Impact of material selection on the efficiency of the crushing unit low-medium carbon steel

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Abstract. The quest for sustainability in feed production industries and crushing machines in agricultural sectors that are more efficient have introduced the use of proper material for hammer material. Around the world, the manufacture of feed from animal waste is expanding quickly, and crushing equipment is now essential to enabling reliability. The issue of early failure of the crushing machine's main components, however, is a challenge for the feed industries and has a direct impact on the machine's maintenance, dependability, and running costs. A significant number of technical components have been created during th e past decade for industrial applications employing novel materials and cutting-edge technologies through the development of carburisation. As a result, this review offers a concise summary of the most recent analysis of tribological issues related to crushing hammers made of low and medium-carbon steels. Recent studies on innovative crushing material design, improvement in hammer surface engineering, use of case-hardened hammers with a focus on material selection, crushing machine design optimisation, and failure mode analysis are included in the study. Additionally, it will intricate on the heat treatment technology's present constraints and its future opportunities.

Keywords: Material selection, Crushing, Production, Efficiency, Sustainability, Advancement

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1 Introduction

The material shortfall has been the main setback for manufacturing industries due to improper machine maintenance and persistence in interruptions observed on the production floor. Therefore, in order to ensure a longer service life, engineering practice mandates a critical analysis of the strength qualities of materials. Manufacturers nationwide are battling to maximize cost savings from missed output due to equipment downtime, while customers are concerned about the goods' dependability and safety[1]. Nowadays regulator is in place to monitor the preventive maintenance processes on crushing or milling machines using a computer system or agent system. The preventive maintenance process becomes essential as it prevents failure, identifies the initiation of the failure, and ascertains an unseen failure but principal modes of failure mostly require deterrent maintenance [2]. Also, the effective maintenance process helps the avoidance of an initial failure mode which triggers the consequent breakdown Downtime is the main factor that contributes to lost production time for the majority of manufacturers Continuous failures of various mechanical parts or machineries are frequently linked to material breakdowns [3] [4]. According to the forensic analysis conducted by [5], choosing the wrong material for a machine component might result in subpar quality and a consequent loss to the industry's output. Some well-known characteristics, including edge geometry, feed, depth of cut, and cutting speed, also have an impact on the dependability of machine components. Only by paying attention to reliability and maintainability, which guarantee both production stability and product quality, the smooth operation of the production process can be guaranteed in any manufacturing process [6]. Recent research initiatives have focused on examining the choice of an appropriate material, which is difficult but necessary and applicable in modern industries, in relation to the material's cost, its impact on the environment, its operational features, accessibility, market trends, societal values, its aesthetics, and its potential uses and users. Likewise, the strength, physical, electrical, magnetic, production, and corrosive properties of the product [7]. Therefore, suitable material with good surface integrity and strength has to be chosen for the development of crushing devices to prevent frequent failure which will eventually lead to a breakdown. Hammer failures could be grouped into chemical wear, fatigue due to tensile and compressive stress, fretting, erosive wear, and abrasive wear. The potential mechanical and electrical failures of the hammer mill system are manufacturing flaws, overload, incorrect material selection, fatigue, stress corrosion cracking, wear and high-temperature failures, noise, vibration, and obstruction [8] Therefore, it is necessary to develop an appropriate hammer material that will be case hardened through a carburisation process, ensuring that the hammers can work at their best efficiency at a reasonable cost. Hence, proper material selection must be embraced to enhance the hammers' life span. The initiation and propagation of the cracks on hammer materials (metal samples) can be hindered by changes in residual stress, grain distribution, and hardness reducing fatigue failure Corrosion researchers have also focused on the need to manage the degrading behavior of metals by grain augmentation technologies in order to find long-term solutions. In addition, the tear and wear can be prevented by the influence of heat treatment such as case hardening, nitriding, carburization, annealing, and so on [9]. [10] reported that good thermomechanical process control can lead to favorable mechanical and metallurgical properties.

2 Literature Review

The increase in the use of low- and medium-carbon steels has been shown to be a result of several factors, including the manufacturing sector. Therefore, it is necessary to control wear and tear by increasing the use of low- and medium-carbon steel materials in as many manufacturing designs and fabrications as is practical. Each and every production expert plays a crucial part in keeping track of and choosing the proper materials for the project in order to increase the usage of low- and medium-carbon steel materials in production projects. The importance of reinforced material has been highlighted as the material modified to endure wear, fatigue, and corrosion that develops depending on the production materials, and procedures [11]. Usually, a high-impact environment is where reinforced hammer materials are used. Consequently, heat-treated materials are utilized preferably in a high-impact environment. Hence, heat-treated materials are chosen to reduce the incessant failure of the component. Globally, there is a lack of research done so far to find out whether manufacturing companies are using low-medium carbon steel materials and the challenges in the adoption of low-medium-carbon steel materials [12]. There is, therefore, a need to fill this gap in knowledge and to avail useful information which can benefit the professionals in the manufacturing industry, and to ensure continuous increase in low-medium carbon steel material and productivity improvement in the production industry, it is important to analyze problems in low-medium carbon steel material in construction and develop coping strategies.

2.1 Previous studies

The rapid development of the production sector has increased the use of low and medium-carbon steel in all countries around the world. Low- and medium-carbon steel products have seen an increase in demand in recent years to meet the need for production. Nowadays, the carbon steel footprint can be seen after many drawbacks have been established [13]. Table 1 summarized the primary wear and/or failure processes in crushing devices as described in the literature below.

Table 1. The primary wear and/or of failure processes in crushing devices

Crushing Device	Results	Source
Hammer mill with separate sieving device	The machine has the advantage of high productivity. The equipment is cumbersome, costly, and not suitable for the individual user i.e small scale	[14]
Cassava Milling Machine	The result obtained from the study showed that the machine either crushed bulk material to pulverize form. However, low output was obtained due to wear as a result of fatigue.	[15]
Mineral crushing machine	The analysis of the hammer's surface reveals many damage characteristics, such as cracking, grooving, metal cutting, carbide fracture, mechanosynthesis, and chromium migration, which cause significant material loss and short service lives. The findings indicate that impact wear and abrasive wear are both involved in the failure mechanism and interact with	[16]

	one another due the brittleness of the hammer.	
Coal Crushing Machine	According to a research study, the hammers' heads prematurely wear out while in use, resulting in production stoppage and the need for recurrent replacements. Detailed metallurgical characterization and failure analysis of a coal-crushing hammerhead revealed that, the usage of alloys with lean interaction and reduced hardness results in increased abrasion rates, which leads to hammerheads failing in abrasive wear mode. Also, only iron chromium carbides were present, which is insufficient to sustain a harsh wear application	[17]
Toothed Double Roll Crusher	A study showed that an increase in hammer speed (which is similar to the loading rate) has a considerable impact on the crushing condition, and by increasing the number of cracks that are formed to release the increasing strain energy, more small-sized fractions of the final product are produced. Furthermore, as hammer speed is increased, the nipping behavior and fracture mechanics of materials are not considerably improved, but rather the hammers are subjected to abrasive and fatigue wear, which results in failure. Additionally, the placement of the crushing hammers greatly affects the caliber of the crushed output. The crushing performance of a Toothed double-roll crusher with a spiral-toothed roll or a staggered-toothed roll can be improved by having a reasonable operating gap between the hammers and better particle-nipping behavior	[18]
Shot Blast Machine	The study discovered that chemical and abrasive wear are the main wear modes for stage 1 steel blades. Erosion and fracture are the primary wear mechanisms for stage 2 blades of the machine with a carbide	[19]

	weld overlay. The observed microcracking has been linked to incomplete carbon-monoxide replacement by iron in the carbide grits' outer layer, which was probably brought on by diffusion during high-temperature welding. By repeatedly coming in contact with the inorganic contents when cutting biomass, microcracking is thought to reduce the overlay's grit strength and fracture toughness, making it more prone to fracture and chemical wear.	
2 Biomass Hammer Mills	Employing the Cost of Unreliability (COUR) technique and Business Consequence Analysis (BC) analysis, a study found that the value of cost losses resulting from machine failure and downtime (unreliability) is considerably high. The ultimate cost of machine unreliability due to downtime computation reveals that the entire cost of downtime brought on by machine unreliability is higher than the whole cost of corrective repair. After determining the COUR, a risk matrix is used to analyze the effects of the machine's unreliability on the business. The findings of the study reveal that the vital parts of the shot blast machine are in the red or high-risk category and have a very high probability of failure.	
Magnetic Hamm er Mill	This study revealed that the gasoline food- grade magnetic hammer mill de signed to grind different foods failed due to the impact of cyclic loading. Hence, the performance of the mill dep ends on the food being ground.	[21]

A forensic examination will steer and aid the prediction of common imperfections thereby having a viable and efficient design. The study's main objective is to investigate the kind of material that performs better with effective productivity in the field of comminution. It was said that choosing the appropriate materials produces better results than choosing the improper ones, however, the justification for this conclusion was not made apparent in other studies. Therefore, the purpose of this study was to empirically assess how well the carburized hammer materials performed. It focused on understanding the reason behind the improvement of the system's performance and enhancement of the hammer efficiency of the hammer mill while using heat-treated components as emphasized by other studies. Hence, the selection of materials during the manufacturing process determines the functionalization of all components for engineering applications.

2.2 Hitches to the use of alternative materials in the production industry

The choice of new materials for manufacturing is hampered by a number of variables [22]. These include a lack of immediate or medium-term economic benefits, ineffective informational marketing and outreach to practicing engineers about new materials, and a dearth of performance data and large-scale demonstration projects to back up the claims. The authors contend that this can be avoided by incorporating design direction alongside successful marketing and stakeholder involvement. Materials are often chosen based on other objectives, even though there are enough knowledge and demonstration projects available. The World Business Council for Sustainable Development (WBCSD) commissioned Arup to undertake an international survey of design teams in 2012, and it found that while several aspects affect material choice, the cost is the most important one [23]. A material's appropriateness and sustainability are strongly influenced by site- and project-specific variables. Depending on the type of structure and the project, different solutions will have different lowest embodied carbon values. Promoting the best choice for each individual project must be the ultimate objective of policymakers and low-carbon construction proponents. Thus, it is crucial to simultaneously promote a wide range of material possibilities. This necessitates the development of skills and regulations that is accommodating a wide range of possibilities. Therefore, it is vital to find common leverage points and interventions that support many solutions in addition to assessing the obstacles to the adoption of specific materials in studies

3 Low-Carbon Steel

Among other steels like medium carbon and high carbon steel, low carbon steels are those with carbon content ranging from 0.05% to 0.35%, and mild steel has a carbon level of 0.16% to 0.25%. It is currently the most popular type of steel that is suitable for a variety of applications due to its low price and availability of material qualities. The weldability, flexibility, and cost-effectiveness in production industries have led to the increasing need for low-carbon steel material. However, according to some studies, mild steel plates (treated and untreated) were utilized to build the hammer mill because they were readily available, sturdy, inexpensive, and affordable [24]. The low-carbon steel's applications are also constrained due to significant flaws such as cracks, deformation, and a lack of corrosion characteristics, which can lead to failure. Due to the erosive wear and elemental evolution from their service environments, which are caused by corrosion processes, many steel structures succumb to catastrophic breakdowns. Because of this, it is vulnerable to deterioration and degeneration [25]. As a result of this treatment, the mechanical strength of these mild steel constructions and their primary components is negatively impacted. According to [26], a low-carbon steel component is vulnerable to wear and tear-induced deterioration and degradation. However, the activity of degradation processes affects how quickly mechanical qualities degrade. As a result, the manufacturers of steel parts for the aerospace and automotive industries are increasingly demanding steel with improved strength qualities, weldability, and high machinability. The main kinds of wear and tear that low-carbon steel experiences are abrasion, erosion, and corrosion. When frictional forces are applied to a surface repeatedly, it is called abrasion. This can lead to material wear and tear. When a surface is subjected to a fast-moving liquid or particle stream, erosion takes place and the substance erodes. The degradation of the surface is the result of a material's reaction to its surroundings, which is known as corrosion. Many industries, including oil and gas, transportation, manufacturing, and infrastructure, are affected by corrosion, which is a serious problem that hinders the safe, dependable, and effective functioning of equipment in these sectors. Equipment failure brought on by corrosion can result in downtime, lost production, and even safety risks [27]. According to [28] the need for materials with higher strength qualities and increasingly efficient production technology is continually rising in the global economy. [29] reported that the mechanical characteristics of the steel were improved by reducing the grain size to a more uniform distribution of the core components. According to a study, structural changes, the production of more pseudo-pearlite, and the strengthening of ferrite all affect the strength of low-carbon steels. As a result, the carbon content affects the degree of ferrite strengthening. Additionally, any alloying elements other than cobalt can be used to improve the hardenability of low-carbon steel According to studies, low-carbon steel's mechanical qualities benefit from finer grain sizes, however, the ferrite grain size mostly determines how well low-carbon steel performs mechanically. The importance of the grain boundary mechanism in carbon diffusion in carbon iron and discovered a linear relationship between the polycrystalline border volume fractions and the carbon diffusion barrier [30]. Temperature increases the dynamics, which also enhances carbon diffusion. It is also very important to note that at low temperatures, this condition does not conform (i.e., there is essentially no bulk diffusion penetration). As a result of the higher energy and chemical activity of grain boundaries, a high density of these boundaries increases the reactivity of the outer layer through increased electron activity, and diffusion which may have an impact on corrosion resistance [31]. According to a literature review, after the steel is quenched from the rolling temperature and contains 0.19% carbon, its resistance to rupture has significantly increased [32]. Currently, one of the finest methods to enhance metallic parts' working qualities is to harden the surfaces of those parts. In order to achieve the latter, protective films or coatings can be applied, or the surface microstructure and microrelief of mild steel's surface layers can be changed. Therefore, a steel's surface layer can operate for longer while using less energy and material provided it has a consistent microrelief with little roughness and a fine-grained microstructure with persistent compressive macro stresses. The mechanical characteristics of mild steels have been improved by a number of works by many researchers [33]. This suggests that by increasing the strength at high temperatures, an appropriate heat treatment process can significantly improve the dual phase of mild steel. In order to prolong the operational life of steel constructions, it is still required and crucial to prevent their degradation under cyclic stress and/or in highly corrosive situations [34]. This is done in order to avoid a number of failures caused by factors like the mechanical strength of a shredder hammer, the lack of a heat treatment method at a specific temperature, and the discontinuity of the hardening process between 200 °C and 300 °C [35]. However, the consistent rise in hammer failure continues to be a major obstacle to increased productivity. Low-carbon steel has limitations that have prompted efforts to develop the material for advanced applications utilizing different heat treatments [36]. In addition, [37] found that when low-carbon steel was rapidly cooled, its mechanical characteristics improved while its brittleness at low temperatures decreased. According to research by [38]. Corrosion frequently shortens the lifespan of low-carbon steels used in chemical industry applications. Thus, low-carbon steels can be coated with an impenetrable layer of filler metal to create corrosion resistance in a highly corrosive environment. The study also revealed the difference in the inhibitive constituents, which can be materials and monetary damage to society. [40] noted that corrosion protection is one of the fundamental ways to slow down material deterioration because the corrosion behavior of low-carbon steel is dependent on the environment, temperature, and period of exposure. Low-carbon steels can be protected against corrosion with pretreatment coatings that are safe for people and the environment, affordable, and environmentally friendly [41]. With an optimal efficacy of 99.5% and 88.88 from potentiodynamic, [42], noticed organic or inorganic—determines the rate of corrosion of low-carbon steel. This is explained by the rise in extract absorption Ct the outer layer. According to [39], the reactivity of materials to the environment is a major factor in the failure of an improvement in the inhibitory effectiveness from the least to the greatest concentration. Different quantities of Azadirachta indica (AZI) oil extracts were used in a 2.5 M citric acid (C6H807) solution on low-carbon steel corrosion and passivation. [43], revealed that the ideal 2-nitroacridone concentration and temperature range for the best corrosion-inhibiting effect has been identified. This was done in order to determine the effects of various 2-nitroacridone concentrations and temperature ranges on the erosive wear of low-carbon steel in an acid solution (1 M HCl). It is essential to choose the proper materials for each component of a machine, especially a hammer mill, according to the required mechanical qualities in order to maximize the machine's efficiency and longevity. To accomplish desired properties for the material and equipment, different mechanical properties are attained as the proportion of the carbon content of the materials changes from low carbon to medium carbon [44].

4 The medium carbon steel

A metal with a material content of 0.25 to 0.60 weight percent carbon is known as medium carbon steel. It demonstrates good wear resistance, good ductility, and strength in balance. This structural steel's strength properties are improved through a heat-treatment process that involves austenitizing, followed by quenching and tempering, which results in a martensitic microstructure that is more resistant to cutting, welding, and forming. Numerous mechanical parts, including bolts, shafts, axles, crankshafts, railway wheels, gears, and agricultural equipment, use it extensively. Due to its high strength, ductility, and exceptional wear resistance, medium carbon steel also has a desirable relevance in the railway industries [44] [45]. According to [46], fatigue failure occurs frequently in medium carbon steels like EN8 since they are used so frequently in engineering fields. Bearings, shafts, and gears, for example, must resist wear phenomena with a hard surface while, at the same time, having a strong inner core that can absorb energy without breaking under high stress. Such heterogeneous properties can be designed via selective hardness of the surface, such as heat and mechanical treatments, alloying, or coating the surface of the components [47]. The creation of a nanocrystallized surface layer and an improvement in the yield strength, hardness, wear resistance, and microstructure refinement of medium carbon steel hammer material were reported in Rabinnowicz's abrasive wear equation 1. The most typical prediction for wear calculations is that the wear volume is proportional to the normal force and sliding distance.

$$V = K\frac{FS}{\sigma_0} \quad \text{Eqn 1}$$

where

$\sigma =$ Hardness of worn material
V = Volume of worn material
F = Normal force
S = Sliding Distance

An additional type of wear seen at the hammer tooth is a fatigue failure brought on by the accumulation of microcracks and voids, as well as plastic deformation, which is discovered by visual inspection analysis and microscopic observation to define the evolution of internal defects using an energy-based damage model. A hammer designer will be able to have the proper structural design and, as a result, increase serviceability with improved knowledge of thermomechanical ductile failure and the behavior of C45 steel [48]. Another surface failure in hammer systems is spalling, which happens when another material impacts the hammers quickly and chips them, or when there is too much rolling pressure, chemical erosion, weathering, or cavitation. Rolling Crack Fatigue can result in surface or subsurface cracks, which can then cause pitting, spalling, and delamination, which lowers the performance and shortens the useful life of the machine parts. As a result, many surface strengthening techniques have been applied to enhance the rolling crack fracture characteristics of various materials [49]. These techniques include surface rolling, coatings, shot peening, carburising, and laser shock peening. Shot peening can shield components from abrasion and wear, according to studies. It is a surface modification method, which is frequently utilised to enhance the material properties in a variety of manufacturing industries. The benefits of hammer peening, on the other hand, are numerous and include low cost, increased fatigue life, improved surface finish and texturing, microstructural refinement, corrosion resistance, and wear resistance [50]. Furthermore, a study on the thermal characteristics of hammers revealed that in hammer mills, hammer wear leads to an increase in the temperature gradient of the materials being crushed. It is common practice to control wear behavior by controlling the material attribute known as hardness [51]. Consequently, the extraordinary fatigue resistance of the austempered ductile iron samples may be related to the higher surface hardness produced by the strain-induced transition of residual austenite into martensite [52]. According to research by [53] [54]. Quenching and tempering can give medium carbon steel the ability to resist lifelong deformation. Medium carbon steel has superior resistance to the start and propagation of long-lasting cracks due to its microstructural characteristics. According to [55], heat treatment techniques have the greatest impact on medium carbon steels' resistance to fracture and abrasion failures since heating metals results in an increase in their hardness and strength.

5. Mechanism for reinforcing strength and toughness of steel

Heat treatment methods mostly influence the resistance to fracture and abrasive failures of medium carbon steels because the increase in the temperature when heated confers high hardness and strength properties. Thus, the increased surface hardness generated by the strain-induced transition of residual austenite into martensite could be linked to the austempered ductile iron samples' exceptional fatigue resistance [56]. A study revealed that quenching and tempering are capable of imparting medium carbon steel to oppose lifelong deformation [57]. The microstructural behavior of medium carbon steel gives it better resistance to lasting crack initiation and deformation. [58] noted an increase in demand for carburised medium carbon steels with improved service life in space, aerospace, transportation, submarine, and other dappled areas of application. Due to graphite's increased lubricating effect, the alloying of malleable medium carbon with manganese and graphite increases scuff resistance. The impact of surface roughness and phosphate coating on medium-grade carbon steel galling resistance was discovered to be significant and evaluated using a load-scanner test rig [59]. This is used to estimate the level and stability of the coefficient of friction, the critical loads for the galling start, the surface quality, and the volume.

6 Conclusion

It is possible to link the fine-grain strengthening and dispersion strengthening mechanisms to the increased hardness and strength of reinforced low-medium carbon steels. More grain boundaries in a refined microstructure may successfully impede the mobility of dislocations. After adding a little amount of strengthening chemicals, the grain size of carburised steels is reduced and pearlite content is raised. Additionally, because no coarse austenite was produced during the liquid-solid phase transformation, the development of the structure containing acicular ferrite was effectively constrained. The enhanced ductility is related to the scattering action of strengthening agents and their fine microstructure. Cracks began to grow more slowly and with greater effort. Low-carbon steels became more ductile as a result. However, the carburization technique helps in the overall selection of functionalized material for production.

We appreciate the financial support of Afe Babalola University, Ado, Ekiti, Nigeria for publication.
Authors declare no conflict of interest.

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