ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2716-7100 (Online)
CODEN: MCEMC2

Materials & Corrosion Engineering Management (MACEM)

DOI: http://doi.org/10.7508/macem.01.2024.20.24

CrossMark

RESEARCH ARTICLE

POTENTIAL SOURCES OF FAILURE IN MACHINES PRODUCED BY AGRO-ALLIED ARTISANAL METAL FABRICATORS IN NIGERIA: POLICY IMPLICATIONS FOR ENHANCING RELIABILITY AND BUILD QUALITY OF POST-HARVEST MACHINES

Waheed Olatunji OLADELE[a]*, Olawale Oladipo ADEJUWON[b], Ibikunle Olalekan OGUNDARI[b]

[a]*Lagos State University, Ojo. Nigeria*
[b]*Obafemi Awolowo University Ile-Ife Nigeria*
**Corresponding Author Email: oladelewaheedolatunji@gmail.com*

ARTICLE DETAILS

Article History:

Received 20 November 2023
Accepted 23 December 2023
Revised 27 January 2024
Available online 29 February 2024

ABSTRACT

This study examines the likely sources of failure of machines fabricated by agro-allied artisanal machine fabricators in Nigeria with a view to inform strategies to enhance the reliability and build quality of the machines produced and reduce likely property damage and personal injury due to machine failure. Information on the frequency (where 0 = none and 4 = always) of machine failure from three sources namely; manufacturing defects, supplied parts and maintenance and handling by end-users was collected from using a set of questionnaire fabricators in selected fabrication clusters in Southwestern Nigeria. The study revealed low frequencies of manufacturing defects. Welding (0.07) and alignment of joints defects (0.31) were almost non-existent while defects in axle seals (1.06), hammers (1.17) and choice of metal (0.61) barely occurred in machine production. However, supplied parts such as substandard bearings (3.59) were always sources of failure while fasteners (3.20) and electrical switches (3.26) and wiring (3.43) were often sources of failure. In addition, end-user issues such as lack of maintenance (3.54) was always was a source, while improper maintenance protocols (3.42) were often sources of failure. The study recommends standardizing, regulating and enforcing quality standards of such machines and machine parts and the provision of maintenance guides for end-users.

KEYWORDS

Machine failure; Artisanal metal fabrication; Agro-allied; Manufacturing defects; End-user maintenance.

1. INTRODUCTION

The progress of the Industrial Machinery Manufacturing Industry (IMMI) in any nation is critical for achieving economic development. This industry is responsible for the manufacture of capital goods which are used in the production of other products and services. Capital goods facilitate the mechanization of industrial processes which promotes domestic production, innovative activities, productivity increases and value-adding activities to natural resources. The ability of a nation to develop machines for many production processes has led to the creation of many industrial and service sectors resulting in the creation of employment opportunities and, multiple sources of generating income. Countries such as Japan, China, South Korea, Finland and Chile among many others have progressed from manufacturing simple machinery by reverse engineering to exporting more technologically advanced machinery to the high-technology demanding countries (Ramos, 1998; Andersen et al., 2015). Therefore, developing capabilities in the IMMI may be vital in promoting industrialization and economic development.

The artisanal metal fabrication sector in Nigeria is a very active sub-sector in the IMMI especially in the production of machines for the postharvest processing of agricultural products. This sub-sector is a major provider of agricultural tools and machinery to smallholders and skilled manpower to equipment maintenance teams of manufacturing firms in Nigeria (Adejuwon, 2018). Prospects of this sector have been further buoyed by the surge in the influx of entrepreneurs in food processing and packaging. Through the imitation of imported machinery, artisanal fabricators in Nigeria have been able to provide machines for oil palm fruit, cassava, maize, yam and wood processing among many others (Faborode, 2003; Taiwo et al., 2002; Adejuwon et al., 2014; Oguntunde et al., 2019; Adejuwon, 2018).

While the machines provided by artisans have substantially reduced human effort in many agro-industrial activities, most of the fabricated machines remain crude, inefficient, and breakdown easily compared with similar machines imported from developed countries. For this reason, the substitution of machinery for specific laborious tasks in the smallholder sector is still low and most unit operations remain labor-intensive.

Machine failure may be caused by wear and tear of components of machines, acts of nature or flaws in the original design of the machine. Failure may also be caused by defects made in the course of manufacture of the machine, the use of substandard materials and handling by customers. This may further be broken down into defects caused by the quality of workmanship (including choice of materials, fabrication and installation) of individuals employed in the manufacture of machines or entities from which material used in the construction were obtained (Russell and Jur, 2019; Gumi et al., 2020).

This paper intends to carry out an assessment of the types of defects usually encountered in machines fabricated by the local artisanal fabricators in Nigeria from the point of view of selected local artisans. An assessment of these defects may lead to the development of ample public action mechanisms to manage and/or reduce machine failure (Russell and Jur, 2017). This may foster innovation among the machine fabricators and ultimately the development of machines with superior build quality and reliability. It is however not the intention of this study to carry out detailed

Quick Response Code	Access this article online	
	Website: www.macej.com.my	**DOI:** 10.26480/macem.01.2024.20.24

technical failure analyses on machines fabricated in the sector as this may require expensive and meticulous assessments at macroscopic and/or microscopic levels to determine the reasons that clearly identify the root cause of the failure. It is simply intended that this study may provide opinions on likely sources of defects of locally produced machinery to entities interested in building capabilities of the local artisanal fabricators and draw attention to the need for intervention in the sector. This study may also be of interest to quality control agencies invested with the responsibility of reducing property damage and personal injury that may occur in the use of defective machines.

This study will be carried out in clusters of local artisans who specialize in the production of agro-allied machinery in Southwestern Nigeria. This is because of the high agro-allied fabrication activities going on in the clusters.

2. Literature Review

2.1 Defects and Failure

A defect is defined as an imperfection that can be shown to cause a failure (Miller et al., 2021). It may also be described as the absence of reasonable efforts to prevent failure (Russell and Jur. 2017). According to the authors, here are many types of defects which may include manufacturing/ workmanship, design, marketing, materials and installation defects to (Russell and Jur, 2017). The defect may help identify causes of failure and the parties, if any, that can be held responsible for the failure.

2.2 Types of Machine Failure

Machine failure may be regarded as when a machine is performing below expectation. That is, when the machine stops functioning in the manner it was designed to operate. Total failure means the machine is practically non-functional. This may include breakdown of a propeller in the machine, bearing failure and vessel, pipe or in-take valve ruptures among others. In some conditions when the machine functionally operates, but not at full capacity, it said that the machine has partial failure. This may include operating below desired speed of an internal combustion engine due spark plug malfunction. Types of machine failure vary and the exact point in time when the failure may occur cannot be predetermined. While many are noticeable failures that render a machine nonfunctional, others gradually increase the possibility of total failure. There are three major classes of machine failure. These are sudden, intermittent and gradual failure. Sudden failure occurs when a machine unexpectedly breaks down completely. Examples of this may include shattered bearings and melted electrical wiring which may make the machine non-operational. These may be due to defects such as incorrect fitting of bearings in the former case and use of inappropriate or substandard wiring specifications in the latter. Intermittent failure happens when the operation of a machine is sporadic. This kind of failure can usually be prevented with timely and precise maintenance procedure. For instance, changing spark plugs as at when due using the correct specification and brand. Gradual failures manifest over a period of time as in a continuous decline of a machine's operation. This may involve the dulling of hammers and slow shredding of belts due to defects in pulleys and bearings. Defects in oil lubrication pipes or maintenance procedures may cause residue accumulation and eventual machine failure. Gradual failures can also be prevented through regular maintenance. Failures also come in various modes such as fracture, fatigue, corrosion and high-temperature mechanisms (Guma et al., 2020). The foregoing shows that machine failure may not be wholly attributable to defects in fabrication. It is the purpose of this paper to assess where the responsibility of machine failure made by the local artisans may be attributed.

2.3 Some Types of Defects

2.3.1 Bearing Defects

Defects in the specifications, design, maintenance procedures, handling, quality, and installation may determine the operational life span of a bearing and resulting failure (Budynas and Nisbett, 2014). Common bearing defects may include defective bearing seats on shafts and bearing housing, misalignment of fit, faulty mounting, inadequate lubrication and ineffective sealing which may lead to loss of lubrication. Bearing defects may manifest in machine vibration which may lead to gradual failure or complete failure of the machine's rotating parts (Schwack et al., 2016).

2.3.2 Welding Defects

Welding is the process of joining metals together during fabrication. It involves the use of high intensity light or heat to melt two or more metal parts. However, there are welding errors that may lead to machine failure. This may include splatter of molten particles, porosity in the welded joint, deformation caused by improper clamping of the melted metal and cracks (Schwack et al., 2020). Deficiencies in the welding process can ultimately result in failure of the welded joint

2.3.3 Structural Defects

This refers to the loss of reliability on structure of items or article fabricated. It can also be the loss of capability of carrying specific load or at designated operational speed. Structural defects begin when the material is pressurized more than its power, which may lead to fracture or deformity of the structure of the machine (Feld and Carper, 1996; Virdi et al., 2000).

2.3.4 Key and Key-Way Defects

A key and the keyway come together to create a keyed joint, which secures a hub and shaft and prevents relative movement between a power transmitting shaft and an attached component (Kurt and Robert, 2021). Defects that may arise in this case may be in the wrong selection or quality and fit of shaft key. This is essential for preventing early failure of keyed joints (Felix et al., 2019; Schmid et al., 2013).

2.3.5 Defects in Fasteners

A fastener is a piece of hardware that mechanically attaches or bonds two or more items. Fasteners are typically used to design non-permanent couplings, or joints that may be taken apart without harming the parts they are connecting. Defects in fasteners may include corrosion and loose bearings which may contribute to excessive vibration of the machine and ensuing machine failure. Types of fasteners include bolts, nuts and washers (Groover, 2010; Manarikkal et al., 2019).

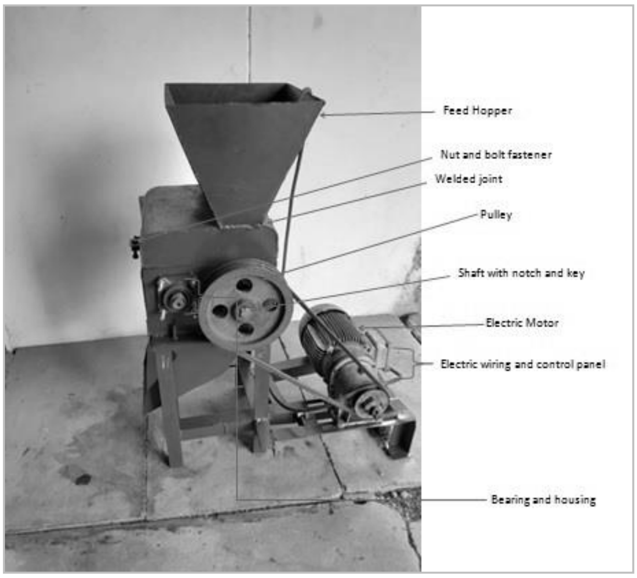

Plate 1: shows a Dry Yam Crusher showing some of the parts mentioned above.

Cite The Article: Waheed Olatunji OLADELE, Olawale Oladipo ADEJUWON, Ibikunle Olalekan OGUNDARI (2024). Potential Sources of Failure in Machines Produced by Agro-Allied Artisanal Metal Fabricators in Nigeria: Policy Implications for Enhancing Reliability and Build Quality of Post-Harvest Machines. *Materials & Corrosion Engineering Management (MACEM), 5(1): 20-24.*

3. Methodology

The study was conducted in three purposively selected states in Nigeria; namely Edo, Ogun and Oyo. These states were purposively selected because they are the major artisanal metal fabrication hubs in Nigeria. A multi-stage sampling technique was used to select the respondents for the study. In the first stage, towns known for the prevalence of artisanal fabricators were selected from the States namely; Abeokuta, Ibadan, and Benin located in Ogun, Oyo, and the Edo States respectively. Known clusters of artisanal metal fabricators were purposively selected from each of the towns. The formula was used to determine the population of the study (Cochran, 1977). At 95% confidence level and 5% margin of error, 384 agro-allied artisanal metal fabricators were selected as respondents for the study.

The study utilized primary data. This was collected by the use of one set of questionnaire and interviews. Information on the types of defects that could lead to machine failure was collected by focus group discussion with the executives of the association of fabricators in a fabrication cluster in Ibadan, Oyo State. This was used to develop the questionnaire for the larger pool of respondents. The defects were later streamlined into 3 groups. That is, defects that could be caused by the fabricator, installed parts and end-user. The respondents were asked to rate how frequently (on a scale of 0 = none; 1 = rarely; 2 = occasionally; 3 = frequently and 4 = always) they observed the defects in the machines fabricated and brought for repair. Copies of the questionnaire were hand delivered and later collected. Interviews based on open ended questions to further reveal more information on the causes of machine failure were later targeted at 10% of the respondents.

4. Results

Three hundred and twenty-six usable copies of the filled questionnaire were retrieved. Table 1 shows the types of machines fabricated and the percentage of respondents that indicated that they fabricated the various types of machines. These machines are mostly used for processing oil palm fruits, cassava, maize, yam, vegetables, rice, fruits, fish, and chicken.

Table 2 shows the mean ratings of the fabricators on the frequency of occurrence of the defects on the machines fabricated. The results are divided into three parts; defects created or attributed directly to the skill of the fabricator, defects which are inherent in the material parts supplied for installation and those that can be traced to the end-user. On the defects that may be traced directly to the fabricator, the results show that welding defects do not normally occur (0.07) in fabrication processes. This implies that welding defects may not be a predominant source of failure of the fabricated machines. Similarly, results show that defects in alignment of joints were also almost non-existent (0.31). This suggests that machine vibration, a result of misalignment, may not be traceable to defects in the fabrication of joints as these types of defects do not occur in machines fabricated by the artisans. The mean ratings of the results also showed that defects in lubrication passages rarely (0.76) occurred in the machines fabricated. This defect may not only result in sudden and total machine failure but also may result in amplification of wear and tear of the machine, reduced expected life-span and increased maintenance costs. Bearing and rotating shaft failure may be traceable to lack of lubrication. Defects in sealing of axles to prevent loss of lubricants also rarely (1.06) occurred. Loss of lubricants may be traced to axle seizure and ultimately total failure. Respondents also indicated that their machines rarely (0.83) had defects in bearing seats on shafts and housing fit. Fits that are too loose or too tight may lead to bearing failure and consequently machine failure. Defects in shafts also rarely (1.16) occur. These defects may be due to a bent shaft, or torsional, contact or axial defects. Interviews revealed a shortage of precision machinery such as lathe machines may affect the manufacture of precise machine parts. The respondents also indicated that hammer defects also rarely (1.17) occur in the fabrication of machines. The hammer described here is the part used to crush dried food products such as yam and cassava in to fine or semi coarse flour. Again a lack of precision in the manufacture of this machine part may be due to its defects such as lack of balance which may make the machine vibrate or when the size of the discharge chute of the output is too large. Choice of metal may also cause defects in machine fabrication. Interviews revealed that the most common mistakes were the selection metal that is difficult to work with. This may result in many types of defects in fabrication. The results showed that these mistakes were rarely (0.61) made in the choice of metal used in fabrication.

Table 1: Types of Machines fabricated by respondents

s/n	Machine fabricated	Percentage %
i	Multi-purpose Hammer Mill Machine	96.3
ii	Palm fruit bunch stripper	92.0
iii	Palm kernel cracker	91.0
iv	Palm oil clarifiers	91.0
v	*Garri* fryer	98.2
vi	Cassava chipping machine	96.9
vii	Cassava peeling machine	96.3
viii	Cassava grater	97.5
ix	Maize sheller	86.2
x	Maize sheller/thresher	81.6
xi	Maize sheller with separator	82.8
xii	Pepper mill	98.8
xiii	Yam pounder	76.9
xiv	Rice dryer	81.0
xv	Rice milling machine	82.2
xvi	Palm kernel oil expeller	86.8
xvii	Fish smoking kiln	80.3
xviii	Dewatering machine	91.1
xix	Pulverizer machine	32.2
xx	Blending machine	41.4
xxi	Dry yam crusher	89.0
xxii	Feed mill mixer	87.1
xxiii	Chicken feather removal machine	36.8
xxiv	Palm kernel separator	85.6
xxv	Rice destoning machine	81.0
xvi	Fruit spinning machine	87.1
xvii	Digester screw press	82.5
xviii	Oil palm fruit sterilizer	90.2

Table 2: Mean Ratings for The Sources Of Machine Failure By The Artisans		
No.	**Defects Attributable to Fabricator**	Mean
i.	Welding error	0.07
ii.	Alignment of joints	0.31
iii.	Lubrication passage	0.76
iv.	Ineffective sealing of axles	1.06
v.	Defective bearing shafts and housing fit	0.83
vi.	Inefficient rotating shaft	1.16
vii.	Hammer defects	1.17
viii.	Wrong choice of metal	0.61
	Defects in Supplied Parts	
i.	Key-way defects	3.10
ii.	Bearing defects	3.59
iii.	Broken fasteners	3.20
iv.	Electrical Switch malfunction	3.26
v.	Cables/Electrical wiring failure	3.43
	User factors	
i.	Improper maintenance	3.42
ii.	Lack of maintenance	3.54
iii.	Handling of machine	0.83
iv.		

Key: none = 0 – 0.44; barely = 0.5 – 1.44; occasionally = 1.45 – 2.44; often = 2.45 – 3.44 and always = 3.45 – 4.00

As far as defects that may be caused by the supplied parts, key-way defects were found to frequently (3.10) occur. A key is used to connect a rotating component to a shaft. These keys are usually procured from machinists with lathe machines. Interviews revealed that these keys do not last as they are not accurately made and at times made from cheap metals. The results also revealed that bearing failure always (3.59) occur. Respondents revealed that the bearings procured and installed in the machines were of poor quality as buying standard bearings would make their machines more expensive and thus uncompetitive. Similarly, fasteners often (3.20) fail because of they are of poor quality. Fasteners include washers, bolts and nuts. Interviews also revealed that failure is mostly due to poor quality of fasteners which crack easily. Furthermore, the threading on some also wears out easily. Electrical switch and wiring failure were also challenges the respondents indicated frequently occurred (3.26; 3.43 respectively). These electrical components were installed on machines powered by large electric motors. Interviews revealed that the wiring installed were usually unable to handle the high power ratings of the machines. Again, the respondents attributed these failures to poor quality materials.

Improper maintenance refers to failure to follow manufacturers recommended procedures. The respondents indicated that improper maintenance by end-users frequently occurred and led to machine failure. Respondents interviewed claimed that end-users usually employed welders with little skills in machine fabrication to do maintenance work on the machines. Lack of maintenance on the part of the end-users was also reported to always occur (3.52) and a main source of machine failure. According to interviews, it was reported that end-users especially failed to keep bearings lubricated especially when they were known to be of inferior quality. Lastly, mishandling of the machines by the end-users rarely occurred. The respondents suggested that this may be due to the fact that large postharvest machines such those used in processing inputs such as oil palm fruit, cassava, chicken and so on were usually operated by skilled machine operators who are typically not the owners of the machines.

5. Discussion

Machine failure may be due to machine design, an Act of God, worn out parts due to age or use, corrosion, fabrication errors, stressed operating conditions, substandard maintenance and repair practices. Others are lack of initial stress tests by manufacturer, poor quality replacement parts, machine abuse and unknown factors among others (Vander Voort, 1975; Guma et al., 2020). However, this study concentrates on only three likely sources of machine failure; fabrication errors, supplied parts and end-user factors. Assessments by the respondents suggested that very few failures may occur from fabrication errors in general. In a review of 24 analyses of failed machinery and structures reported failure mainly due to corrosion caused by environmental factors, end-users, wear and tear, and aging (Guma et al., 2020). Two major sources of machine failure under other categories can however be deduced from the study. The first is the failure attributable to substandard machine parts especially with bearings, fasteners and electrical parts. Interviews revealed that these substandard parts were most sought after as they decreased the final cost of fabrication and consequently the price. The fabricators revealed that their machines would not be price competitive if higher quality parts were installed. Some stated that on the failure of these bearings or fasteners, the end-users may wish to install higher quality parts if they so wished to prevent further failure and downtime. Another noted source of failure was parts fabricated by machinists such as keys and in some instances hammers. Most defects were also attributed to the use of cheap metal and inaccurate lathe machines and other tools used in the fabrication of supplies parts. It also reported that the absence of precision machines used in the fabrication of supplied parts was a major influencing factor of inefficiencies in the operation of locally fabricated wood milling equipment in Southwestern Nigeria (Adejuwon, 2018). Machine failure attributable to end-users has been well documented in the literature. These include lack of and mismanagement of maintenance protocols, and mishandling of machines (which may include overworking the machine). Observing proper maintenance protocols may reduce the occurrence or extent of machine failure. Russel and Jul (2017)traced the sudden rupture of a steam accumulator due to a lack of proper maintenance procedure. A crack in the vessel was caused by an initial welding defect at the time of manufacture. Though the initial defect caused a leak in the shell, required integrity tests were not conducted after the repair of the leak. This led to a sudden rupture of the vessel. Overloading of semi-trailers with cargo was found to cause the structural failure of the sidewall of the trailer. The trailer was found to be carrying a load of 19 tons of copper wire instead of the about 7 tons maximum stipulated by the manufacturer (Roberts, 2023; Guma et al., 2020). Interviews revealed that fabricators hardly provide written instructions on how to maintain the fabricated machines. They also claimed that in many instances, their machines are marketed to end-users by salesmen and so are unable to give verbal instructions.

6. Conclusion and Recommendations

Determining causes of failure in machine manufacturing systems is important for growing such industries especially in developing countries. According to the results of this study, machine failure in the agro-allied artisanal fabrication sector may be mainly attributed to substandard parts supplied and installed in machines and lack of proper maintenance protocols by end-users. Strategies to resolve these challenges may include standardizing, regulating and enforcing the quality standards of such machine and machine parts. There seem to be no current policy regulating the standards of such fabricated machines in Nigeria according to the Standards Organization of Nigeria regulated products list. In addition, fabricators may provide written maintenance instructions to end-users on how to maintain the machines and reduce failure rates. Further studies in other defects that can cause machine failure are also very important. Design imperfections are also main causes of failure. However, most machines fabricated are imitations as there seem to be very little skills in making new designs and diagnose design defects. Other causes such as corrosion of parts are also major issues in machine failure. This study also calls for expert analysis on failures of specific machines to contribute to the literature on the causes of machine failures in this industry and strategies that can be employed to enhance capabilities in the sector.

REFERENCES

Adejuwon, O. O., 2018. An examination of linkages in the sawn wood sector of the Nigerian forest industry: Policy implications for natural resource-based development. Technological Forecasting and Social Change, 128, Pp. 74-83. https://doi.org/10.1016/j. techfore.2017.10.022

Adejuwon, O. O., Taiwo, K. A. Ilori, M. O., 2014. Promoting technology adoption in the small-scale oil palm fruit processing sector in southwestern Nigeria: An innovation systems approach. African Journal of Science, Technology, Innovation and Development, 6(2), Pp. 75-92. https://doi.org/10.1080/20421338.2014.924267

Andersen, A. D., Johnson, B. H., Marín, A., Kaplan, D., Stubrin, L., Lundvall, B-Å. Kaplinsky, R., 2015. Natural resources, innovation and development. Aalborg Unive rsitet sforlag. http://doi.org/10.5278/VBN/MISC/NRID

Budynas, R., Nisbett, K., 2014. Shigley's mechanical engineering design. McGraw-Hill

Cochran, W. G., 1977. Sampling techniques. John Wiley and Sons.

Faborode, M. O., 2003. Oil palm production improvement programme. New Nigeria Foundation Report. Engineering Bulletin 70: Pp. 15–223.

Feld, J., Carper, K. L., 1996. Construction failure. John Wiley and Sons.

Felix, K., Erhard, L., and Alexander, H., 2019. Different failure mechanisms in keyed shaft-hub connections under dynamic torque load. Procedia Structural Integrity, 17, Pp. 162–169. https://doi.org/10.1016/j.prostr.2019.08.022

Groover, M. P., 2010. Fundamentals of modern manufacturing. John Wiley and Sons

Guma, T. N., Ozoekwe, N. C. W., Odita, K. V., 2020. An overview of approaches and techniques used in failure analysis of engineering systems. Arid Zone Journal of Engineering, Technology and Environment, 16(3): Pp. 587-604. https://www.azojete .com.ng/index.php/azojete/article/view/343

Kurt, M. M., Robert C. J., 2021. Fundamentals of machine component design. John Wiley and Sons.

Manarikkal, I., Elasha, F., Laila, D.S., Mba, D., 2019. Dynamic Modelling of Planetary Gearboxes with Cracked Tooth Using Vibrational Analysis. In: A. Fernandez Del Rincon, F. Viadero Rueda, F. Chaari, R. Zimroz and M. Haddar (eds) Advances in Condition Monitoring of Machinery in Non-Stationary Operations. CMMNO 2018. Applied Condition Monitoring, vol 15. Springer, Cham. https://doi.org/10.1007/978-3- 030-11220-2_25

Miller, B. A., Shipley, R. J., Parrington, R. J., and Dennies, D. P., 2021. ASM Handbook: Failure Analysis and Prevention. ASM International.

Oguntunde, T. F., Adejuwon, O. O., Ogundari, I. O., 2019. Through a systems looking glass: strategies for enhancing the diffusion of innovations in artisanal yam flour processing in Nigeria. African Journal of Economic and Sustainable Development, 7(2), Pp. 120-137. http://dx.doi. org/10.1504/AJESD.2019.103562

Ramos, J., 1998. A development strategy founded on natural resource-based production clusters. Cepal Review. 66, Pp. 105–129.

Roberts, C. C., 2023, August 7. Structural Failure in Semi-Trailers from Overloading. http://www.croberts.com/Trailer-failure.htm

Russell, M. D., Jur, T. A., 2017. Engineering Analysis of Failure: A Determination of Cause Failure Analysis and Prevention. Journal of Failure Analysis and Prevention, 17; Pp. 8-14 https://doi.org/10.1007/s11668-016-0224-9

Schmid, S. R., Hamrock, B. J., Jacobson, B. O., 2013. *Fundamentals of machine elements. CRC Press*

Schwack, F., Bader, N., Leckner, J., Demaille, C., Poll, G., 2020. A study of grease lubricants under wind turbine pitch bearing conditions. Wear. Pp. 454 – 455: https://doi.org/10.1016/j.wear.2020.203335

Schwack, F., Stammler, M., Poll, G., Reuter, A., 2016. Comparison of Life Calculations for Oscillating Bearings Considering Individual Pitch Control in Wind Turbines. Journal of Physics, Conference Series 753 112013 https://doi.org/10.1088/1742-6596/753/11/ 112013

Taiwo K. A., Owolarafe O. K., Sanni L. A., Jeje J. O., Adeloye K., Ajibola O. O., 2000. Technological assessment of palm oil production in Osun and Ondo States of Nigeria. Technovation, 20(4): Pp. 215–223. https://doi.org/10.1016/S0166-4972(99)00110-8

Vander Voort, G.F., 2001. Conducting the failure examination. Practical Failure Analysis. 1, Pp. 14–19. https://doi.org/10.1007/BF02715156

Virdi, K. S., Matthews, R., Clarke, J. L., Garas, F., 2000. Abnormal loading on structures: Experimental and numerical modelling. Taylor and Francis Group.