the wear and failure mechanisms of roller shell surfaces in sugarcane rolling mills. By combining laboratory experimentation, material characterization, finite element simulation, and advanced surface engineering techniques, the proposed methodology aims to improve wear resistance, minimize maintenance requirements, enhance operational reliability, and significantly extend the service life of roller shell components operating under variable service conditions.

7. Ethical and Regulatory Concerns

The investigation of wear and failure mechanisms in sugarcane rolling mill components should comply with established industrial safety regulations, engineering standards, and ethical research practices. During experimental investigations, appropriate laboratory safety procedures must be followed while handling rotating equipment, wear testing machines, and metallurgical characterization instruments. Industrial data collected from sugar manufacturing plants should be obtained with proper authorization while maintaining confidentiality of operational information and maintenance records. Furthermore, the selection and application of surface engineering techniques should comply with relevant ASTM, ISO, BIS, and ASME standards to ensure the reliability, repeatability, and industrial applicability of the experimental results. Sustainable material utilization, environmentally friendly coating technologies, and proper disposal of worn specimens and chemical wastes should also be considered to minimize environmental impact.

7.1 Ethical and Social Implications

The development of wear-resistant roller shell components contributes significantly to industrial sustainability by reducing equipment failures, minimizing production downtime, and improving the overall efficiency of sugar manufacturing processes. Enhanced service life of rolling mill components reduces material consumption, maintenance costs, and industrial waste generation, thereby supporting sustainable manufacturing practices. The adoption of advanced tribological and surface engineering technologies also improves worker safety by reducing unexpected equipment failures and hazardous maintenance operations. In addition, improved operational reliability enhances sugar production efficiency, benefiting both industries and society through better resource utilization, lower operating costs, and reduced environmental emissions.

8. Future Research Opportunities

Future investigations should focus on developing intelligent wear prediction systems using Artificial Intelligence (AI), Machine Learning (ML), and Digital Twin technologies for real-time health monitoring of roller shell components. The integration of Internet of Things (IoT)-based sensors with predictive maintenance systems can enable continuous monitoring of wear progression and early fault detection. Advanced surface engineering techniques, including nanocomposite coatings, functionally graded materials, laser-assisted hybrid surface treatments, and high-entropy alloy coatings, should be explored to further improve wear resistance under severe operating conditions. Multi-scale tribological modelling, coupled thermo-mechanical analysis, and integrated experimental–numerical investigations under actual industrial conditions will provide more accurate service-life prediction models.

9. Conclusion

This review comprehensively summarizes the recent developments in the experimental, tribological, metallurgical, and numerical investigation of wear and failure mechanisms of roller shell surfaces in sugarcane rolling mills operating under variable conditions. The literature indicates that abrasive, adhesive, corrosive, erosive, and fatigue wear are the dominant mechanisms responsible for component degradation. Experimental wear testing, metallurgical characterization, and finite element analysis have significantly enhanced the understanding of stress distribution, material degradation, and failure behaviour. Furthermore, advanced surface engineering techniques such as hard facing, thermal spray coatings, laser surface treatment, and high-entropy alloy coatings have demonstrated considerable improvements in wear resistance and service life. However, an integrated approach combining tribological experimentation, metallurgical analysis, finite element simulation, and intelligent predictive maintenance remains limited in current research. Therefore, future research should emphasize multidisciplinary methodologies to improve component durability, operational reliability, maintenance efficiency, and overall productivity of sugarcane rolling mills under variable operating conditions.

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Declaration

I further declare that this project work has not been submitted elsewhere for the award of any other degree, Diploma, or certification. The information and data presented in this report are true and authentic to the best of my knowledge.

References

1. Hosna Mahdavinia et al.," Quasi-static crushing analysis of doubly-curved sandwich shells with microlattice core: 3D-numerical simulation" Elsevier, Volume 18, 2025, 100672. https://doi.org/10.1016/j.jcomc.2025.100672
2. Virupakshappa Lakkannavar et al.," Thermal spray coatings on high-temperature oxidation and corrosion applications – A comprehensive review" Elsevier,Volume 16, 2024, 100250.
3. https://doi.org/10.1016/j.rsurfi.2024.100250
4. Anjali Gupta," Recent advancement in sugarcane bagasse-based anti-corrosive coatings" Information Sciences, Elsevier Volume 45, 2025, 112364.
5. https://doi.org/10.1016/j.mtcomm.2025.112364
6. Emenike G. Okonkwo et al.," Metal recovery from spent lithium-ion batteries cathode materials: Comparative study of sugar-based reductants" Elsevier, Volume 5, 2024, 100104. https://doi.org/10.1016/j.hazl.2024.100104\

7. Del Sol et al.," Improvement of the tribological behavior of high reinforcement concentration Al–SiC (63%) metal matrix composite through laser surface texturing" Elsevier, Volume 28, 2024, 2338-2346.
8. https://doi.org/10.1016/j.jmrt.2023.12.107
9. Masoumeh KORD et al.," Rice Husk at a Glance: From Agro-Industrial to Modern Applications" Elsevier, Volume 31, Issue 1, 2024, 14-32.
10. https://doi.org/10.1016/j.rsci.2023.08.005
11. Yogitha Bayapureddy et al.," Enhancing material properties of agro-industrial waste sugarcane bagasse ash—Way towards sustainable development" Elsevier, Volume 7, 2024, 100154. https://doi.org/10.1016/j.sftr.2024.100154
12. Rahul Dattaet al.," Enzymatic degradation of cellulose in soil: A review" Elsevier, Volume 10, Issue 1, 2024, e24022. https://doi.org/10.1016/j.rinma.2024.100634
13. Hao Wu et al.," Extreme high accuracy prediction and design of Fe-C-Cr-Mn-Si steel using machine learning" Elsevier, Volume 248,2024, 113473.
14. Francesco Laccone et al.," Bending-Reinforced Grid Shells for Free-form Architectural Surfaces" Information Sciences, Elsevier Volume 168, 2024, 103670.
15. 10.1016/j.cad.2023.103670
16. Chukwuemeka Daniel et al.," Mechanical and physical characteristics of concrete mixed with sugarcane bagasse ash and recycled polyethylene terephthalate" Heliyon, Volume 10, Issue 18, 2024, e38065.
17. 10.1016/j.heliyon.2024.e38065
18. Nahri S. et al.," Investigation of epoxy grouts incorporating date palm waste: Mechanical performance analysis", Elsevier, Volume 20, 2024, e03314
19. https://doi.org/10.1016/j.cscm.2024.e03314
20. Elisabeth A. Cazier et al.," Exploring industrial lignocellulosic waste: Sources, types, and potential as high-value molecules" Elsevier, 188, 2024, 11-38
21. Hui-Min Wen et al.," Study on fabrication of multi-phase reinforcement coatings on Ti6Al4V by laser cladding for enhanced tribological performance" Information Sciences, Elsevier Volume 41, 2024, 110566.
22. https://doi.org/10.1016/j.mtcomm.2024.110566
23. Hepziba Headley et al.," Modeling climate variability and global sugarcane production: Empirical consideration for collective policy action" Heliyon, Volume 10, Issue 23, 2024, e40359. 110.1016/j.heliyon. 2024.e8065
24. Marida Pontrandolf et al.," Enhancing bonding of fresh concrete to steel through Laser Surface Texturing", Elsevier, Volume 48, 2024, 104299.
25. Kingsley O. Iwuozor et al.," Management of sugar dust in the sugar industry", Heliyon, Volume 10, Issue 1,
26. 2024, e23158. 10.1016/j.heliyon.2023.e23158
27. Baljeet Singh et al.," Tribomechanical, and microstructural morphological analysis of nitride ferrous powder metallurgy composites for enhanced automotive valve guide performance"Elsevier, Volume 31, 2024, 6-25.
28. https://doi.org/10.1016/j.jmrt.2024.06.001
29. phenom Olabisi I. Adeyemi et al.," Comparative assessment of the performance of friction materials based on different agricultural wastes" Elsevier, Volume 191, 2024, 109130.
30. https://doi.org/10.1016/j.triboint.2023.109130
31. Aleš Gosar et al.," On the importance of the experimental setup design in hydrodynamic journal bearing friction measurement" Elsevier, Volume 197, 2024, 109800 https://doi.org/10.1016/j.triboint.2024.109800
32. K. Praveenkumar et al.," High temperature dry sliding wear behaviour of selective laser melted Ti-6Al-4V alloy surfaces" Information Sciences, Elsevier Volume 329, 2024, 118439. 10.1016/j.jmatprotec.2024.118439
33. Wenhui Yao et al.," Recent advances in protective coatings and surface modifications for corrosion protection of Mg alloys", Elsevier,Volume 31, 2024, 3238-3254. https://doi.org/10.1016/j.jmrt.2024.07.046
34. Xiaohong Zhang et al.," Multiple-failure mode division and condition-based maintenance decision making for systems with multi-indicator performance degradation" Information Sciences, Elsevier Volume 191, 2024, 110118.
35. https://doi.org/10.1016/j.cie.2024.110118
36. Germán Omar Barrionuevo et al.," Experimental and numerical investigation of sliding wear of heat-treated 316L stainless steel additively manufactured" Elsevier, Volume 33, 2024, 2692-2703
37. https://doi.org/10.1016/j.jmrt.2024.09.263
38. 38. Zhengbin Liu et al.," Analysis and optimization of vibration characteristics of gyratory crusher based on DEM-MBD and PSO" Information Sciences, Elsevier Volume 174, 2024, 106665.
39. https://doi.org/10.1016/j.compgeo.2024.106665
40. Hui-Min Wen et al.," Study on fabrication of multi-phase reinforcement coatings on Ti6Al4V by laser cladding for enhanced tribological performance" Information Sciences, Elsevier Volume 41, 2024, 110566.
41. https://doi.org/10.1016/j.mtcomm.2024.110566
42. G. Velmurugan et al.," Experimental analysis of sugarcane and coconut shell fibre impregnated with glass fiber
43. 43. composite for aircraft application" Information Sciences, Elsevier 2024.
44. 44. 10.1016/j.matpr.2024.04.074
45. 45. Tarcísio Martins et al.," Sugarcane biorefinery: Unlocking the potential of the pyrolytic process to convert waste biomasses into value-added products" Information Sciences, Elsevier Volume 318, 2024, 118913. https://doi.org/10.1016/j.enconman.2024.118913

46. 46. PanelJun Qian et a.,” Experimental study on the sugarcane stubble base-cutting mechanism” Information Sciences, Elsevier Volume 245, 2024, 122-134.
47. 47. https://doi.org/10.1016/j.biosystemseng.2024.07.005
48. 48. Chuanyao Dong et al.,” Topographical hard protective coating for joint replacement implants””, Elsevier Volume 33, 2024, 861-873.
49. 49. https://doi.org/10.1016/j.jmrt.2024.09.139
50. 50. Joseph B. Morake et al.,” Failure analysis of corroded heat exchanger CuNi tubes from a geothermal plant” Information Sciences, Elsevier Volume 153, 2023, 107543. 10.1016/j.engfailanal.2023.107543
51. 51. Igor Stadnyk et al., “Effect of the inhibitor on the durability of corrosive wear of metals”2023.
52. 52. Bose M. Edun et al.,” Effect of case hardening on the wear and hardness properties of medium carbon steel for bone crushing application” Heliyon, Volume 9, Issue 7,2023, e17923. 10.1016/j.heliyon. 2023.e17923
53. 53. Rae Eon Kim et al.,” The effect of laser surface treatment for cellular structure-induced
54. 54. Natividad García-Troncoso et al.,” Preparation and performance of sugarcane bagasse ash pavement repair mortars” Elsevier, Volume 19, 2023, e02563. https://doi.org/10.1016/j.cscm.2023.e02563
55. 55. Vikas Yadav et al.,” Dry sliding wear characteristics of natural fibre reinforced poly-lactic acid composites for engineering applications: Fabrication, properties and characterizations” Elsevier,2023.
56. 56. Jiang Ding et al.,” Numerical calculation of sugarcane crushing process based on Smooth Particle Hydrodynamics” Information Sciences, Elsevier   Volume 141, 2023, 107-115.
57. 57. https://doi.org/10.1016/j.fbp.2023.07.008
58. 58. Md Arif Mahmud et al.,” Development of a biocomposites material using sugarcane bagasse and modified starch for packaging purposes” Elsevier,2023.
59. 59. M. Imraan et al.,” Sugar palm (Arenga pinnata) fibers: new emerging natural fibre and its relevant properties, treatments and potential applications” Elsevier,2023.
60. 60. Pedro Akira Bazaglia Kuroda et al.,” Micro-abrasive wear behavior by ball cratering on MAO coating of Tie25Ta alloy” Elsevier,2023.
61. 61. María Teresa Molina et al.,” Protective coatings for metallic heritage conservation: A review” Elsevier,2023.
62. 62. Witold Nawrocki et al.,” Application of the vibro-acoustic signal to evaluate wear in the spindle bearings of machining centers. In-service diagnostics in the automotive industry” Elsevier, Volume 92, 2023, 165-178.
63. 63. Christian Semmler et al.,” Plasma sprayed ceramic coatings for the thermal protection
64. 64. of carbon fiber reinforced plastics (CFRP): Thermal and mechanical properties of YSZ, aluminum titanate, cordierite and mullite coatings” Information Sciences, Elsevier Volume 462, 2023, 129509.
65. 65. https://doi.org/10.1016/j.surfcoat.2023.129509
66. 66. Marc Ackermann et al.,” Explainable machine learning for predicting the mechanical properties in bainitic steels” Elsevier, Volume 230,2023, 111946.
67. 67. Si-Yuan Ma et al.,” Failure analysis on abnormal leakage of shell and tube heat exchanger in specialty chemical plant” Information Sciences, Elsevier, Volume 143, Part A,2023, 106859.
68. 68. 10.1016/j.engfailanal.2022.106859
69. 69. Hrishikesh Patil et al.,” Development and characterization of rigid packaging material using cellulose/sugarcane bagasse and natural resins” Information Sciences, Elsevier, Volume 246,2023, 125641.
70. 70. 10.1016/j.ijbiomac.2023.125641
71. 71. Joseph B. Morake et al.,” Failure analysis of corroded heat exchanger CuNi tubes from a geothermal plant” Information Sciences, Elsevier, Volume 153,2023, 107543.
72. 72. 10.1016/j.engfailanal.2023.107543
73. 73. Ashish Kumar et al.,” The utilisation of coconut shell ash in production of hybrid composite: Microstructural characterization and performance analysis” Information Sciences, Elsevier, Volume 398,2023, 136494.
74. 74. 10.1016/j.jclepro.2023.136494
75. 75. Sajjan Singh Rawat et al.,” Sugarcane bagasse ash—The future composite material: A literature review” Information Sciences, Elsevier. 2023
76. 76. 10.1016/j.matpr.2023.07.272
77. 77. Peng Huo et al.,” Sugarcane leaf-stalk separating technology: A critical review” Information Sciences, Elsevier Volume 228, 2023, 120-148. https://doi.org/10.1016/j.biosystemseng.2023.03.009
78. 78. Jiang Ding et al.,” Numerical calculation of sugarcane crushing process based on Smooth Particle Hydrodynamics” Information Sciences, Elsevier Volume 141, 2023, 107-115
79. 79. https://doi.org/10.1016/j.fbp.2023.07.008
80. 80. Noor Amira Sarani et al., “Physical-mechanical properties and thermogravimetric analysis of fired clay brick incorporating palm kernel shell for alternative raw materials” Information Sciences, Elsevier Volume 376, 2023, 131032.
81. 81. https://doi.org/10.1016/j.conbuildmat.2023.131032
82. 82. Qiangguo Li et al.,” Impact abrasive wear behaviour of the multiphase microstructure in a medium carbon quenched and partitioned bainitic steel” Information Sciences, Elsevier Volumes 518–519, 2023, 204644
83. 83. .https://doi.org/10.1016/j.wear.2023.204644

84. 84. Lukas Widder et al.," Abrasive wear protection in material handling: Mechanism-based combination of lab-experiments for optimal material selection" Information Sciences, Elsevier Volumes 530–531, 2023, 204979.
85. 85. Arkadiusz Gendek et al.," Physico-mechanical and energy properties of pellets made from ground walnut shells, coniferous tree cones and their mixtures" Information Sciences, Elsevier Volume 211, 2023, 248-258
86. 86. https://doi.org/10.1016/j.renene.2023.04.122
87. 87. Khalil Ranjbar et al.," Primming assisted failure of superheater tubes in a sugarcane industry" Information Sciences, Elsevier Volume 151,2023, 107382.
88. 88. 10.1016/j.engfailanal.2023.107382
89. 89. Peng Huo et al.," Sugarcane leaf-stalk separating technology: A critical review" Information Sciences, Elsevier Volume 228, 2023, 120-148
90. 90. https://doi.org/10.1016/j.biosystemseng.2023.03.00958.
91. 91. Wenhui Luo et al.," Numerical simulation and experiment on wrapping characteristics between sugarcane leaves and rotating roller of returning machine" Elsevier, Volume 202, 2022, 107441.
92. 92. Priyabrat Pradhan et al.," Investigation on sliding wear behaviour of walnut shell powder (WSP) filled polyester composites using finite element method" Information Sciences, Elsevier Volume 44, Part 6, 2022, 4190-4195.
93. 93. 10.1016/j.matpr.2020.10.531
94. 94. Oisik Das et al.," Natural and industrial wastes for sustainable and renewable polymer composites" Elsevier, Volume 158, 2022, 112054
95. 95. https://doi.org/10.1016/j.rser.2021.112054
96. 96. Ricardo Aparecido Sasso et al.," Failure analysis of oscillating hammer mill used in the sugarcane industry" Information Sciences, Elsevier Volume 139, 2022, 106472. 10.1016/j.engfailanal.2022.106472
97. 97. Lewei He et al.," Impact and bonding behavior of core-shell powder particles" Information Sciences, Elsevier Volume 441, 2022, 128591.
98. 98. https://doi.org/10.1016/j.surfcoat.2022.128591
99. 99. T. Vennila et al.," Investigation on tensile behaviour of Al/Si3N4/sugarcane ash particles reinforced FSP composites" Information Sciences, Elsevier Volume 59, Part 2, 2022, 1266-1270. 10.1016/j.matpr.2021.11.477
100. 100. Hussein Sayed et al.," A novel method to evaluate the journal bearing forces with application to flexible rotor model" Elsevier, Volume 173, 2022, 107593.
101. 101. https://doi.org/10.1016/j.triboint.2022.107593
102. 102. Ricardo Aparecido Sasso et al.," Failure analysis of oscillating hammer mill used in the sugarcane industry" Information Sciences, Elsevier Volume 139, 2022, 106472. 10.1016/j.engfailanal.2022.106472
103. 103. K G Ravindra et al.," Optimization of design parameters to evaluate the performance of journal bearing: ANN approach" Information Sciences, Elsevier Volume 54, Part 2, 2022, 171-178. 10.1016/j.matpr.2021.08.205
104. 104. Che Wang et al.," Elasto-hydrodynamic lubrication of the journal bearing system with a relief groove in the scroll compressor: Simulation and experiment" Information Sciences, Elsevier Volume 165, 2022, 107252 https://doi.org/10.1016/j.triboint.2021.107252
105. 105. Veronica Testa et al.," Corrosion and wear performances of alternative TiC-based thermal spray coatings" Information Sciences, Elsevier Volume 438, 2022, 128400. https://doi.org/10.1016/j.surfcoat.2022.128400
106. 106. Manoj Settem et al." Surface reconstruction in core shell nanoalloys: Interplay between size and strain" Information Sciences, Elsevier Volume 234, 2022, 118038. 10.1016/j.actamat.2022.118038
107. 107. panel Gülen Tekin et al" Photo-degradation of sugar processing wastewater by copper doped bismuth oxoiodide: Assessment of treatment performance and kinetic studies" Information Sciences, Elsevier Volume 318, 2022, 115432. 10.1016/j.engfailanal.2020.104898
108. 108. Eyal Madar et al.," A new model for bearing spall size estimation based on oil debris" Information Sciences, Elsevier Volume 134, 2022, 106011.
109. 109. 10.1016/j.engfailanal.2021.106011
110. 110. Usman Safder et al.," Optimal configuration and economic analysis of PRO-retrofitted industrial networks for sustainable energy production and material recovery considering uncertainties: Bioethanol and sugar mill case study" Information Sciences, Elsevier Volume 182, 2022, 797-816. https://doi.org/10.1016/j.renene.2021.10.047
111. 111. Hannah Neumann et al.," Comparison of RC-model and FEM-model for a PCM-plate storage including free convection" Information Sciences, Elsevier Volume 196, 2021, 117232. 10.1016/j.applthermaleng.2021.117232
112. 112. Prabhat Kumar et al.," Finite element modelling, analysis and identification using novel trial misalignment approach in an unbalanced and misaligned flexible rotor system levitated by active magnetic bearings" Information Sciences, Elsevier Volume 152, 2021, 107454. 10.1016/j.ymssp.2020.107454
113. 113. Yanmei Meng et al.," Modeling and optimization of sugarcane juice clarification process" Information Sciences, Elsevier Volume 291, 2021, 110223.
114. 114. 10.1016/j.jfoodeng.2020.110223
115. 115. J.P. Siregar et al.," Mechanical properties of hybrid sugar palm/ramie fibre reinforced epoxy composites" Information Sciences, Elsevier Volume 46, Part 4,2021, 1729-1734. 10.1016/j.matpr.2020.07.565
116. 116. Nahieh Toscano Miranda et al.," Sugarcane bagasse pyrolysis: A review of operating conditions and products properties" Information Sciences, Elsevier Volume 149, 2021, 111394.
117. 117. https://doi.org/10.1016/j.rser.2021.111394

118. 118. Shahriar Dastjerdi et al.," On the generalized model of shell structures with functional cross-sections" Information Sciences, Elsevier Volume 272, 2021, 114192.
119. 119. Xin Zhang et al.," Surface modification, adsorption behavior, and optical properties of α-Fe2O3@SiO2/Au core-shell ellipsoids" Information Sciences, Elsevier Volume 625,2021, 126888. 10.1016/j.colsurfa.2021.126888
120. 120. E. García et al.," Mechanical, dynamic and tribological characterization of HDPE/peanut shell composites" Elsevier, Volume 98,2021, 107075.
121. 121. 10.1016/j.polymertesting.2021.107075
122. 122. Annett Dorner-Reisel et al.," Thermally sprayed coatings for protection of integrated sensor systems on tribological loaded surfaces" Information Sciences, Elsevier Volume 424, 2021, 127619
123. 123. https://doi.org/10.1016/j.surfcoat.2021.127619\\
124. 124. J.R. Deepak et al.," Microstructure and metallurgical property investigation of welded IRSM 41-97 rail steel joints" Information Sciences, Elsevier Volume 47, Part 14, 2021, 4827-4832. 10.1016/j.matpr.2021.06.056