Hindawi
Advances in Materials Science and Engineering
Volume 2023, Article ID 5616909, 9 pages
https://doi.org/10.1155/2023/5616909

Research Article

Investigation on Three-Body Abrasion Resistance of Mild Steel Soil Slurry Condition-Simulating Agricultural Condition

Talal Alsaeed,[1] Ayedh Eid Alajmi,[2] Jasem Ghanem Alotaibi,[2] and Belal F. Yousif[3]

[1]*Department of Manufacturing Engineering Technology, The Public Authority for Applied Education and Training, Kuwait City, Kuwait*
[2]*Department of Automotive and Marine Engineering Technology, Public Authority for Applied Education and Training, Adailiya 42325, Kuwait*
[3]*Centre for Future Materials, School of Engineering, University Southern Queensland, Toowoomba, Australia*

Correspondence should be addressed to Belal F. Yousif; belal.yousif@usq.edu.au

Received 29 May 2023; Revised 24 July 2023; Accepted 26 July 2023; Published 14 August 2023

Academic Editor: Hany Abdo

The agricultural industry heavily relies on machinery and equipment for efficient farming practices, but harsh environmental conditions can cause premature wear and tear, leading to financial losses. Three-body abrasion research is essential for developing more durable materials for various industries, including agriculture. Mild steel is commonly used in agricultural machinery but lacks resistance to moisture and corrosion. Slurry handling equipment is prone to wear due to abrasive particles, and red soil presents challenges for farmers. A study was conducted to investigate the wear resistance of mild steel under three-body abrasion under slurry conditions, simulating real-life agricultural environments. Different loads and operating durations were considered, and SEM was used to examine the worn surfaces. Weight loss during sliding wear was found to increase proportionally with duration and applied load. Increasing load leads to more severe wear due to higher shear forces and the formation of nucleation sites for wear particles. There is an increase in the weight loss by about 8 times when the applied load increased from 10 N to 70 N. The slurry regime and rotational speeds also affect wear rate, with higher speeds leading to deeper penetration of abrasive particles and greater impact force. The severity of wear increases with time and different wear mechanisms dominating at different durations, as observed through the SEM analysis. These findings emphasize the importance of considering load, slurry regime, and rotational speed when designing materials for sliding wear applications.

1. Introduction

The agricultural industry heavily relies on machinery and equipment to ensure efficient and productive farming practices. However, the constant exposure of these machines to harsh environmental conditions can result in premature wear and tear, reducing their lifespan and increasing maintenance costs [1]. In addition to reduced lifespan and increased maintenance costs, the premature wear and tear of agricultural machinery also results in significant financial losses for farmers [2]. These losses are incurred through repairs, replacement of parts, and even the complete replacement of machinery. The cost of machinery is already high, and farmers cannot afford frequent replacements, making the durability of these machines a critical factor in ensuring profitability in agriculture. Moreover, the downtime caused by machinery breakdowns also adds to the overall cost, as it affects productivity and delays the completion of critical tasks, such as planting and harvesting. This further underscores the need for durable machinery that can withstand harsh environmental conditions [3].

The three-body abrasion study is a critical area of research that is important for understanding the complex interactions between materials and their environment [4]. This type of study involves the investigation of the wear and tear that occurs when three surfaces come into contact and rub against each other, resulting in the loss of material from all three surfaces. This process can occur naturally, as in the case of erosion caused by soil debris under wet or dry conditions. The importance of a three-body abrasion study lies in its relevance to various industries, including agricultural, aerospace, automotive, construction, and biomedical engineering. In these fields, materials are subjected to harsh environments and must endure extensive wear. Understanding the mechanisms and factors that contribute to three-body abrasion can help engineers develop more durable and efficient materials and components [5–7].

Mild steel is a commonly used material in agricultural machines due to its durability, strength, and affordability. It can withstand the harsh environmental conditions that come with agricultural work [8]; however, it has a lack of resistance to moisture, rust, and corrosion. Mild steel is also relatively easy to work with, making it a popular choice for manufacturers of agricultural machinery. On the other hand, three-body abrasion under slurry conditions is a type of wear that occurs when a solid material is subjected to repeated contact with abrasive particles suspended in a liquid medium. This type of wear is commonly encountered in industrial processes such as mineral processing, oil and gas, agriculture, and wastewater treatment, where slurries containing abrasive particles are transported through pipelines and equipment [9]. The presence of liquid in three-body abrasion can significantly affect the wear rate and mechanism, as it can change the contact conditions between the surfaces and affect the particle transport and distribution. Three-body abrasion under slurry conditions is a critical wear mechanism in agricultural equipment that handles slurries such as manure, fertilizer, and pesticides [10]. Slurry handling equipment such as pumps, pipes, and valves are often exposed to high levels of abrasive particles suspended in the liquid, leading to significant wear and tear [11].

Red soil is a type of soil that is prevalent in the word [12] and is particularly suited to agriculture due to its high nutrient content and water-holding capacity [13]. Red soil is particularly important, as it provides a fertile base for growing crops such as cotton, sorghum, and wheat, which are essential to the agricultural industry. However, red soil can also present challenges for farmers, particularly in terms of soil erosion [14], nutrient management, and salinity control.

It can be summarised that current agricultural industry relies on durable machinery, but harsh environmental conditions can cause premature wear and tear, resulting in financial losses. Three-body abrasion research can help develop more durable materials. Mild steel is commonly used in agricultural machinery but lacks resistance to moisture, rust, and corrosion. Slurry handling equipment is prone to wear due to abrasive particles. Red soil is important for agriculture but presents challenges such as erosion and nutrient management. Innovation and research are necessary to address these challenges and ensure the sustainability and profitability of the agricultural industry.

The research gap identified from the literature is the lack of specific studies focusing on the three-body abrasion resistance of mild steel under slurry conditions in agricultural environments. While there have been investigations into mild steel wear in various applications, there is limited research dedicated to its performance under three-body abrasion, specifically in agricultural settings. Previous studies have primarily examined mild steel wear in dry or wet conditions without considering the presence of abrasive particles suspended in a liquid medium, which is a characteristic of agricultural slurry conditions. Accordingly, the current study is motivated and initiated to raise the awareness of the issues and investigate the wear resistance of mild steel under three-body abrasion under slurry conditions, simulating the real-life application in agricultural environment. Different applied loads of 10 N–70 N and operating duration up to 90 mins are considered in the three-body abrasion experiments. SEM was used to examine the worn surfaces of the mild steel subjected to different tribological loading conditions.

2. Materials and Experimental Details

2.1. Material Selection. The main material selected for the purpose of conducting this study is mild steel. The main reason for choosing mild steel for the purpose of the study was because it has great use in agricultural applications in which it has been used to design most of the agricultural equipment. Mild steel has great resistance and long-life sustainable use in agricultural equipment; however, the prolonged life of mild steel depends on the wearing environment. The more wear, the shorter the lifetime of the equipment. As the agricultural equipment is mainly used in contact with soil, they face the following two types of wear: wear caused by soil (it could be in dry or slurry condition) and wear that happens between the equipment parts as the surfaces of the parts slide or rotate amongst each other.

2.2. Tribology Setup. The newly fabricated tribological machine is a piece of equipment designed for conducting wear and frictional experiments under dry or wet conditions [3]. The loading system is responsible for applying a specific load to the specimen surface to simulate the contact force between two surfaces in real-world applications. It consists of several components: (1) counterface, (2) block on ring (BOR) load lever, (3) BOR-specimen, (4) load cell, (5) lubricant container, and (6) dead weights, as shown in Figure 1. The measurement and control system includes various sensors and instruments for measuring and monitoring the wear and frictional behaviour of the specimen. The system includes a load cell to measure the frictional force. The control system is adopted to measure the speed and interface temperature through software for data acquisition and analysis. The machine is designed to perform experiments under dry or wet conditions. In wet conditions, a liquid medium such as water, oil, or slurry can be introduced into the system to simulate real-world conditions. The specimen is submerged in the liquid. In the current study, the ASTM G105 standard [15] is used in conducting the experiments. A similar approach of study has been used recently by H. Raushan [16]. The specimen size was 20 mm × 50 mm × 20 mm. It should be mentioned that in accordance with the ASTM G105 standard, the three-body abrasion resistance of mild steel was investigated under soil slurry conditions, simulating agricultural environments.

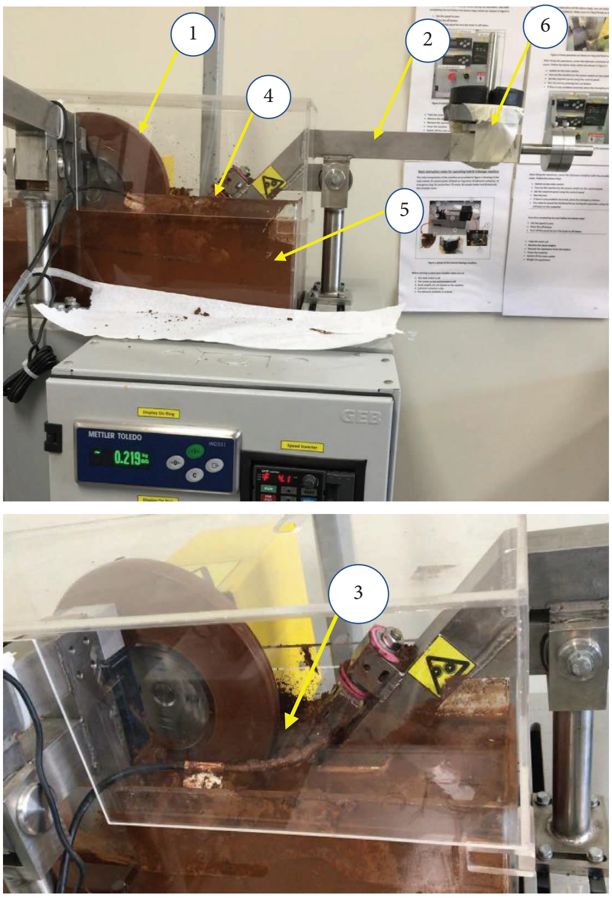

Figure 1: A drawing of the new tribo-test machine. (1) Counterface, (2) BOR load lever, (3) BOR-specimen, (4) load cell, (5) lubricant container, and (6) dead weights.

During the tribotesting process, it is acknowledged that worn steel particles may be introduced into the slurry due to the abrasive wear of the material. These worn particles have the potential to influence the wear behaviour rather than alter the fundamental wear mechanism. While the presence of worn steel particles in the slurry could lead to changes in the environmental components, such as the slurry composition, it is essential to emphasise that the experimental setup was designed to strictly adhere to the ASTM G105 standard. Therefore, the three-body testing was conducted under controlled conditions.

Experiments were conducted at room temperature. The samples of mild steel were cut, ground, and polished to 0.1 μm Ra roughness. The experiment involved testing the tribological behaviour of mild steel samples using a slurry-containing red soil. The AISI/EN number for mild steel is 1006. The chemical composition of 1006 steel typically includes a maximum of 0.08% carbon, 0.25–0.40% manganese, 0.04% phosphorus, and 0.05% sulphur.

In Queensland, Australia, red soil is commonly found in various regions. Red soil in Queensland, Australia, typically consists of a mixture of sand, silt, and clay. It contains a significant amount of iron oxide, particularly hematite and goethite, which gives it the characteristic reddish colour. Other minerals commonly found in red soil include quartz, feldspar, and mica. Red soil in Queensland is generally acidic in nature. It often has low fertility due to leaching of nutrients caused by heavy rainfall and the presence of iron oxides. The physical properties of red soil in Queensland can vary depending on factors such as parent material and climate. In general, red soil has a relatively coarse texture, with a mixture of sand, silt, and clay particles. Sieving process was used in obtaining red soil particles of the desired grain size. The soil sample has been collected and placed on the top sieve of the stack. By gently shaking and tapping the sieve set, the soil particles are separated based on their size. The sieving process continues until no significant amount of soil passes through the sieve. As a result, the red soil particles were in the range of 500 μm. The chemical composition of the red soil includes approximately 3.6% iron, 2.9% aluminium, 0.2% magnesium, 0.56% lime, and 0.2% potassium. The slurry was prepared by mixing red soil with water in a 1 : 1 ratio by volume, and the mixture was homogenized to ensure that the particles were uniformly dispersed.

2.3. Experimental Procedure. The surface of the mild steel samples was prepared by polishing them to remove any irregularities or impurities. This was performed to ensure uniformity in the surface. The weight of the samples was measured before the start of the experiment to record the initial weight of the samples. The counterface surface was prepared by polishing it to a roughness of about 0.1 μm Ra. Sandpapers made of paper and silicon carbide grain were used with different grits (500–2000). The sandpaper was supplied by Bunnings Warehouse, Australia. This was conducted to ensure a smooth and uniform surface for the samples to slide against.

The samples were placed in a holder and firmly fixed to ensure that they did not move during the experiment. The speed and the applied load were set to the required value for the experiment. The experiment was run for a set duration to test the tribological behaviour of the samples. At the end of the test, the samples were washed and cleaned with water, and then, acetone was used to remove any residue or impurities. The weight of the samples was measured again using a high accuracy weight scale with a resolution of 0.1 μg. The slurry was replaced for each set of experiment to ensure that the same conditions were maintained for all tests. Three samples were tested at each test condition to ensure the reproducibility of the results. Overall, these experimental details were carefully planned and executed to ensure accurate and reliable results. To measure the wear rate, the weight loss first to be determined as Δwear = weight (before) – weight (after) and then divided by either the distance (m) or applied load (N). The study considered varying levels of applied load ranging from 10 N to 70 N, rotational speeds ranging from 100 rpm to 500 rpm, and duration ranging from 10 to 90 minutes. In addition, micrographs of the worn surfaces are introduced as well.

Scanning electron microscopy (SEM) JEOL desktop was used to examine the worn surface. The worn surface of the mild steel, which had undergone three-body abrasion, was prepared for the SEM examination. Prior to the experiment, the surface underwent a thorough cleaning process to eliminate any contaminants that could affect the accuracy of the results. This involved washing the surface and removing residual oils, dirt, and debris. Acetone, a commonly used cleaning agent, was used to ensure proper cleaning. After cleaning, the surface was carefully dried to prevent the introduction of moisture into the SEM chamber. To facilitate high-resolution imaging, the SEM chamber was evacuated to a high vacuum state. With the high vacuum established, the electron beam settings were adjusted to suit the imaging requirements. In this specific case, an accelerating voltage of 5 kilovolts (5 kV) was chosen.

3. Results and Discussion

This section presents the experimental results of mild steel under three-body abrasion loading conditions. The experimental results are presented in Figures 2(a)–2(c), which depict the specific weight loss as a function of duration for different sliding speeds. It is observed that there exists a proportional relationship between the specific weight loss and sliding duration, as an increase in sliding duration leads to a corresponding increase in weight loss for all the operating speeds considered. Furthermore, the applied load also had a significant impact on the specific weight loss, with an increase in applied load, leading to an increase in weight loss at all operating speeds. This observation suggests that the longer the duration of sliding wear, the greater the material degradation, which can have significant implications for the design and maintenance of materials in sliding wear applications. Also, this observation highlights the importance of considering the applied load when designing materials for sliding wear applications, i.e., there is an increase in the weight loss by about 8 times when the applied load increases from 10 N to 70 N. As the duration of sliding increases, the amount of material removed generally increases as well. This is because the longer the surfaces are in contact and sliding against each other, the more severe the wear conditions become and the more opportunity there is for the material to be removed [17].

As the load increases, the degree of deformation and the size of the contact area also increase, resulting in higher shear forces between the surfaces. The increase in the shear force leads to more severe wear, which causes the material to be removed from the surface at a faster rate. Furthermore, an increase in applied load can also lead to the development of cracks or other forms of surface damage. This surface damage can act as nucleation sites for the formation of wear particles, leading to even greater material removal. One factor that may potentially augment the magnitude of weight loss at elevated loads is the slurry regime. Specifically, at lower loads, the presence of a boundary often prevails, and the debris undergoes a rolling process as opposed to a sliding one, wherein the surfaces are demarcated by the mentioned debris. Conversely, at higher loads, the debris may intrude upon the mild steel surface and commence a scratching action in lieu of rolling thereupon.

Studies have shown that an increase in the applied load can lead to a significant increase in the wear rate of materials [18]. For example, in a study conducted by B. Yousif [19], it was found that the wear rate of thermoset increased by a factor of three when the applied load was increased. Moreover, an increase in the applied load can also lead to the development of cracks or other forms of surface damage, which can act as nucleation sites for the formation of wear particles, leading to even greater material removal [20]. For instance, in a study conducted in [21], it was observed that an increase in load led to the formation of microcracks on the surface of a material, which eventually resulted in material removal and increased wear rate. Regarding the slurry regime, studies have shown that at lower loads, the presence of a boundary often prevails, and the debris undergoes a rolling process as opposed to a sliding one, leading to less severe wear [22]. Conversely, at higher loads, the debris may intrude upon the surface and commence a scratching action, resulting in more severe wear. Further explanation will be given in the SEM observation in the following section.

Figure 3 depicts the relationship between the wear rate of mild steel and the applied load under varying rotation speeds. The results illustrate a notable escalation in the wear rate, as the applied load increases from 10 N to 50 N, particularly at high and medium speeds. Conversely, at a low speed of 100 rpm, there appears to be no discernible impact of the rise in applied load on the wear rate. Furthermore, an increase in rotational speeds is observed to correspond with an augmentation in the wear rate. When the rotational speed is increased, the abrasive particles are more likely to penetrate deeper into the contacting surfaces, leading to a greater degree of material removal. This effect is due to the increased centrifugal force generated by the higher rotational speeds, which can drive the abrasive particles deeper into the surface of the material. In addition, at higher rotational speeds, the abrasive particles are subjected to a greater degree of acceleration, which can increase the impact force of the particles on the surface of the material [23]. This increased impact force can cause more severe damage to the surface of the material, leading to a higher wear rate. Therefore, the combination of deeper penetration of the abrasive particles and the increased impact force results in an increase in the wear rate of the material with an increase in the rotational speed in three-body abrasion [24]. Furthermore, as the load on a rotating component increase, the contact force between the surfaces rises, leading to more intense frictional interactions and significant abrasive and adhesive wear. In addition, at medium rotational speeds, the lubrication regime may transition from full-fluid film (hydrodynamic) to mixed or boundary lubrication under higher loads, causing increased metal-to-metal contact and wear.

3.1. SEM Observation. The SEM observations on the mild steel sample subjected to the slurry three-body abrasion provide insights into the wear behaviour of the material under these conditions. Figure 4 shows the micrographs of the worn surface of mild steel at 70 N applied load and 100 rpm rotation speeds at different sliding durations.

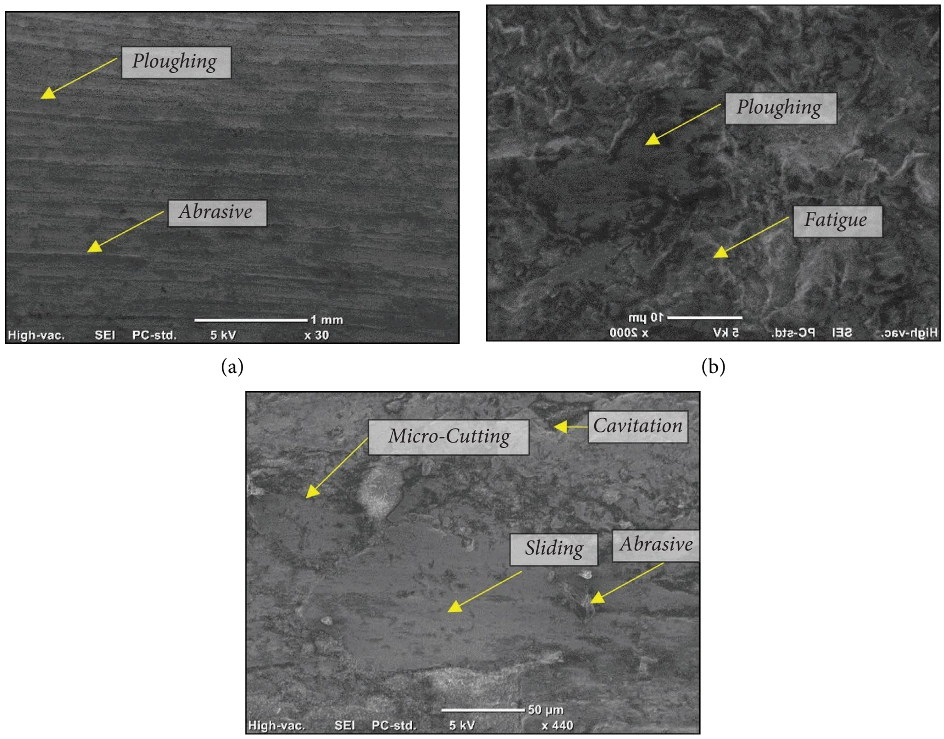

Figure 2: Micrographs of the worn surface of the mild steel after (a) 30 minutes, (b) 60 minutes, and (c) 90 minutes of sliding at an applied load of 70 N with a rotation speed of 500 rpm.

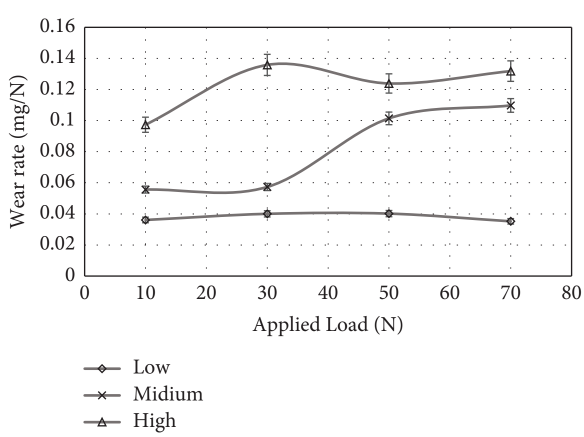

Figure 3: Wear rate mg/N vs. applied load, N.

Figure 4 reveals that the severity of the wear increases with time, and different wear mechanisms dominate at different durations. The ploughing observed at 30 minutes suggests that the abrasive particles in the slurry were not deep enough to cause cutting or pitting. However, at 60 minutes, the abrasive particles had penetrated deeper into the material, resulting in pitting and cutting. The severe erosion, pitting, and high material removal observed at 90 minutes indicate that the abrasive particles had continued to penetrate deeper into the material, causing severe damage. This can explain the results in Figure 5. Similar wear mechanisms were reported by H. Pourasiabi [25]. Since the early stages of wear, ploughing was the dominant wear mechanism, followed by microcutting and microploughing. At a later stage, severe deformation, cracking, and delamination occurred, leading to material removal.

Figure 2 presents a collection of micrographs portraying the worn surface of mild steel subjected to a sliding process at an applied load of 70 N and a rotation speed of 500 rpm for the following three distinct durations: (a) 30 minutes, (b) 60 minutes, and (c) 90 minutes. Compared to the corresponding images captured at a lower rotation speed of 100 rpm (Figure 4), the micrographs exhibited more pronounced damages to the steel surface. Specifically, Figure 2 reveals several types of surface wear mechanisms, such as fatigue, microcutting, cavitation, plastic deformation, and abrasion. The presence of fatigue and microcutting is indicative of the cyclic nature of the loading applied to the material, leading to progressive damage accumulation and eventual failure. Cavitation, characterized by the formation and implosion of microscopic bubbles on the surface, can lead to local material removal and further damage. Plastic deformation, as seen in Figure 2, is a result of the severe loading conditions and can cause permanent changes in the material's shape and structure. Finally, abrasion, which occurs when two surfaces slide against each other, can result in surface roughening and material loss.

Figure 6 displays the images of the worn surface of mild steel under specific testing conditions. The tests were conducted for 90 minutes, using a rotation speed of 500 rpm and varying applied loads. The images show the surface at

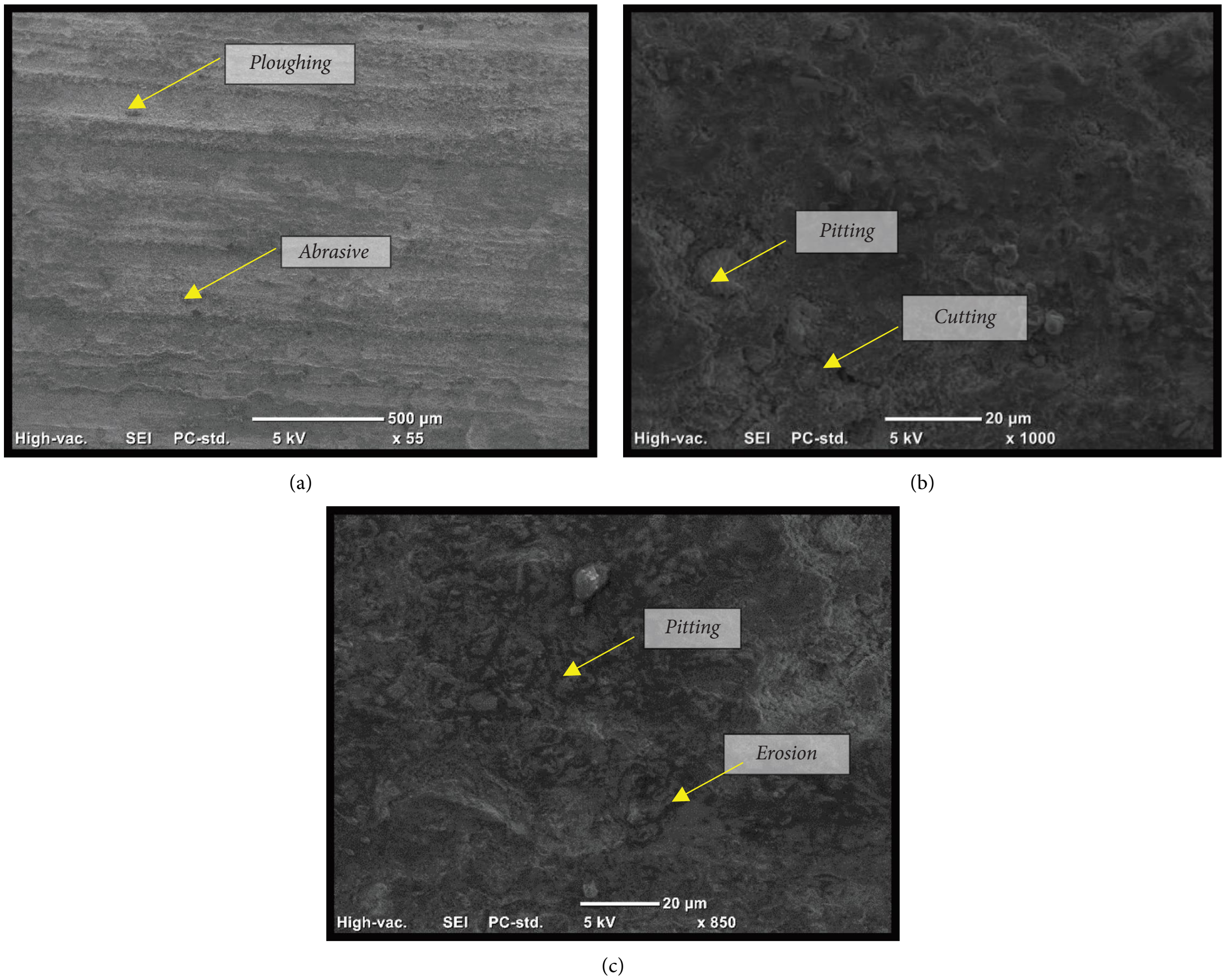

Figure 4: Micrographs of the worn surface of the mild steel after (a) 30 minutes, (b) 60 minutes, and (c) 90 minutes of sliding at an applied load of 70 N with a rotation speed of 100 rpm.

applied loads of (a) 30 N, (b) 50 N, and (c) 70 N. The micrographs reveal a severe damage to the surface of the mild steel, particularly at higher applied loads. This suggests that there was a high level of material removal under severe loading conditions. The wear mechanism responsible for this material removal is likely to be the one observed in previous tests but on a larger scale. In [26], it has been reported that at low abrasive particle loads, ploughing and microcutting were the dominant wear mechanisms, whereas at high loads, fracture, cracking, and delamination occurred, leading to severe material removal in steel alloys.

In addition, the study was conducted to determine the friction coefficient between mild steel and stainless steel when a slurry was present at the interface. The experimental results revealed that the friction coefficient fell within the range of 0.25– 0.31 under various operating conditions, including different speeds, loads, and sliding distances. Interestingly, no significant influence of any of these operating parameters on the friction coefficient values was observed. The presence of the slurry in the interface played a crucial role in determining the frictional behaviour between the two materials. The slurry acted either as a lubricant or as a third body [27], affecting the frictional interaction. In both cases, the exact identification of the friction coefficient between mild steel and stainless steel became challenging due to the presence of the slurry in the interface region. The range of friction coefficients suggests that the slurry, acting as a lubricant, helped to reduce the frictional resistance between the two surfaces. This reduction in friction could be attributed to the formation of a thin film of slurry that facilitated smoother sliding and reduced direct contact between the materials [27]. Consequently, the friction coefficient remained relatively stable across different operating conditions.

Alternatively, when the slurry acted as a third body, it introduced additional particles or debris into the interface region [28]. These particles could have altered the contact mechanisms and influenced the friction behavior. Despite the presence of these foreign particles, the friction coefficient exhibited consistent values, indicating that the slurry played a significant role in regulating the frictional interaction.

On the other hand, while the current study focused on investigating the three-body abrasion of mild steel against a stainless steel counterface under slurry conditions, it is

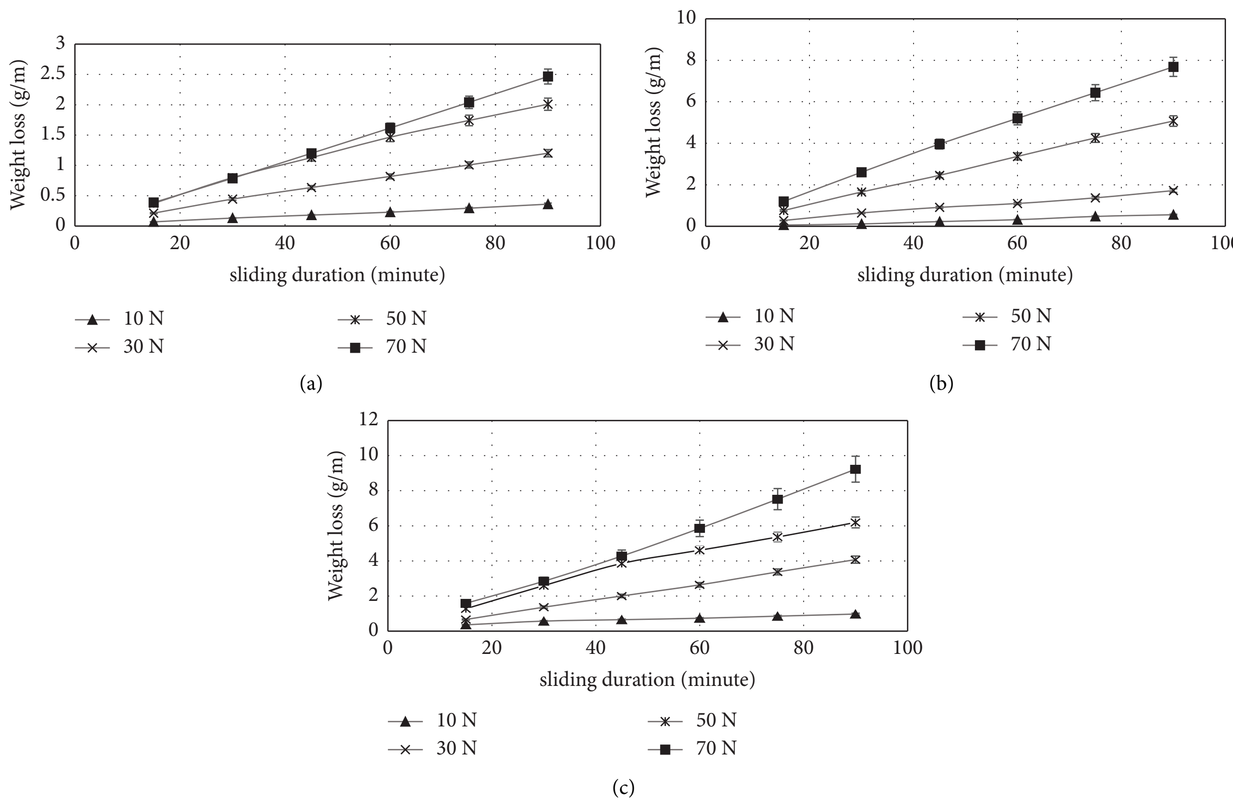

FIGURE 5: Weight loss vs. sliding duration for different speeds. (a) Weight loss vs. time at a low speed of 100 rpm. (b) Weight loss vs. time at a medium speed of 300 rpm. (c) Weight loss vs. time at a high speed of 500 rpm.

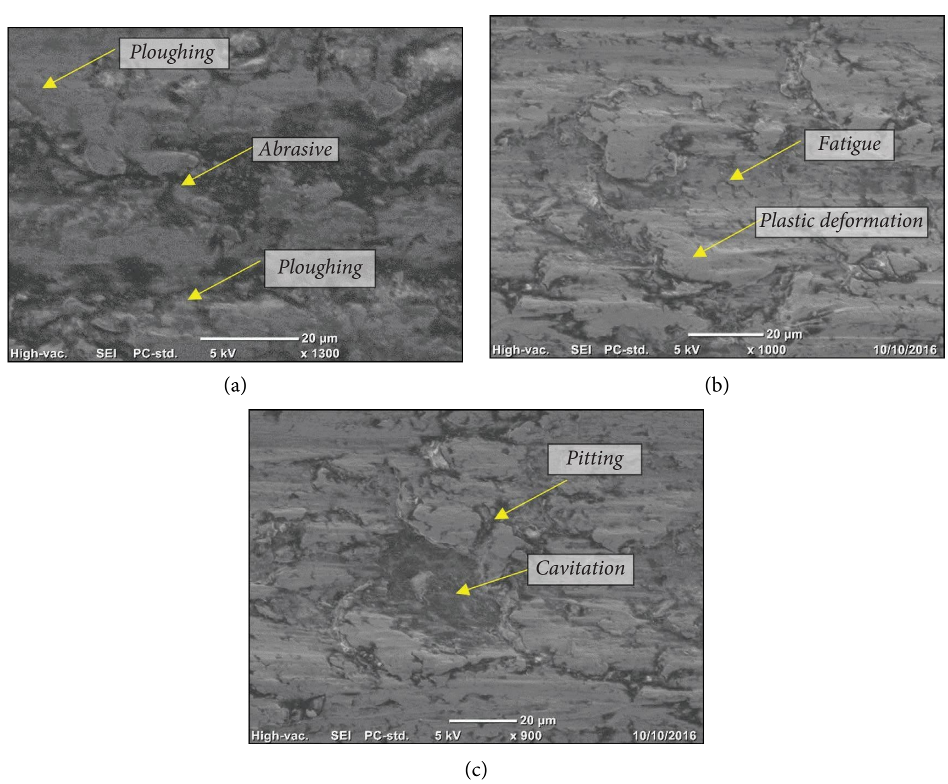

FIGURE 6: Micrographs of the worn surface of the mild steel after 90 minutes and rotation speed of 500 rpm at applied loads of (a) 30 N, (b) 50 N, and (c) 70 N.

important to note that the influence of corrosion on wear was not specifically addressed. Considering the potential impact of corrosion on wear in slurry conditions, particularly with water and at lower speeds, should be a valuable direction for future research. Moreover, understanding the specific wear mechanisms resulting from the synergistic interaction between corrosion and abrasion is crucial. Investigating the role of chemical attack, localized material removal, formation of pits or craters, and the contribution of corrosion products as additional abrasive agents can provide deeper insights into the complex nature of corrosion-induced wear in slurry environments with water and lower speeds.

4. Conclusion

This study investigated the behaviour of mild steel under three-body abrasion loading conditions with varying levels of applied load, rotational speed, and duration. The findings of this study can be summarised as follows:

A proportional relationship between specific weight loss and sliding duration across all operating speeds was found. An increase in applied load resulted in higher weight loss at all operating speeds. It was evident that longer sliding wear durations led to greater material degradation, underscoring the need for careful material selection and maintenance strategies.

An increase in the applied load led to an escalation in deformation and contact area, consequently generating higher shear forces in the sliding area. This led to more severe wear and increased material removal rate. Higher applied loads had the potential to induce cracks and surface damage, acting as nucleation sites for wear particle formation and exacerbating material removal.

Slurry regime played a role in the magnitude of weight loss at elevated loads. At lower loads, the debris underwent a rolling process, resulting in less severe wear. Conversely, at higher loads, the debris intruded upon the surface and initiated scratching actions, leading to more severe wear.

Increase in rotational speeds was found to correlate with an increased wear rate, i.e., higher rotational speeds generated greater centrifugal forces, propelling abrasive particles deeper into the material surface. The acceleration of abrasive particles at higher speeds amplified their impact force on the material, contributing to more severe damage and higher wear rates. The combined effect of deeper particle penetration and increased impact force resulted in elevated wear rates with increasing rotational speeds in three-body abrasion scenarios.

Examination using SEM revealed that ploughing was observed initially, indicating insufficient penetration of abrasive particles. However, as time progressed, pitting and cutting were observed, signifying deeper particle penetration and increased damage. At longer durations, severe erosion, pitting, and high material removal were evident, indicating continued particle penetration and extensive damage.

Data Availability

The experimental data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

Open access publishing was facilitated by the University of Southern Queensland, as part of the Wiley-University of Southern Queensland agreement via the Council of Australian University Librarians.

References

[1] D. Y. Pimenov, M. Mia, M. K. Gupta et al., “Resource saving by optimization and machining environments for sustainable manufacturing: a review and future prospects,” *Renewable and Sustainable Energy Reviews*, vol. 166, Article ID 112660, 2022.

[2] A. Sobirjonov, “Prevention of corrosion and accelerated wear of agricultural machinery,” *Ilkogretim Online-Elementary Education Online*, vol. 20, no. 5, pp. 7482–7486, 2021.

[3] B. Yousif, “Design of newly fabricated tribological machine for wear and frictional experiments under dry/wet condition,” *Materials and Design*, vol. 48, pp. 2–13, 2013.

[4] M. Petrica, C. Katsich, E. Badisch, and F. Kremsner, “Study of abrasive wear phenomena in dry and slurry 3-body conditions,” *Tribology International*, vol. 64, pp. 196–203, 2013.

[5] A. A. Shurpali, “Laboratory investigation of the abrasive wear mechanism of concrete crosstie rail seat deterioration (RSD),” in *ASME/IEEE Joint Rail Conference*, American Society of Mechanical Engineers, New York, NY, USA, 2012.

[6] N. M. Pujar, Y. Mani, and S. Mouleeswaran, “Experimental investigation on three-body abrasive wear behaviour of novel natural cellulosic pigeon pea stalk fibre reinforced epoxy biocomposites,” *Materials Research Express*, vol. 9, no. 8, Article ID 085501, 2022.

[7] A. Asif, Y. Zheng, S. Rahman, A. Amiri, H. J. Jun, and A. A. Polycarpou, “Three-body abrasive wear in the presence of inorganic fullerene-like tungsten disulfide and ionic liquid containing alkanolamines and phosphates,” *Wear*, vol. 486-487, Article ID 204073, 2021.

[8] Q. Li, X. Xia, Z. Pei et al., “Long-term corrosion monitoring of carbon steels and environmental correlation analysis via the random forest method,” *Npj Materials Degradation*, vol. 6, no. 1, p. 1, 2022.

[9] Z. Sydow, M. Sydow, Ł. Wojciechowski, and K. Bieńczak, “Tribological performance of composites reinforced with the agricultural, industrial and post-consumer wastes: a review,” *Materials*, vol. 14, no. 8, p. 1863, 2021.

[10] M. Gros, J. Mas-Pla, M. Boy-Roura, I. Geli, F. Domingo, and M. Petrović, “Veterinary pharmaceuticals and antibiotics in manure and slurry and their fate in amended agricultural soils: findings from an experimental field site (Baix Empordà, NE Catalonia),” *Science of the Total Environment*, vol. 654, pp. 1337–1349, 2019.

[11] J. Singh, S. Kumar, and H. S. Gill, “Review on testing facilities assisting in development of numerical models for erosion calculation in centrifugal slurry pumps,” *International Journal on Interactive Design and Manufacturing*, pp. 1–27, 2023.

[12] M. Baldwin, C. E. Kellogg, and J. Thorp, *Soil Classification*, Bobbs-Merrill, Indianapolis, Indiana, 1938.

[13] V. Baligar, *Nature And Properties of Red Soils of the World. The Red Soils of China: Their Nature, Management and Utilization*, Springer, Berlin, Germany, 2004.

[14] P. Gruhn, F. Goletti, and M. Yudelman, "Integrated nutrient management, soil fertility, and sustainable agriculture: current issues and future challenges," *The International Food Policy Research Institute*, vol. 8, 2000.
[15] G. Astm, *105-02 Standard Test Method for Conducting Wet Sand. Rubber Wheel Abrasion Tests*, ASTM International, West Conshohocken, PA, USA, 2007.
[16] H. Raushan, A. Bansal, V. Singh et al., "Dry sliding and slurry abrasion behaviour of wire arc additive manufacturing – cold metal transfer (WAAM-CMT) cladded inconel 625 on EN8 steel," *Tribology International*, vol. 179, Article ID 108176, 2023.
[17] Y. Yan, "Tribology and tribo-corrosion testing and analysis of metallic biomaterials," in *Metals for Biomedical Devices*, Elsevier, Amsterdam, Netherlands, 2010.
[18] C. Ramesh, R. Keshavamurthy, B. Channabasappa, and S. Pramod, "Influence of heat treatment on slurry erosive wear resistance of Al6061 alloy," *Materials and Design*, vol. 30, no. 9, pp. 3713–3722, 2009.
[19] B. Yousif and N. El-Tayeb, "Wear characteristics of thermoset composite under high stress three-body abrasive," *Tribology International*, vol. 43, no. 12, pp. 2365–2371, 2010.
[20] A. M. Kirk, P. Shipway, W. Sun, and C. Bennett, "The effect of frequency on both the debris and the development of the tribologically transformed structure during fretting wear of a high strength steel," *Wear*, vol. 426-427, pp. 694–703, 2019.
[21] A. Cenna, P. Dastoor, A. Beehag, and N. W. Page, "Effects of graphite particle addition upon the abrasive wear of polymer surfaces," *Journal of Materials Science*, vol. 36, no. 4, pp. 891–900, 2001.
[22] B. Bhushan and P. L. Ko, "Introduction to tribology," *Applied Mechanics Reviews*, vol. 56, no. 1, pp. B6–B7, 2003.
[23] S. Kumar, A. Harsha, H. Goyal, A. A. Hussain, and S. Wesley, "Three-body abrasive wear behaviour of aluminium alloys," *Journal of Engineering Tribology*, vol. 227, no. 4, pp. 328–338, 2013.
[24] Y. Li and Y. Gao, "Three-body abrasive wear behavior of CC/high-Cr WCI composite and its interfacial characteristics," *Wear*, vol. 268, no. 3-4, pp. 511–518, 2010.
[25] H. Pourasiabi and J. D. Gates, "Effects of matrix chromium-to-carbon ratio on high-stress abrasive wear behavior of high chromium white cast irons dual-reinforced by niobium carbides," *Tribology International*, vol. 167, Article ID 107350, 2022.
[26] R. Jia, T. Tu, K. Zheng, Z. Jiao, and Z. Luo, "Abrasive wear behavior of TiC-strengthened eutectic high chromium cast iron composites," *Materials Today Communications*, vol. 29, Article ID 102906, 2021.
[27] Y. Li, P. Schreiber, J. Schneider, and C. Greiner, "Tribological mechanisms of slurry abrasive wear," *Friction*, vol. 11, no. 6, pp. 1079–1093, 2023.
[28] M. Shen, B. Li, Z. Zhang, L. Zhao, and G. Xiong, "Abrasive wear behavior of PTFE for seal applications under abrasive-atmosphere sliding condition," *Friction*, vol. 8, no. 4, pp. 755–767, 2020.