An Analysis of Engineering Safety Practices and Occupational Hazards in Local Blacksmith Forging Workshops: A Cross-Sectional Study of Damaturu Metropolis, Nigeria

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Abstract

Background. *The informal metallurgical sector, particularly local blacksmithing, is central to the grassroots economy in Northern Nigeria. However, the shift from manual to mechanised forging has introduced serious occupational hazards without comparable safety improvements.*

Methods. *A cross-sectional study was conducted in 60 blacksmithing workshops in Damaturu city, Yobe State, selected by stratified random sampling. Data were collected through researcher-administered observation checklists and structured interviews and were analysed using descriptive statistics, Chi-square tests, and multiple linear regression.*

Results. *Major deficiencies were found in engineering controls: only 31% of motorized and electric workshops (n = 36) had functional machine guarding, equivalent to 18% of the total sample (N = 60). The mean electrical safety score was 3.2 out of 10. Personal Protective Equipment (PPE) compliance was critically low (mean 24%), and no workshop possessed a standard fire extinguisher. The average accident rate over a two-year period was 2.8 injuries per workshop. Multiple regression analysis showed that machine guarding ($\beta = -0.45$, $p < .01$) and electrical safety score ($\beta = -0.38$, $p < .05$) were significant negative predictors of accident history.*

Conclusion. *The high rate of occupational injuries in Damaturu's blacksmithing industry is directly linked to the absence of basic engineering controls. It is recommended that the Small and Medium Enterprises Development Agency (SMEDAN) and local technical institutes initiate urgent, context-specific interventions.*

Keywords: *Occupational Health and Safety, Informal Sector, Engineering Controls, Blacksmithing, Damaturu, Nigeria*

1. INTRODUCTION

In a developing country such as Nigeria, the informal manufacturing sector is considered a major contributor to economic growth and labour creation (International Labour Organization [ILO], 2022). Blacksmithing in the local context remains a basic element of the grassroots economy and plays a part in the manufacturing of important home equipment, construction materials, and agricultural implements (Ibitoye & Ilori, 1998). The blacksmithing workshops are located in important commercial centres in Yobe State such as Potiskum, Nguru, Geidam, Gashua, and Yadin Buni, especially within the Damaturu metropolis. These centres are critical linkages for local supply chains (Yobe State Ministry of Commerce and Industry, 2024).

Despite its economic relevance, the hazardous working environment that characterises the local blacksmith sector is a major drawback (Lawal et al., 2020). Historically, this sector relied on manual forging. Recently, however, many workshops in Damaturu and other thriving communities across Nigeria have shifted to motorised and electrically powered tools (e.g., power hammers, electric grinders) to boost productivity (Okonkwo & Ibeanu, 2016). This mechanisation has occurred without the integration of fundamental engineering safety controls. Consequently, personnel are exposed to severe occupational hazards, including mechanical entanglement, electrocution, thermal burns, and respiratory issues from forge fumes (Afolabi, 2022; Oleru & Ademiluyi, 1987).

While extensive Occupational Health and Safety (OHS) research exists for Nigeria's formal industrial sectors, such as oil and gas and large-scale manufacturing (Akinbode et al., 2024), the informal metallurgical business remains largely under-researched, particularly in geopolitical Northern Nigeria. This study aims to bridge this empirical gap by analysing engineering safety practices in Damaturu metropolis. The specific objectives are to: (1) assess the pervasiveness of engineering controls (machine guarding, ventilation, electrical safety); (2) evaluate PPE compliance and administrative safety practices; and (3) determine the relationship between these safety practices and occupational accident rates.

2. LITERATURE REVIEW

2.1 Occupational Hazards in Metallurgy

Blacksmithing involves working with heavy materials and high-temperature operations. Steel and other metallic components are usually heated to extreme temperatures, mostly above 1,000 °C, to become workable; the materials are, by their characteristics, dense and heavy, requiring significant physical effort to shape (Lekakh et al., 2026). According to the literature, the major risks include thermal burns, musculoskeletal disorders due to repetitive heavy lifting, noise-induced hearing loss, and respiratory problems from the inhalation of metallic and carbonaceous fumes (Ghosh et al., 2011). With the development of grinding machines and power hammers in motorized workshops, workers are exposed to additional hazards of mechanical laceration, projectile injury, and electrocution.

2.2 The Hierarchy of Controls

The National Institute for Occupational Safety and Health (NIOSH, 2020) has a Hierarchy of Controls model that emphasizes the implementation of controls to reduce hazards in the workplace; The hierarchy (see Figure 1) represents the relative effectiveness of hazard control techniques, from elimination (most effective) to personal protective equipment (PPE) (least effective). In the Damaturu blacksmithing sector, most of the workshops operate largely at the lower levels of controls, that is, administrative controls and PPE, while engineering controls such as machine guarding and electrical safety systems are still largely

under implemented. The imbalance emphasizes the need to shift safety interventions up the hierarchy, with a focus on engineering and elimination actions to make real progress in reducing injuries at work.

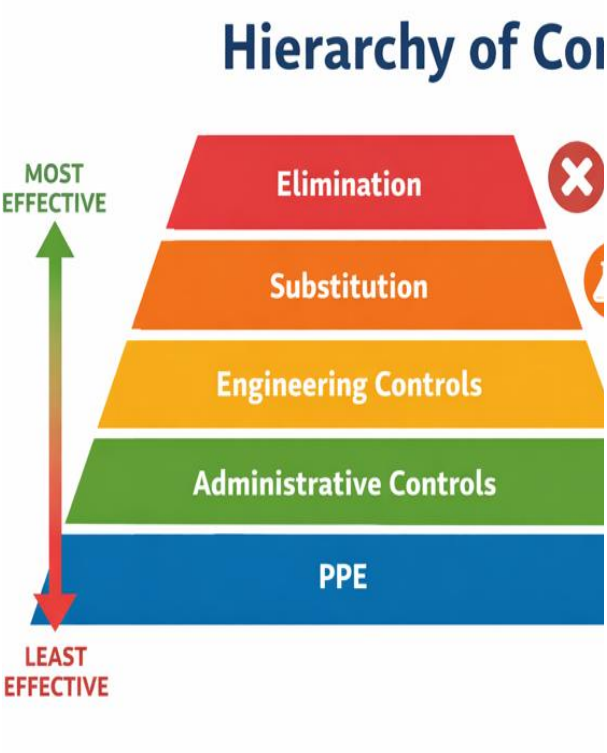

Figure 1 *Hierarchy of Controls in Relation to Safety Practices in Damaturu Blacksmith Workshops.*

2.3 Safety in the Informal Sector

In Sub-Saharan Africa, studies of informal artisan workshops consistently report systematic neglect of OHS (McCann, 1996). Significant differences were observed in the adherence to rules of use of protective wear among industrial workers in Kano State as 25% of the workers always wore PPE, 62% occasionally used PPE and 12% never wore PPE. (Rayyan et al., 2022). However, the study does not directly specify informal metalworkers or their working devices/machines. The study found that the key predictors of PPE use were statutory regulations and the availability of PPE at the worksite.

Unsafe electrical generators were often wired wrong and ungrounded, creating a high risk of electrocution. A similar study in Kenya reported that electrical systems in informal workshops are characterised by poor installation and lack of proper grounding, creating a risk of electrocution for personnel (Mutai et al., 2007). Fatal electrocutions were also found to be associated with poor wiring, lack of insulation, and absence of PPE. That survey further concluded that 70% of informal workshops showed poor regulatory non-compliance with the Kenya Standards Organisation. This paper adds to these findings by providing localised empirical data for the Damaturu metropolis.

3. METHODOLOGY

3.1 Study Area and Design

The study was conducted in Damaturu metropolis, the capital of Yobe State, Nigeria (see Figure 2). The study utilized a cross-sectional survey design to assess the safety practices of local blacksmithing workshops.

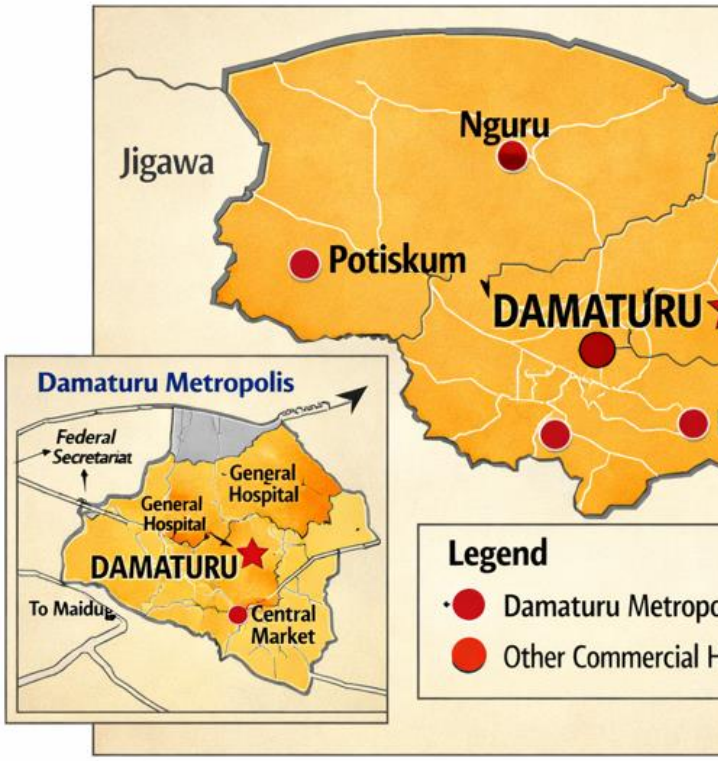

Figure 2 *Map of Yobe State Showing Damaturu Metropolis and Other Commercial Hubs.* Base map data: Yobe State Ministry of Lands and Survey. Map created by the authors.

3.2 Population and Sampling

The population of the study was all the functional blacksmith workshops in Damaturu metropolis. Stratified random sampling technique was adopted by stratifying the workshops by location (Makera, Old Market, Tsohuwar Kasuwa, Bindigari and Nasarawa). The study selected a total number of 60 workshops, representing about 30% of the estimated population of blacksmithing clusters in the metropolis.

3.3 Data Collection Instruments

Two instruments were used to collect the data:

1. **Workshop Observation Checklist:** Administered by the lead researcher to objectively measure engineering controls (machine guarding, ventilation quality, electrical safety scored on a 0-10 scale, and ergonomic factors).
2. **Structured Interview Schedule:** This schedule was administered to the master blacksmiths to gather demographic data, workforce size, power sources, PPE usage rates, and accident history in the last 24 months.

3.4 Data Analysis and Ethical Considerations

Data were analysed using IBM SPSS Statistics Version 26. Descriptive statistics (frequencies, percentages, means) were used to describe safety practices. Inferential statistics were employed to test relationships between variables (Chi-square tests and multiple linear regression).

Ethical approval was obtained from the Research Ethics Committee of the Federal Polytechnic Damaturu, Nigeria. Permission to access the workshops was obtained from the Damaturu Blacksmiths Association, and informed verbal consent was obtained from all participating workshop master's prior to data collection.

4. RESULTS

4.1 Demographic and Workshop Characteristics

Table 1: Descriptive Statistics of Surveyed Workshops (N = 60)

Variable	Category/Statistic	Value
Workforce	Mean workforce members	4.2
	Sample size (workshops)	60
Power source	Manual forging	40% (n=24)
	Motorized/generator-powered tools	45% (n = 27)
	Fully electric	15% (n = 9)
Years in operation	>10year	65% (n = 39)

The survey was carried out in 60 workshops with an average of 4.2 employees (see Table 1). The majority of tools used were motorized/generator-powered (45%), 40% were manual forging tools and 15% were fully electric. Furthermore, most workshops (65%) had been in existence for more than 10 years.

4.2 Assessment of Engineering Controls

Table 2: Engineering Control Evaluation in Surveyed Workshops (N = 60)

Variable	Category/Statistic	Value
Machine Guarding	Functional guards on grinding wheels/flywheels	31% (n = 11)
	As proportion of total sample (N=60)	18%
Ventilation	Natural cross-ventilation ("Poor")	72% (n = 43)
	Mechanical exhaust systems ("Good")	8% (n = 5)
Electrical Safety	Mean safety score (all workshops, scale 0–10)	3.2
	Mean score (portable petrol generator workshops)	2.1
	Key issues	Exposed wiring; lack of earthing

As shown in Table 2, the engineering controls were evaluated, and serious deficiencies were identified in the surveyed workshops. Machine guarding was particularly inadequate. Only 31% (n = 11) of the motorised and electric workshops (n = 36) had functional guards on grinding wheels or power hammer flywheels, representing 18% of all surveyed workshops. Ventilation practices were generally poor, with 72% (n = 43) of workshops using only natural cross-ventilation, classified as "Poor," and only 8% (n = 5) using mechanical exhaust, classified as "Satisfactory." Electrical safety was below standard, with an average safety score of 3.2 out of 10 across all workshops. Workshops with portable petrol generators with no earthing/grounding and exposed wiring had the lowest scores (M = 2.1). These results highlight major limitations of engineering controls, with significant implications for worker safety.

4.3 PPE and Administrative Practices

Table 3: Administrative Control and PPE Usage in Surveyed Workshops (N = 60)

Variable	Category/Statistic	Value
PPE Compliance	Mean Compliance Score	24%
PPE Types Used	Leather aprons	Widely used
	Safety goggles	12%
	Steel-toed boots	8%
Emergency Preparedness	Workshop with basic first aid box	15%(n=9)
	Workshop with fire extinguisher	0%(n=0)

As shown in Table 3, the evaluation of administrative controls and personal protective equipment (PPE) use indicated critically low levels of compliance across the surveyed workshops. Compliance with PPE was only 24% on average, suggesting that basic safety was largely ignored. Leather aprons were the most common, but other essential protective gear was used sparingly: only 12% of workshops reported the use of safety goggles and 8% reported the use of steel-toed boots. In respect of emergency preparedness, only 15% (n = 9) of workshops had a basic first aid box available and none (0%) had a standard fire extinguisher available on the premises. These findings highlight serious deficiencies in administrative safety measures and the provision of PPE that leave workers exposed to preventable injuries.

4.4 Accident History and Inferential Analysis

Table 4: Occupational Injuries and Predictors in Surveyed Workshops (N = 60)

Variable	Category/Statistic	Value/Result
Occupational injury	Mean injuries per workshop (2 years)	2.8
Chi-square Test	Power source x Accident history	$\chi^2(2) = 8.45$, $p = .014$
	Higher injury rates	Motorized/generator workshops
Regression Model	Overall model significance	$R^2 = .42$, $p < .001$
	Predictor: Machine Guarding	$\beta = -0.45$, $p < .01$
	Predictor: Electrical Safety Score	$\beta = -0.38$, $p < .05$
	Predictor: PPE Compliance Score	ns (not significant)

Occupational injury data were analyzed and showed (see Table 4) an average of 2.8 injuries (burns, lacerations, and eye injuries) reported per workshop in the past two years. A Chi-square test indicated a significant association between power source and accident history, $\chi^2(2) = 8.45$, $p = .014$, with motorized/generator-powered workshops reporting significantly higher rates of injury than manual ones. A multiple linear regression was also run to predict accident history using machine guarding (binary), electrical safety score, and PPE compliance score. The overall model was significant, ($R^2 = .42$, $p < .001$). Machine guarding ($\beta = -0.45$, $p < .01$) and electrical safety score ($\beta = -0.38$, $p < .05$) were both significant negative predictors of accident history, meaning that increases in these engineering controls were strongly related to decreases in workplace injuries.

5. DISCUSSION

The findings of this study indicate an unsafe OHS environment in the blacksmithing industry of Damaturu, with systemic inadequacies in engineering controls, administrative controls, and PPE compliance. The critically low prevalence of machine guarding buttresses the idea that the cost of fabrication and lack of access to localised engineering support are major hindrances to adoption in the region (Adeyemi & Ojo, 2021). Furthermore, artisans commonly believe that machine guards interfere with workflow efficiency, which overrides safety concerns (Adeyemi & Ojo, 2021). This cultural resistance presents a challenge for targeted awareness campaigns that must emphasise the productivity benefits of safe work practices.

Worst of all was electrical safety, which averaged 3.2 out of 10. Damaturu relies on portable petrol generators because the national grid is unreliable. Exposed wiring in bad condition and poor earthing pose a high electrocution risk. The presence of wet and conductive metallic dust on workshop floors further intensifies these risks (Mutai et al., 2007). Regression analysis showed that electrical safety significantly contributed to accident history ($\beta = -0.38$, $p < .05$), indicating the critical need for interventions to improve electrical infrastructure.

The study also revealed a critical inadequacy in administrative controls and PPE usage. The average PPE compliance is a paltry 24%, while safety goggles (12%) and steel-toed boots (8%) are seldom worn by workers, leaving them without the "last line of defense" against injury. The lack of fire safety equipment increases the risk; no workshops have fire extinguishers. The findings are consistent with wider evidence that PPE alone is not sufficient to manage risk in high-hazard environments. The regression

analysis revealed that PPE compliance did not significantly predict accident reduction, whereas engineering controls such as machine guarding ($\beta = -0.45$, $p < .01$) and electrical safety were highly correlated with reduced injuries.

5.1 Limitations

This study has several limitations that should be considered when interpreting the findings. The cross-sectional design captures data at a single point in time, precluding causal inferences about the relationship between safety practices and accident rates. The sample size ($N = 60$), while representative of the local clusters, limits the generalisability of the findings to other regions of Nigeria or West Africa. All checklist observations were administered by a single researcher, introducing the possibility of observer bias; no inter-rater reliability assessment was conducted. Finally, accident history was based on self-reports from workshop masters and was not independently verified through medical records, which may introduce recall or social-desirability bias.

6. CONCLUSION

This study provides critical insights into the occupational health and safety (OHS) challenges facing Damaturu's blacksmithing sector. Four key conclusions emerge:

1. **Engineering controls are the most effective safeguard.**
   Regression analysis found machine guarding and electrical safety to be significant predictors of lower accident history indicating engineering interventions are more important than administrative controls or reliance on PPE.
2. **Electrical safety deficits pose severe risks.**
   With a mean score of 3.2/10, and even lower scores in generator-dependent workshops, inadequate earthing and exposed wiring create a high-risk environment for electrocution. Addressing electrical infrastructure is therefore an urgent priority.
3. **PPE and administrative measures remain critically underutilized.**
   Compliance averaged only 24%, with minimal adoption of goggles and steel-toed boots, and a near-total absence of fire safety equipment. These findings confirm that workers lack even the "last line of defence" against injury.
4. **Modernization without safety controls increases injury rates.**
   Workshops using motor or generator powered tools reported significantly higher rates of injury compared to those using manual tools, a paradox of higher productivity with higher risk when safety systems are absent.

To summarize, the findings underscore the need for an engineering-based approach, backed by policy enforcement, subsidized access to safety equipment and targeted training programs, to achieve sustainable improvements in OHS in the blacksmithing sector of Damaturu. "Without interventions, the sector will continue to work under precarious conditions that threaten workers' health and productivity."

7. RECOMMENDATIONS

Based on the findings of this study, the following specific recommendations for the improvement of the occupational health and safety of the blacksmiths in Damaturu are proposed:

7.1 Policy and Regulatory Interventions

- Policy and Regulatory Response Policymakers should formulate and implement minimum safety standards

for blacksmith shops, particularly regarding machine guarding and electrical installations.

- To break down cost barriers we need to have subsidized programs for locally made guards and standard electrical components.
- Regulatory agencies should conduct periodic inspections and penalize non-compliance and provide technical support to promote corrective action.
- For Government and SMEDAN: The Yobe State Ministry of Industry and Commerce, in partnership with SMEDAN, should collaborate with local technical institutions, such as the Federal Polytechnic Damaturu and Mai Idris Alooma Geidam Polytechnic, to design, fabricate, and distribute **low-cost, locally adaptable machine guards** for power hammers and grinding machines.

7.2 Capacity Building for Local Artisans

- Develop training programs that counter the cultural aversion to safety practices and emphasize that engineering controls will boost productivity, not hinder it.
- Demonstration workshops and peer learning schemes can demonstrate practical, low-cost safety solutions.
- Develop a collective purchasing power for the blacksmith operators to buy PPE and safety gear at lower prices through local cooperative societies and better availability.

7.3 Strengthening Emergency Preparedness

- All workshops should be equipped with basic emergency equipment, such as first-aid kits and fire extinguishers, and regulators and local cooperatives should ensure compliance. Regulators and local cooperatives should have basic emergency tools, such as first-aid kits and fire extinguishers.
- Community-based safety committees could be adopted to monitor and respond quickly in case of accidents.

7.4 Integrated OHS Support Systems

- Government agencies, NGOs, and local trade associations should join forces to provide ongoing technical assistance and awareness campaigns.
- Strategies should be directed to long-term issues such as the integration of OHS in the curricula of vocational training to ensure that future artisans enter the workplace with a positive safety culture.

8. Implications for Future Research

The present study provides useful information about the occupational health and safety (OHS) practices in the blacksmithing sector in Damaturu, but also shows some areas where further research is necessary:

1. **Comparative Studies Across Regions** Future research should extend to blacksmithing workshops in other regions of Nigeria and West Africa to determine whether the observed shortcomings in Damaturu are specific to the area or more pervasive. Such comparisons would help identify structural and local determinants of OHS performance.
2. **Longitudinal Assessments of Interventions** Engineering controls were the strongest predictors of accident reduction in this study. Longitudinal studies are required to assess the sustained impact of interventions such as subsidized machine guarding, improved electrical

installations and PPE distribution programs over time.

3. **Economic and Cultural Determinants of Safety Compliance** Further studies on the economic limitations and cultural perceptions that discourage the implementation of safety measures may be enlightening. Mixed-method techniques for example quantitative surveys and qualitative interviews may be relevant when trying to uncover nuanced barriers to compliance.

4. **Integration of OHS into Vocational Training** Research on OHS Integration in Vocational Education and Training should look into the effectiveness of integrating OHS modules in vocational training courses for artisans and craftsmen. It would be useful for workforce development policy to track trainees' retention of knowledge, behaviour change, and numbers of accidents.

By addressing these areas, future research can build a more comprehensive understanding of the interplay between engineering controls, administrative measures, and socio-cultural factors, ultimately guiding evidence-based strategies to improve worker safety in informal industrial sectors.

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