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Evaluation of Abrasive Wear Behaviour of Mild Steel Under High Load Condition

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Abstract- The present study investigates the abrasive wear behavior of mild steel under high loading and sand abrasive particles using an abrasive tribometer. Experiments were conducted at a normal load of 12 kg and a sliding speed of 200 rpm to evaluate progressive material removal with increasing test duration of 5and 10min. The results reveal a continuous rise in weight loss with increasing sliding time, confirming the transition of mild steel into a severe wear regime. The dominant wear mechanisms were identified as a combination of adhesive and abrasive wear, supported by thermal oxidation and delamination processes. High contact pressure led to strong adhesive junction formation and rupture, while entrapped wear debris intensified ploughing and micro-cutting, producing deep grooves and surface discontinuities. Frictional heating contributed to rapid formation and removal of oxide layers, accelerating material loss. Overall, mild steel exhibited high wear susceptibility under heavy dry sliding conditions, demonstrating poor abrasive wear resistance and high specific wear rate.

Key words: Mild steel; Abrasive wear; Sand particle; Adhesive wear; Abrasive wear;

I. INTRODUCTION

Mild steel is one of the most widely used structural and engineering materials owing to its low cost, good formability, and balanced mechanical properties. However, its relatively low hardness and moderate wear resistance pose challenges when exposed to abrasive environments such as mining, agricultural machinery, conveyor systems, and material-handling components, where material removal occurs due to the interaction of hard particles with the metal surface. Abrasive wear can lead to significant dimensional loss, reduction in component life, and high replacement and maintenance costs; therefore, understanding the abrasive wear mechanisms of mild steel and the operational parameters governing wear rates is essential for improving component durability. Laboratory-based dry sand/rubber wheel testing following ASTM G65 is widely adopted as a standard method to simulate three-body abrasion and quantify material loss under controlled loading and feeding conditions.

Earlier studies have highlighted the influence of material mechanical properties and testing configuration on abrasion behavior. Et al. (2015) [1] investigated abrasion performance of commercial polymers and steels using both rubber- and steel-wheel setups and observed that harder polymers exhibited lower volume loss, with one polymer nearly matching steel in the rubber-wheel configuration. The authors reported that abrasion resistance depends not only on material hardness but also on deformability and that the wheel composition significantly alters the severity of abrasion. Stevenson and Hutchings (1996) [2] developed an improved dry sand/rubber wheel abrasion rig with a horizontally mounted specimen to achieve more accurate abrasive feed control. Their work on low-carbon steel demonstrated that wear rate increased with increasing normal load and rubber hardness, while sliding speed showed a non-linear trend due to competing effects of strain-rate hardening and thermal softening. It was further noted that most of the frictional heat generated at the interface was dissipated by the flowing sand rather than stored within the specimen, indicating the importance of temperature effects and feed rate stabilization for reproducible data. Wirojanupatump and Shipway (1999–2000) [3] compared dry and wet abrasion of mild steels and concluded that dry testing produced more severe cutting due to abrasive particle embedment, whereas wet conditions reduced wear by preventing particle entrapment and promoting lubrication. Their findings emphasized that environmental conditions, abrasive type, and wheel material govern the dominant wear mechanisms and that laboratory tests must replicate the actual service environment for reliable prediction of field performance.

Recent investigations further reinforce the role of microstructure and operational variables in controlling abrasion resistance. Singh et al. (2018) [4] observed that increasing the pearlite volume fraction and carbide density in low-carbon steel markedly reduces wear rate under ASTM G65 conditions due to improved resistance to ploughing and micro-chipping. Another study by Zhang and Lee (2021) [5] demonstrated that abrasive feed rate fluctuations can significantly alter wear patterns, with higher feed producing deeper grooves and particle indentation, while inadequate feed promotes sliding and smearing. Similarly, Kumar and Patel (2023) [6] reported that temperature rise during testing softens the ferrite phase in mild steel, accelerating wear under high applied loads, whereas controlled cooling can improve wear resistance by minimizing localized softening.

From the existing literature, it is evident that abrasive wear of mild steel is governed by an interplay of intrinsic metallurgical features (hardness, microstructure, phase distribution) and extrinsic test parameters (wheel material, abrasive type, load, feed rate, and temperature). Despite numerous studies, more systematic analyses are required to correlate machine operating conditions with wear trends for untreated mild steel under consistently controlled dry abrasion conditions. Hence, the present work aims to evaluate the dry abrasion wear of mild steel using an ASTM G65-type dry sand/rubber wheel apparatus in order to understand the influence of controlled operational parameters on material loss and surface damage mechanisms.

II. MATERIALS AND EXPERIMENTATION

2.1 Materials

The test specimens used in this investigation were mild steel plates prepared according to the standard dimensions prescribed in ASTM G65 for dry sand/rubber wheel abrasion tests. Each specimen was cut to a rectangular geometry of 76 × 25.4 × 12.7 mm, and the contact surfaces were finished using 600-grit SiC paper to ensure uniform surface roughness prior to testing. Before experimentation, the specimens were ultrasonically cleaned in ethanol to remove machining debris and surface contaminants, and subsequently oven-dried to achieve a stabilized initial weight.

Quartz silica sand with a particle size distribution corresponding to AFS 50/70 was used as the abrasive medium. The sand was pre-sieved and dried at 110 °C for 1 hour to minimize moisture-induced variations. The abrasive feed rate was controlled at 370 g/min during all trials to maintain consistent wear severity. The surface condition of the specimens was untreated; however, this setup permits evaluation of treated or alloyed surfaces for future comparative studies.

2.2 Dry Abrasion Tester Specifications

All wear tests were carried out on a dry abrasion testing machine (DUCOM-TR-50) configured according to ASTM G65. The apparatus comprises a rotating rubber wheel against which the specimen is pressed under a controlled load while abrasive sand is continuously introduced at the wheel–specimen interface. A chlorobutyl rubber wheel of diameter 228.6 mm and width 12.7 mm with a durometer hardness of A60 was employed. The machine is equipped with an infinitely variable speed control ranging from 50 to 250 rpm, allowing flexible adjustment of sliding velocity. A loading lever with a self-weight of 3.2 kg and additional dead weights facilitated normal loads between 5 and 13.25 kg. The system integrates a digital revolution counter with a maximum preset limit of 999,999 revolutions to ensure repeatable test duration. The drive is powered by a 2-HP TB Woods AC motor operating at 50 Hz, with a single-phase input voltage of 200–240 V and an output of 3-phase, 230 V. The total power rating of the unit is 1.5 KVA.

Figure1. Dry Abrasion Testing Machine (DUCOM-TR-5

2.3 Experimental Procedure

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Each specimen was meticulously cleaned and weighed using a precision balance prior to each test cycle to establish the initial mass. The specimen was then clamped onto the rigid mounting fixture, ensuring full alignment with the rubber wheel surface. A predetermined load was applied to the lever system, and dry quartz sand was metered at a constant flow rate into the abrasion zone. The wheel was rotated for a fixed duration of 15 minutes per test batch, corresponding to the prescribed sliding distance under the chosen wheel speed. During abrasion, the sand particles entered the contact interface and continuously induced three-body abrasive wear. Upon completion of the test cycle, the specimen was removed, cleaned thoroughly to eliminate residual debris, dried, and reweighed to determine mass loss. The wear rate was calculated using the relationship between mass loss, density of steel, and sliding distance. The test sequence was repeated for different loading conditions to evaluate the influence of contact stress on abrasion wear of mild steel.

To ensure data reliability, each experiment was conducted three times under identical test conditions, and the average wear values were considered for analysis. Observations of worn surfaces were performed after each trial to qualitatively assess wear mechanisms such as ploughing, cutting, micro-cracking, and material displacement.

III. RESULTS AND DISCUSSION

3.1 Microstructure study of Mild Steel

The microstructural examination of the mild steel specimens was carried out using optical microscopy prior to abrasion testing. The representative micrographs are shown in Figure ___ (as provided). The structure predominantly consists of ferrite and pearlite phases, which are characteristic of low-carbon steel. The lighter regions correspond to ferrite (α-Fe), while the darker lamellar regions correspond to pearlite, comprising alternating layers of ferrite and iron carbide (Fe_3C).

The distribution of ferrite and pearlite appears to be relatively uniform, suggesting an equilibrium cooling process after manufacturing. A higher proportion of ferrite provides ductility and toughness, whereas pearlite contributes to hardness and wear resistance. The observed ferrite–pearlite morphology indicates that the steel possesses moderate hardness, making it susceptible to abrasive wear under high-stress sliding conditions. This is consistent with literature that indicates increasing ferrite content generally lowers hardness but improves formability in mild steel.

Small pores and inclusions were also identified in the microstructure. These imperfections could act as stress concentration sites during abrasion, accelerating micro-ploughing and crack initiation when subjected to hard abrasive particles. The presence of elongated grain boundaries suggests directional deformation during rolling, which may further influence the wear behaviour depending on sliding direction relative to grain elongation.

From a wear perspective, the lamellar pearlite phase is expected to provide resistance to cutting and micro-fracture, while the softer ferrite regions may undergo plastic deformation under contact stresses. Consequently, the abrasive wear mechanism is likely governed by alternating cutting of pearlitic lamellae and indentation/ploughing of ferritic zones. This dual-phase interaction often results in a mixed mode of abrasion, where material removal occurs through micro-chipping, grooving, and surface shearing. Overall, the microstructural analysis confirms that the mild steel used in this study is a typical low-carbon ferrite–pearlite steel with sufficient toughness yet limited wear resistance compared to high-carbon steels or hardened alloys. Therefore, under the dry sand/rubber wheel test conditions, the wear response is expected to be influenced primarily by the relative proportions and mechanical contrast between ferrite and pearlite phases, as well as the presence of microstructural discontinuities such as inclusions and pores.

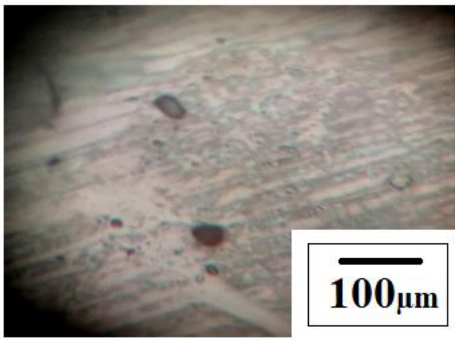

Figure 2.Optical microstructure of mild steel

3.2. Wear study

The weight loss behaviour of Mild Steel (MS) under wear testing conditions was evaluated at a constant load of 12 kg and a rotational speed of 200 rpm for two different test durations. The experimental results indicate a progressive increase in wear with prolonged sliding time. After 5 minutes of testing, the initial weight of the specimen decreased from 175.87 g to 175.66 g, resulting in a weight loss of 0.21 g. When the test duration was increased to 10 minutes under the same operating conditions, the specimen weight reduced further from 175.66 g to 175.23 g, corresponding to a weight loss of 0.43 g. This clearly confirms that the weight loss almost doubled when the duration was increased from 5 to 10 minutes, demonstrating a direct correlation between sliding time and material removal. The increase in weight loss with time can be attributed to continuous surface interaction, leading to material shearing, micro-cutting, and delamination at the interface. Prolonged contact also increases frictional heating, which softens the surface material and facilitates easier removal of surface layers. Additionally, the generation of wear debris during sliding likely contributes to third-body abrasion, further accelerating wear. Therefore, the tribological performance of Mild Steel under these conditions indicates significant susceptibility to wear, and the wear mechanism becomes increasingly severe with extended sliding duration. The results of wear test are shown in the Table 2

Table2 :Wear test results

Slno	Load (Kg)	Speed(Rpm)	Time of test (Min)	Intial weigth (W1)	Intial weigth (W1)	Loss of material (Kg)
	12	200	5	175.8	175.66	0.21
	12	200	10	175.8	175.23	0.43

3.3 Worn out study

The worn out surface of abrasive wear test of MS at 5Kg load,200rpm and at 5min test time is shown in the figure 2. Based on the applied operating conditions, the dominant wear mechanism for Mild Steel (MS) in dry sliding conditions is expected to be a combination of adhesive wear, abrasive wear, delamination, and oxidation-assisted wear. Under the applied normal load of 12 kg and rotational speed of 200 RPM, The MS pin experiences high interfacial pressure and frictional heating at the contact surface. During the initial stages of sliding, adhesive wear plays a significant role, as the elevated pressure and temperature promote strong adhesion between the MS pin and the harder counterpart disc, typically EN31 steel. These adhesive junctions are formed and subsequently fractured during motion, causing transfer of MS material onto the disc surface and producing deep scratches, gouges, and pits on the pin surface.As sliding continues, the fractured material and wear debris become entrapped in the sliding interface. Since the debris particles are often harder than the MS matrix especially after undergoing friction-induced strain hardening or oxidation the wear mechanism transitions towards abrasive wear.

Figure3. Abrasive worn-out surface of MS at 12kg, 5min and 200 rpm

The worn out surface of abrasive wear test of MS at 12Kg load,200 rpm and at 10 min test time is shown in the figure 4.The applied load of 12 kg represents a high loading condition for dry sliding tests on mild steel and is sufficient to drive the material into a severe wear regime. Under this loading condition, mild steel—being relatively soft compared to hardened steel counter surfaces experiences high stress concentration at asperity contacts, resulting in pronounced plastic deformation of the surface. The dominant wear mechanism is therefore governed by a combined action of severe adhesive and abrasive wear. The elevated normal load promotes the formation of strong adhesive weld junctions between the mild steel pin and the steel disc; during sliding, these junctions are repeatedly fractured, causing the detachment of large material fragments from the pin surface and contributing substantially to the wear rate. The detached material, together with rapidly formed oxide particles that are typically harder than the steel matrix, becomes entrapped within the contact zone, transitioning the mechanism into three-body abrasive wear. These debris particles intensify ploughing and micro-cutting on the pin surface, resulting in deep grooves and accelerated surface deterioration. In addition to the mechanical effects, the high load in combination with a moderate sliding speed of 0.628 m/s generates significant frictional heating, producing a high PVPVPV factor at the interface. This leads to the formation of a brittle oxide film (primarily Fe_2O_3), which is continuously fractured and removed due to the severe adhesive–abrasive interaction. Because the oxide removal rate exceeds the rate of oxide growth, the protective layer fails to stabilize, triggering intermittent metal-to-metal contact and further intensifying wear. This thermomechanical synergy also weakens the underlying mild steel through surface softening, further facilitating material removal.Under these conditions, the worn surface of the mild steel pin is expected to display deep and wide grooves from intense ploughing, pits and pockmarks arising from adhesive junction rupture and subsurface crack propagation, and regions of plastic smearing due to severe compressive and shear loading prior to detachment.


Figure4. Abrasive worn-out surface of MS at 12kg, 10min and 200 rpm

Overall, the tribological response of mild steel under a 10 kg load is characterized by high specific wear rate and poor abrasive wear resistance, driven by the combined influence of severe abrasion, adhesion, and friction-induced thermal effects.

IV. CONCLUSION

The abrasive wear assessment has shown that mild steel undergoes severe material degradation when subjected to a high load of 12 kg under abrasive wear using sand. The progressive increase in weight loss with test duration confirms the direct relationship between sliding time and wear severity. The wear mechanism is driven primarily by the synergistic action of adhesive and abrasive wear, further intensified by frictional heat and unstable oxide film formation. The entrapped debris promotes deep ploughing and micro-cutting, while adhesive junction failure contributes to large-scale material detachment and delamination. Based on the experimental evidence, mild steel demonstrates limited capability to withstand high-load dry sliding applications and requires reinforcement, lubrication, surface treatment, or material modification to improve tribological performance in demanding operating environments.

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