
FIELD-VALIDATED FAILURE ANALYSIS OF COMMERCIAL TRICYCLES IN NIGERIA AND THE POTENTIAL OF AGRICULTURAL RESIDUE-REINFORCED ALUMINIUM MATRIX COMPOSITES FOR PISTON DURABILITY ENHANCEMENT

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ABSTRACT

Commercial tricycles are indispensable to the Nigerian transport network, yet their reliability is compromised by recurring mechanical failures whose material origins remain poorly understood. This study integrates a cross-sectional survey of 333 stakeholders, comprising riders, mechanics, and dealers, across six Nigerian states with materials-science analysis to interpret reported faults and identify sustainable intervention strategies. TVS accounted for 73.0% of the fleet. The most prevalent faults were clutch wear (14.2%), piston damage (13.3%), kick-rod fracture (13.3%), frame corrosion (10.0%), and chassis cracking (7.5%). Three primary degradation mechanisms emerged: fatigue-induced fracture, abrasive wear, and substandard components, with 48.6% of respondents attributing failures to these factors. These constitute a self-perpetuating triad that sustains reactive maintenance practices among 59.5% of operators. Logistic regression identified duration of use (AOR = 1.297 per year; $p < 0.001$) and fairly-used purchase (AOR = 1.887; $p = 0.032$) as significant predictors of piston damage. The study aims to map component failures, prioritise targets for materials intervention, and establish a foundation for developing agricultural residue-reinforced aluminium matrix composites. Published studies demonstrate the potential of such composites to enhance wear resistance and mechanical properties, yet no work has validated their application under Nigerian tricycle operating conditions. By linking field-reported faults to a viable materials solution, this study provides the empirical basis for designing and testing locally sourced, reinforced pistons for the Nigerian tricycle sector.

Keywords: Agricultural-residues; Failure-analysis; Mechanical-degradation; Nigeria; Piston-failure; Tricycle

1. INTRODUCTION

The commercial tricycle has emerged as the backbone of intra-urban mobility across Nigeria, filling gaps left by inadequate public transport. Low acquisition cost, fuel economy, and superior manoeuvrability have driven rapid adoption. In Kano State alone, there are over 41,000 registered tricycles, which together make about 383,000 trips each day and bring in more than ₦2.1 billion in revenue (Ibrahim, 2025). Their relatively low start-up cost has also made it easier for many people to enter the transport business (Ojekunle, 2009).

Despite their importance, the reliability of these tricycles is often undermined by repeated mechanical breakdowns. They are involved in about 6% of traffic-related injuries (Animasahun *et al.*, 2022), and the Federal Road Safety Corps estimates that mechanical failures play a part in nearly 30% of deadly crashes (Ogunleye *et al.*, 2024). When a tricycle breaks down, each day off the road means a loss of between ₦3,000 and ₦5,000 in earnings, which puts serious financial pressure on operators (Ameen *et al.*, 2025).

Commonly reported faults including clutch slippage, piston seizure, chassis cracking, and crankshaft fracture are usually the result of metal fatigue, corrosion, abrasive wear, and substandard alloy compositions (Kuram *et al.*, 2024; Suresh, 1998; Stephens *et al.*, 2000). Fatigue alone is implicated in up to 90% of automotive service failures (Stephens *et al.*, 2000). Metallurgical examination of a failed tricycle front axle revealed carbon content of 0.354 wt%, below specification, with ferrite-pearlite microstructures indicating inadequate heat treatment (Abubakar *et al.*, 2025).

The situation is worsened by the poor quality of replacement parts. More than 60% of imported components do not meet safety standards (Okonkwo *et al.*, 2024), and a staggering 95% of imported spare parts are considered substandard (Adebayo *et al.*, 2024), all within a spare parts market worth between \$5 and \$6 billion (Adewale *et al.*, 2025).

Earlier work has been limited to single component analyses without examining interrelationships. Aluminium matrix composites reinforced with agricultural residues have emerged as promising low-cost alternatives (Asafa *et al.*, 2025; Mogal *et al.*, 2024). Nigeria generates approximately 32 million tonnes of agricultural waste annually (Asafa *et al.*, 2025). Coconut shell ash reinforcement decreased wear loss by 64.7% and raised tensile strength by 45.6% (Ghosh *et al.*, 2025). Rice husk ash improved tensile strength to 121.6 MPa at 10 wt% addition (Abolusoro *et al.*, 2024).

This study addresses knowledge gaps by integrating a large-scale field survey of 333 stakeholders with materials science analysis of fault patterns. The aim is to map tricycle components failures, identify priority targets for sustainable materials intervention, and lay the foundation for developing agricultural residue reinforced aluminium matrix composites.

2. MATERIALS AND METHODS

2.1 Study Design and Population

A cross-sectional descriptive survey was conducted between October 2025 and April 2026 across Lagos, Oyo, Osun, Ondo, Ogun, and Ekiti states. The target population comprised tricycle riders, mechanics, and dealers. A multi-stage stratified random sampling technique was employed. A total of 333 respondents completed questionnaires: 252 riders (75.7%), 45 dealers (13.5%), and 36 mechanics (10.8%). Sample size was determined using Cochran's formula at 95% confidence level with 5% margin of error.

2.2 Survey Instrument and Data Collection

A structured questionnaire captured socio-demographics, usage history, common faults, spare-parts availability, and maintenance practices. Respondents could report multiple fault types. Face and content validity were established through expert review. Pilot testing on 20 respondents yielded Cronbach's alpha of 0.82. Trained research assistants administered questionnaires through face-to-face interviews.

2.3 Data Processing and Statistical Analysis

Data was coded and verified through double-entry verification. Statistical analyses were performed using IBM SPSS (version 29.0). Descriptive statistics, cross-tabulations, and Pearson chi-square tests were employed, with statistical significance set at $p < 0.05$.

The sample size was determined using Cochran's formula:

$$n_0 = Z^2 pq / e^2 \quad (1)$$

Where:

n_0 is the initial sample size,

Z is the Z-score corresponding to the desired confidence level (1.96 for 95% confidence),

p is the estimated population proportion (assumed 50% as the most conservative estimate),

q is $1-p$, and

e is the margin of error (5%).

To account for potential non-response, the sample size was increased by 10%. Degrees of freedom for chi-square tests were derived from contingency table dimensions: duration of use (four categories) against piston damage (two categories), $df = 3$; brand (three categories) against piston damage (two categories), $df = 2$; and mode of purchase (two categories) against piston damage (two categories), $df = 1$.

To examine the simultaneous influence of multiple risk factors on piston damage prevalence while controlling for potential confounding variables, binary logistic regression analysis was performed. The dependent variable was coded as 1 for respondents reporting piston damage and 0 otherwise. Independent variables included tricycle brand (categorical: TVS, Bajaj, Piaggio), duration

of use (continuous, in years), mode of purchase (binary: new compared to fairly used), and respondent type (categorical: rider, mechanic, dealer).

The logistic regression model was specified as:

$$\ln \left(\frac{p}{1-p} \right) = \beta_0 + \beta_{1(\text{Brand})} + \beta_{2(\text{Duration})} + \beta_{3(\text{Purchase Mode})} + \beta_{4(\text{Respondent Type})} \quad (2)$$

Where:

p is the probability of piston damage occurrence.

The model was estimated using maximum likelihood estimation with robust standard errors. Model fit was assessed using the Hosmer-Lemeshow goodness-of-fit test and the Nagelkerke R² statistic. The Hosmer-Lemeshow test evaluates whether observed event rates match expected event rates in subgroups of the model population, with a non-significant p-value ($p > 0.05$) indicating good model fit. Nagelkerke R² provides an approximation of the proportion of variance explained by the model. Results are reported as adjusted odds ratios (AOR) with 95% confidence intervals and corresponding p-values.

2.4 Ethical Considerations

Informed consent was obtained from each participant. No personal identifiers were collected; data was stored securely and used in aggregated form.

3. RESULTS AND DISCUSSION

3.1 Demographic and Operational Characteristics

Table 1 summarises the demographic and operational characteristics of the sample (N = 333). The majority were male (86.5%) and riders (75.7%), with TVS as the dominant brand (73.0%). Most tricycles were manufactured between 2016 and 2020 (40.5%), used for 1–3 years (43.2%), and purchased new (56.8%). Lagos (24.9%) and Osun (24.0%) contributed the highest proportions.

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Table 1: Demographic and Operational Characteristics (N = 333)

Variable	Category	n	%	Variable	Category	n	%
Respondent Type	Dealer	45	13.5	Tricycle Brand	Bajaj	63	18.9
	Mechanic	36	10.8		Piaggio	27	8.1
	Rider	252	75.7		TVS	243	73.0
Gender	Female	45	13.5	Manufacturing Year	2006–2010	72	21.6
	Male	288	86.5		2011–2015	72	21.6
Age (years)	< 20	9	2.7		2016–2020	135	40.5
	20–29	108	32.4	*Usage Duration	2021–2025	54	16.2
	30–39	99	29.7		< 1 year	27	8.1
	40–49	81	24.3		1–3 years	144	43.2
	≥ 50	36	10.8		4–6 years	117	35.1
Experience (years)	< 2	90	27.0	Purchase Type	> 6 years	45	13.5
	2–5	135	40.5		Fairly used	144	43.2
	6–10	81	24.3		New	189	56.8
	> 10	27	8.1				
Location	Ekiti	47	14.1				
	Lagos	83	24.9				
	Ogun	46	13.8				
	Ondo	26	7.8				
	Osun	80	24.0				
	Oyo	51	15.3				

**Year refers to manufacturing year; Duration refers to years in use by current respondent.*

3.2 Common Faults and Priority Target Identification

Total fault mentions (1062) exceed sample size as multiple faults could be reported. Figure 1 shows distribution; Table 2 provides mechanisms. Clutch problems (14.2%), piston damage (13.3%), and kick-rod issues (13.3%) were most frequent. Brake leather issues (10.8%), frame corrosion (10.0%), ring damage (8.3%), and crankshaft issues (8.3%) were also prevalent.

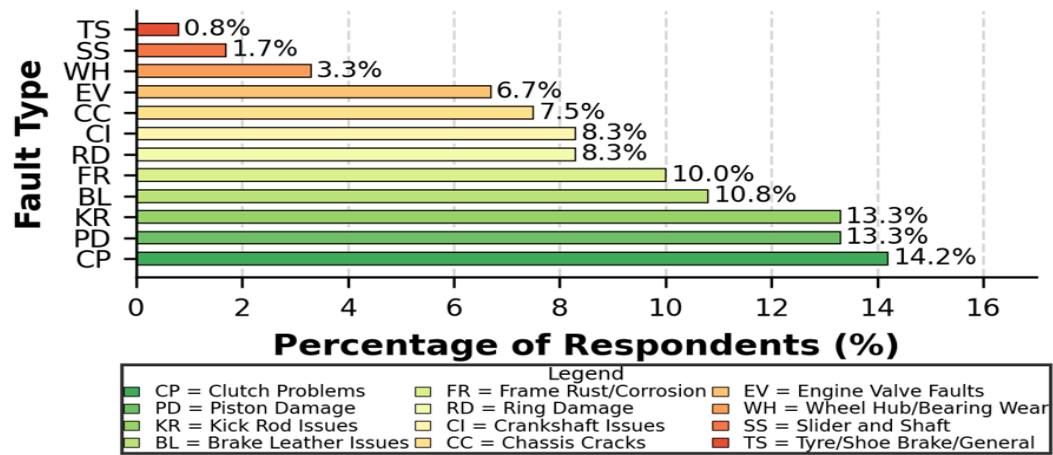


Figure 1: Prevalence of common mechanical faults (CP = Clutch Problems, PD = Piston Damage, KR = Kick Rod, BL = Brake Leather, FR = Frame Rust, RD = Ring Damage, CI = Crankshaft, CC = Chassis Cracks, EV = Engine Valve, WH = Wheel Hub, SS = Slider/Shaft, TS = Tyre/Brake).

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Table 2: Frequency of Reported Faults and Associated Material Degradation Mechanisms

Fault Type	Respondent (n)	Frequency (%)	Primary Metallurgical Mechanism(s)
Clutch Problems	153	14.2	Wear of friction material; thermal degradation of organic binders
Piston Damage	144	13.3	Casting defects in Al-Si alloy; inadequate heat treatment; adhesive wear
Manual Kick-Rod Issues	144	13.3	Fatigue fracture at stress concentrators
Brake Leather Issues	117	10.8	Abrasive wear; delamination of friction lining
Frame Rust/Corrosion	108	10.0	Uniform and pitting corrosion of unprotected mild steel
Ring Damage	90	8.3	Poor-quality cast iron; insufficient hard-chrome plating
Crankshaft Issues	90	8.3	Fatigue crack initiation at crankpin fillet; insufficient surface hardness
Chassis Cracks/Breakage	81	7.5	High-cycle fatigue; weld-defect-induced crack propagation
Engine Valve Faults	72	6.7	Adhesive/abrasive wear of valve seat; thermal fatigue
Wheel Hub/Bearing Wear	36	3.3	Rolling-contact fatigue; inadequate lubrication
Slider and Shaft	18	1.7	Fretting wear
Tyre/Shoe Brake/General	9	0.8	Mixed mechanisms
Total	1062	100.0	

3.2.1 Piston Damage as Priority Target

Piston damage (13.3% of fault mentions) represents a priority target. Pistons operate under extreme conditions: 250–350°C, cyclic loading, and sliding contact (Kowalski *et al.*, 2024). Failure mechanisms (adhesive wear, fatigue cracking, inadequate heat treatment) are addressable through composites.

Table 3 shows piston failure rates by brand and duration. Chi-square analysis revealed significant association with duration of use ($\chi^2 = 23.56$, $df = 3$, $p < 0.001$), with 54.2% of tricycles beyond six years reporting damage compared to 8.2% under one year. Brand differences were significant ($\chi^2 = 6.08$, $df = 2$, $p = 0.048$), with Bajaj highest (15.9%), followed by Paggio (14.3%) and TVS (12.3%). Mode of purchase showed significant association ($\chi^2 = 4.62$, $df = 1$, $p = 0.032$), with fairly used vehicles at 18.5% against 10.8% for new.

Table 3: Piston Damage Prevalence by Tricycle Characteristics

Variable	Category	Piston Damage Reported (%)	χ^2	df	p-value
Brand	TVS	12.3	6.08	2	.048
	Bajaj	15.9			
	Piaggio	14.3			
Duration of Use	<1 year	8.2	23.56	3	< .001
	1–3 years	11.2			
	4–6 years	16.8			
	>6 years	54.2			
Mode of Purchase	New	10.8	4.62	1	.032
	Fairly Used	18.5			

3.2.2 Multi-Factor Assessment of Piston Damage Risk

Binary logistic regression identified independent predictors of piston damage. As shown in Table 4, the model showed good fit (Hosmer-Lemeshow $\chi^2 = 6.34$, $df = 8$, $p = 0.609$) and explained 28.7% of the variance (Nagelkerke $R^2 = 0.287$). Duration of use was the strongest predictor; each additional year increased the odds of damage by 29.7% (AOR = 1.297; 95% CI: 1.178–1.428; $p < 0.001$). Fairly used vehicles had 88.7% higher odds than newer ones (AOR = 1.887; 95% CI: 1.058–3.367; $p = 0.032$). Vehicle brand and respondent type were not significant. The remaining variance reflects the influence of unmeasured field factors, including load variations, road conditions, and maintenance practices.

Table 4: Logistic Regression Analysis of Factors Associated with Piston Damage

Variable	Category	AOR	95% CI	p-value
Brand	TVS	1.000	—	—
	Bajaj	1.342	0.891–2.021	0.159
	Piaggio	1.218	0.742–1.999	0.436
Duration	Per year	1.297	1.178–1.428	<0.001
Purchase	New	1.000	—	—
	Fairly Used	1.887	1.058–3.367	0.032
Respondent	Rider	1.000	—	—
	Mechanic	1.124	0.642–1.969	0.684
	Dealer	0.978	0.554–1.727	0.938

AOR = adjusted odds ratio; CI = confidence interval; bold = $p < 0.05$.

3.3 Failure Initiation Factors and Maintenance Practice

Low-quality materials (48.6%) and poor road conditions (37.8%) account for 86.4% of reported failure factors as presented in Figure 2. Poor maintenance (10.8%) and overloading (2.7%) were secondary. This corroborates the Standards Organisation of Nigeria's report that 95% of imported spare parts are substandard (Adebayo *et al.*, 2024).

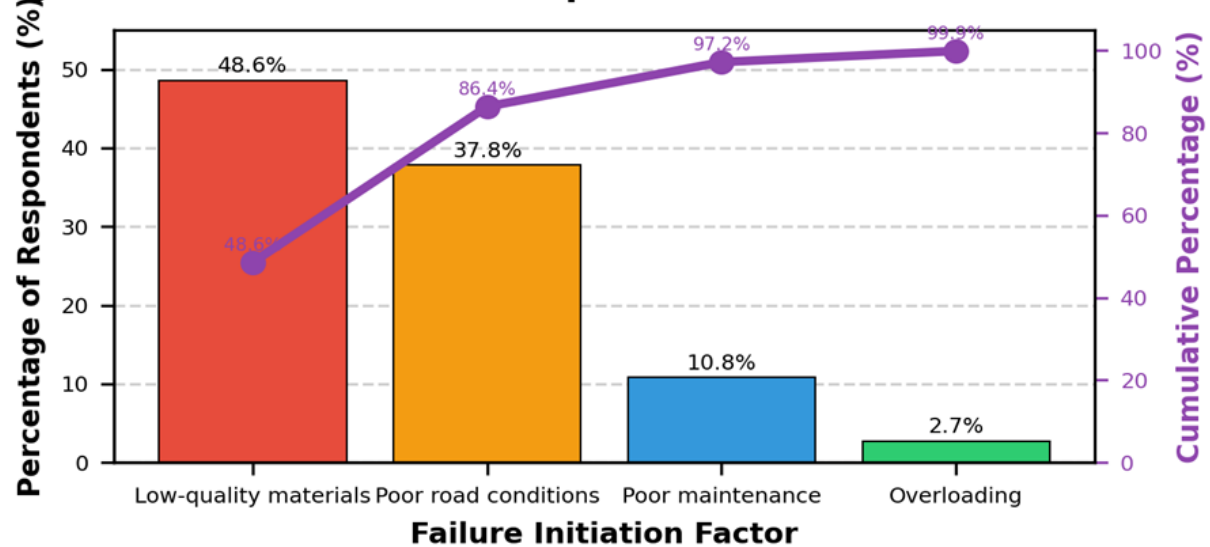


Figure 2: Pareto chart of reported failure initiation factors in commercial tricycles showing Low-quality materials (48.6%) and poor road conditions (37.8%) account for 86.4% of all reported factors, indicating these are the primary drivers of recurrent mechanical failures. Poor maintenance (10.8%) and overloading (2.7%) represent secondary contributing factors. The cumulative percentage line shows the progressive contribution of each factor.

Figure 3 shows maintenance practices. Reactive maintenance predominates (59.5%), with operators repairing only after failure. Scheduled maintenance at 3–6 months (16.2%), monthly (13.5%), weekly (8.1%), and annual (2.7%) were less common.

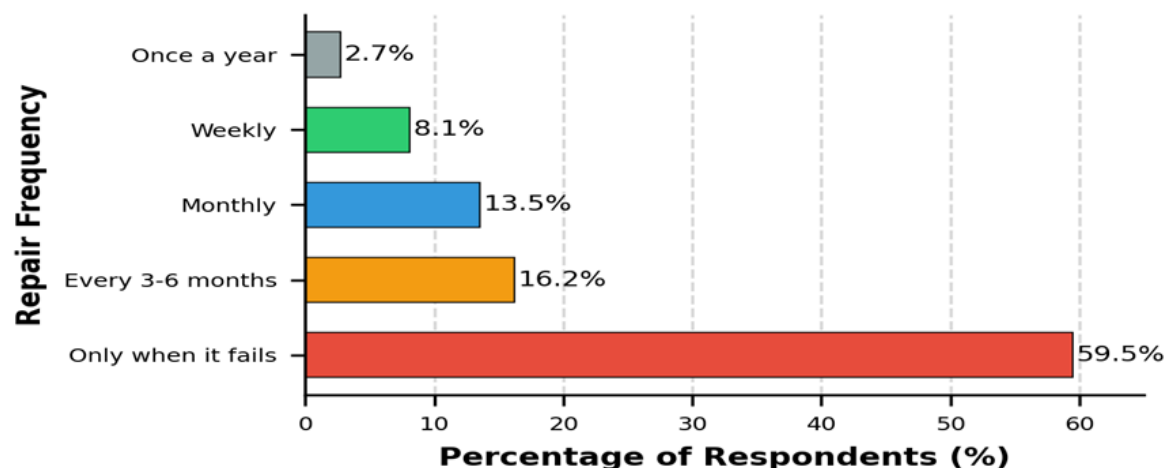


Figure 3: Maintenance practices among commercial tricycle operators (N = 333). The majority (59.5%) adopt a reactive approach, repairing components only after failure. Scheduled preventive maintenance is practiced by 40.5% of operators, with intervals ranging from weekly (8.1%) to annual (2.7%). Data collected through structured questionnaire from 333 respondents across six Nigerian states

3.4 Spare-Parts Availability, Quality Perception and Ease of Maintenance

Table 5 shows spare-parts availability by brand. TVS had best availability (67.6% available, 8.1% not available). Bajaj had 70.3% available, 10.8% not available. Piaggio had the poorest availability (45.9% available, 32.4% not available).

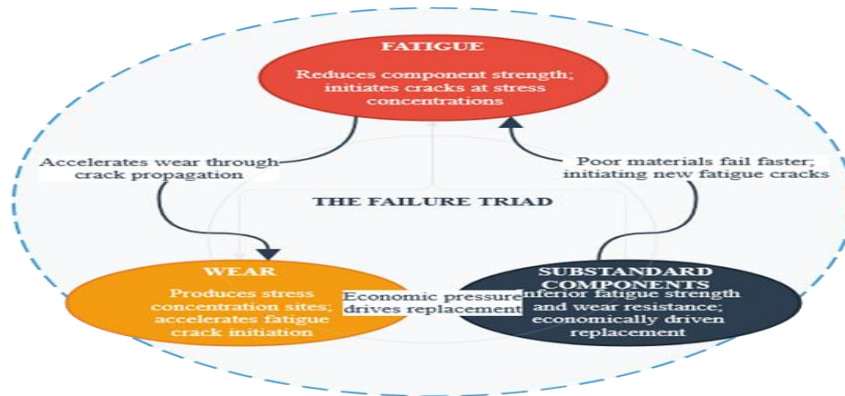
Table 5: Spare-Parts Availability by Brand

Brand	Available (%)	Expensive but Available (%)	Not Available (%)
Bajaj	70.3	18.9	10.8
Piaggio	45.9	21.6	32.4
TVS	67.6	24.3	8.1

TVS parts were unavailable 8.1% of the time, a considerably smaller gap than the 32.4% recorded for Piaggio, yet this still poses a risk of substandard parts entering the supply chain. When genuine parts are scarce, operators often turn to inferior alternatives, a pattern well documented in Nigerian aftermarket studies (Okonkwo *et al.*, 2024). Perceptions of maintainability mirrored these availability trends: 73.0% of respondents rated TVS as the easiest brand to maintain, versus 16.2% for Bajaj, whereas only 10.8% found Piaggio easy to maintain. Furthermore, 59.5% of respondents believed that material quality substantially affects tricycle performance and lifespan.

3.5 Theoretical Framework: The Failure Triad

Findings establish fatigue, wear, and substandard components as a self-perpetuating triad as illustrated in Figure 4. Fatigue reduces strength and accelerates wear; wear generates debris and stress concentrations promoting fatigue; economic pressure drives substandard replacement (Stephens *et al.*, 2000; Suresh, 1998). Reactive maintenance ensures replacement after failure, often with substandard parts, completing the cycle. Logistic regression as shown in Table 5 quantified this: each year increases odds by approximately 30%; fairly-used purchase elevates odds by 89%.



Source: Field survey data (N=333). Reactive maintenance reported by 59.5% of operators.

Figure 4: Schematic representation of the self-perpetuating failure triad in commercial tricycles. Fatigue reduces strength; wear produces stress concentration; economic pressure drives substandard replacement.

3.6 Agricultural Residue-Reinforced Aluminium Composites as a Sustainable Materials Strategy

Agricultural residue-reinforced aluminium matrix composites mitigate abrasive wear, fatigue fracture, and substandard materials (Sanusi and Adebisi, 2026). Palm kernel shell powder (15 wt%) in Al-Mg-Si reduces wear (Mohammed *et al.*, 2022); rice husk ash raises fatigue endurance from 0.224×10^6 to 2.582×10^6 cycles (Asafa *et al.*, 2014). Coconut shell ash (45.1% SiO₂, 15.5% Al₂O₃, 12.4% Fe₂O₃) lowers wear loss 64.7%, reduces friction coefficient from 0.34 to 0.22, increases tensile strength by 45.6% from 98 MPa to 143 MPa, and improves Microhardness by 22.5% from 31.5 HV to 38.6 HV (Ghosh *et al.*, 2025). Rice husk ash (10 wt %) gives 121.6 MPa and 74.5 HBW (Aboloruso *et al.*, 2024); with granite dust, wear drops 56.25% (Mogal *et al.*, 2024). Challenges include poor bonding, addressed by 2–5% Mg for wettability, and agglomeration, mitigated by double stir casting; optimal reinforcement is 5–10 wt% (Asafa *et al.*, 2025; Ge *et al.*, 2025; Olorunfemi *et al.*, 2021). These renewable residues enable 95% energy savings in secondary Al production and 15–25% cost reduction over SiC

composites, offering a sustainable pathway to enhanced durability and reliability (Ge *et al.*, 2025; Sanusi and Adebisi, 2026).

4. CONCLUSION

This investigation identifies clutch wear (14.2%), piston damage (13.3%), kick-rod fracture (13.3%), frame corrosion (10.0%), and chassis cracking (7.5%) as the most prevalent faults, originating from fatigue, abrasive wear, and substandard components (48.6%). Logistic regression confirmed duration of use (AOR = 1.297/year; $p < 0.001$) and fairly-used purchase (AOR = 1.887; $p = 0.032$) as significant piston-damage predictors, while reactive maintenance (59.5%) perpetuates the failure cycle. Piston damage is prioritised for materials intervention, with coconut shell ash composites offering 64.7% wear reduction, 45.6% tensile strength improvement, and 22.5% hardness enhancement. Future research should experimentally validate these composites through XRF characterisation, ASTM-standard mechanical testing, and accelerated wear simulation, while policymakers enforce stricter quality standards and manufacturers invest in double-stir casting with 5–10 wt% agricultural residue reinforcement.

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