

Analyzing Frictional Noise for Wear Monitoring under dry and lubrication condition: Experimental Modelling with Pin-On-Disc Tribometer.

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Abstract

In industrial settings, the use of frictional noise to improve wear monitoring is highly promising. It enables the identification of changes in friction and wear conditions, the assessment of different phases of wear, and the examination of the impact of wear on machine performance. By analysing acoustic signatures, it is conceivable to continuously monitor the wear characteristics and surface conditions. This helps in predicting wear and detecting aberrant wear regimes in real-time. The data demonstrate that in dry conditions, the aluminium disc has higher coefficients of friction relative to cast iron and mild steel, likely due to the absence of graphite flakes in aluminium. Under lubricated conditions, a layer of lube significantly decreases the coefficient of friction, with no apparent deviations across the materials, demonstrating that complete lubrication avoids direct metal contact. In lubrication-starved applications, oily depictions nevertheless help minimize friction, though less efficiently than complete lubrication. In dry conditions, frictional sound levels for mild steel are higher due to direct surface hits, while lubrication reduces noise by eliminating metal-on-metal contact. As a result, monitoring noise levels is a helpful indicator of lubrication difficulties, aiding in maintenance and repairs.

Keywords: Wear monitoring, Frictional Noise, Pin-on-Disc, Tribology, Mechanical Systems.

1. Introduction

Monitoring wear through frictional noise using a pin-on-disc setup is a valuable approach for assessing the condition of mechanical components[1–3]. This method involves utilizing a ball holder with two-point contact over a rotating disc to simulate real-world machine environments[3,4]. By analyzing the sound signals obtained from a microphone placed near the contact area, correlations between wear and frictional noise can be established, aiding in the modeling of wear dependencies [5,6]. Additionally, the use of a pin-disc type friction and wear testing machine equipped with sensors like torque and pressure sensors can provide accurate data for calculating the friction coefficient and monitoring wear processes in a controlled manner[7,8] . Therefore, integrating frictional noise analysis with wear monitoring can offer insights into the health and performance of mechanical systems.

The challenges posed by wear processes are significant in the industrial sector. This is due to wear decreasing the useful life of machine components and thus, replacing or repairing machine components is quite expensive [4,5,7] . A technique that detects changes in the surface contact conditions is required to monitor the process and estimate the wear rate. When two materials come into contact, deterioration and the accompanying noise are unavoidable [9–14] To monitor the process and predict the wear rate, a method capable of detecting changes in the surface contact conditions is needed. Acoustic emission techniques can be used to detect the stress changes caused by asperity contact between mating surfaces [15–18]. The mechanical interactions between machine components produce inevitable wear and airborne noise. In addition, the unavoidable relationship between airborne noise, friction, and wear can be used to estimate wear accurately. [19–21].

Friction, wear, noise, lubrication, and rough surface are all related in the context of mechanical systems. Wear is the gradual removal of material from a surface due to friction. Noise is the result of irregular vibrations that occur in a mechanical system due to friction. Surface with an irregular surface texture which can increase friction and wear and cause noise. Lubrication is the application of a substance to reduce friction and wear [11,22,23]. The relationship between these factors can be complex and is determined by many factors, including the materials of the surfaces in contact, the loads applied, and the operating conditions. [22,24]. Acoustic emission techniques can be used to detect stress fluctuations during asperity contact between mating interfaces [25]. Mechanical interactions between equipment parts produce wear and ambient noise that can be identified precisely. Factors such as friction, wear, noise, lubrication, and rough surfaces have implications for motion systems [26,27]. Wear is the unwilling removal of substances from a surface due to friction; noise is the result of irregular

vibrations; and lubrication reduces friction and wear. The association between these factors is complex and determined by different circumstances.

The generation of wear and airborne noise is inevitable in the mechanical contacts of the machine components [4,20,28]. Two primary wear mechanisms occur: adhesive wear and abrasive wear. During friction processes, wear is produced, leading to airborne noise and increased temperature [9]. The surface wear in mechanical contacts under operational conditions is consistently challenging. However, the unavoidable link between the airborne noise and the surface wear can be used to predict the latter with good accuracy [20,29]. From a theoretical perspective, most friction and wear models were developed individually to analysis the noise due to friction. However, friction noise was not included in analytical, numerical, physical, or empirical models in all those cases [30–33]. However, most of the models that predict wear and friction have limitations. In addition, just few models have examined friction, wear, and noise without considering the effect of lubrication [19,34]. Wear caused by friction between sliding contacts has garnered significant interest from researchers, particularly due to its impact on gear motion, brake application, and other similar interactions between mechanical components[35–37].

In terms of the importance of minimizing noise for clients in the industry, the primary area of research on sound emissions revolves around disc braking systems. Conversely, many previous initiatives relied heavily on real-world connections. These algorithms produce wear assessments in actual working settings and are often valid in laboratory tests [38–40]. For example, wear that happens in an unlubricated condition can be readily identified and applied in situations that occur outside of the laboratory. It is also possible to understand several wear processes and use them in manufacturing processes [41–43]. When evaluating machinery with multiple corrupted sections or in more complex scenarios, including the use of lubrication, the correctness of these correlations is put into doubt [44–46]. As a result of these challenges, condensed all the different wear mechanisms into one coherent wear model.

Friction-induced noise is an essential aspect of maintenance plans because of how it impacts efficiency in operations, security, and budget control. By recognizing the beginnings and implications of noise that results from friction, maintenance employees can formulate effective techniques to oversee, analyses, and resolve fundamental problems. Implementing this proactive plan not only improves the effectiveness and longevity of machines, but it also ensures secure and economical operations. With the rapid advancement of technological devices, the inclusion of noise analysis in maintenance protocols will become more relevant, providing fresh opportunities for innovation and enhancement across numerous sectors. Furthermore, after reviewing the literature, a gap was identified in understanding the connection between wear-related noise and emitted noise. The analysis considered noise, wear, and friction collectively.

Notably, only two current models address these factors, and they primarily focus on scenarios without lubrication.

As previously demonstrated, all models that predict wear and friction have limitations. In addition, just one model has examined friction, wear and noise without taking into account the effect of lubrication. However, for analyses, the noise emitted may provide a viable method of diagnosing and detecting fault complements. It is a single analytical model by Lontin et al. 2021 [1] that include friction noise, friction coefficient, surface roughness and wear under the sliding surface; however, the model has some limitations. For example, the model requires redefining the samples' surface, modelling distribution impact force on both surfaces and defining the asperity's impact on real contact areas. Moreover, the model ignored the effect of the flash temperature, humidity, and wear debris and did not address the lubricant Furthermore, Basit et al. 2023 [47] developed an analytical model based on vibration analysis; however, the model was designed for dry conditions. And the table 1 show models that correlate friction, wear, and noise.

Table 1 Models that link friction, wear, and noise

Model type	Author, year	Results	Limitations
Theoretically and experimentally	Yokoi & Nakai [48] (1979)	The outcome indicated the noise emitted increases when surface roughness increased, suggesting there is a relationship between the sound generated and surface roughness.	Without lubrication.
Empirical	Stamenov et al[49]. (2006).	Studied the generation of frictional noise when two flat surfaces slide against each other without lubrication. The sound spectra depended on the load. The most significant changes in the sound spectrum peak are caused by changes in surface roughness.	Dry sliding condition.
Numerical and experimental	Wang et al[50]. (2015)	The pad-on-disk model was adopted to evaluate frictional and acoustic performance. The findings show the surface roughness of objects directly affect sound level and instability.	Unlubricated
Analytical models with experimental	Lontin & Khan [51] (2021).	Materials were scanned under various loads using a pin on disk. A theoretical approach and experimental verification are presented to predict the sound level wear magnitude produced during the sliding process. The collected data showed good agreement with experimental results.	In dry condition,

The current study aims to evaluate the effect of dry and lubricating conditions on frictional performance, wear rates, and noise level. Three different materials—aluminum, mild

steel, and cast iron—were tested at different loads and different wear distances. The purpose is to determine how the presence or absence of an oil layer affects tribological performance. The materials were tested under diverse load circumstances and wear routes to completely evaluate their performance properties.

2. Methodology

An experiment on the pin-on-disk using a tribometer tester (TRB3) was carried out in the manufacturing lab at Cranfield University, as shown in Figure 1, to investigate the interdependence between the wear rate and sound pressure under dry and lubrication conditions.

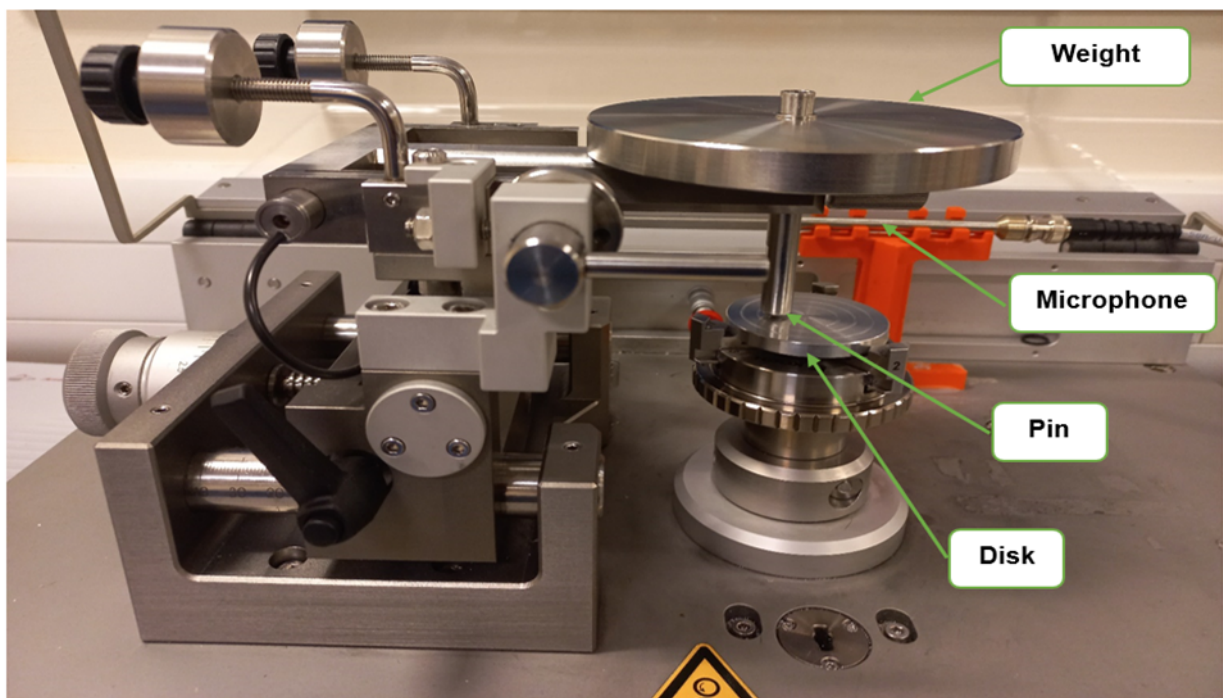


Figure 1 A schematic of Tribometer tester (TRB3).

1.2. Wear Parameter

Experiments were conducted on three different materials: mild steel, aluminium, and cast iron, as presented in Table 1. The experiments were carried out at a constant sliding speed of 300 RPM is within the range of rotational rates encountered by brake rotors in regular driving circumstances. As a result, the chosen speed is particularly relevant for researching brake noise and wear patterns. Under three different loads: 5 N, 10 N, and 20 N as typical loads represents the changing pressures that brake components may experience under fluctuating driving conditions, from moderate deceleration to more forceful braking. The test is conducted under two different conditions: one under dry conditions and the other with lubrication conditions and used 12 samples for each material, used the tribometer as illustrated in Figures 2-a and 2-b, respectively. A lubricant with a viscosity of 30W-50 was used with a volume of 20 ml for all the experiments. The duration of each experiment was 60 seconds for each test, and the test was

repeated three times. They were conducted at the laboratory's standard temperature. The dimensions of the disc, which have a diameter of 50 mm and a thickness 5 mm, are fixed to the disc holder, while the pin of stainless steel has a diameter has a diameter of 6 mm, Table 1 presents several properties of the fourth material used in the experiment for both the disc and the pin. The test under full conformity to the standards – ASTM G 99, G 133 and DIN 50324 TRB3 is fully compliant with the most important tribology testing standards to ensure that users perform tribological testing according to the best practice and convention[52–54].

Table 2 Mechanical properties of materials

<i>Property</i>	Cast Iron (CI),	Mild Steel	Aluminium T351	Stainless Steel (440C) (Pin)
<i>Young's Modulus</i>	110 Gpa	206 Gpa	74 Gpa	190 Gpa
<i>Poisson's ratio</i>	0.28	0.3	0.33	0.285
<i>Density</i>	7.2 g/cm ³	7.85 g/cm ³	2.78 g/cm ³	7.7 g/cm ³

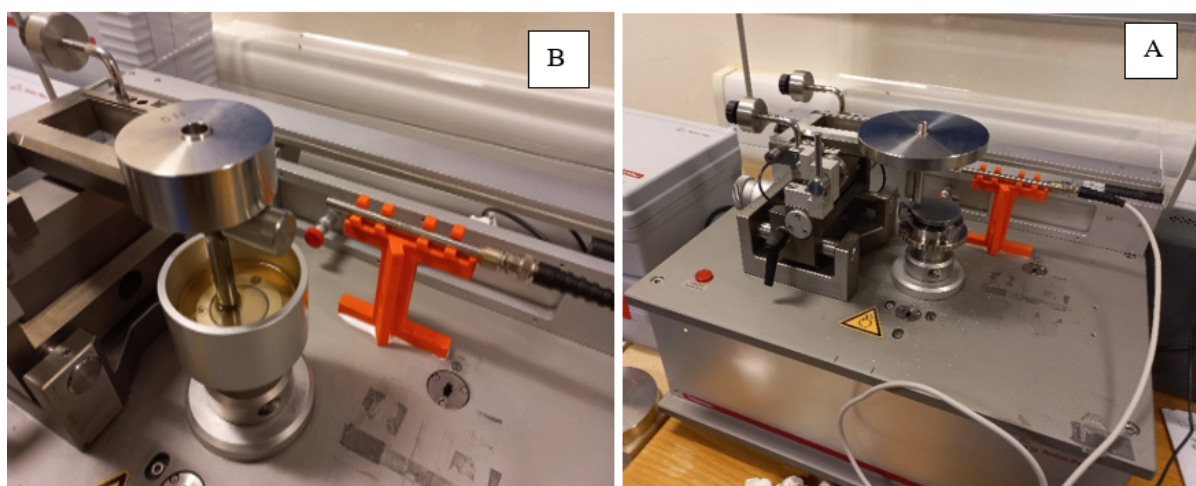


Figure 2. The test conducted under dry conditions (A) and with lubrication (oil inside the cup) (B)

2.2.Wear rate calculation

The wear rate can be determined from the results obtained using a tribometer, a which is a device used to measure friction and wear characteristics of materials. The wear rate is typically expressed in terms of volume loss per unit sliding distance or time. On a tribometer, measuring the depth of wear penetration involves determining how much a material has been worn away by friction and/or abrasive processes. This measurement aids in comprehending how materials and lubricants wear in various applications. Depending on the configuration of the tribometer and the precise parameters being measured, the exact formula for calculating wear penetration depth may change. The Archard wear model is introduced at this point to calculate the amount of wear. It is the most widely used model for estimating and predicting wear, based on the theory of asperity contact. According to the Archard wear model as shown in equation (1) [55,56]:

$$V = \frac{skF}{H} . \quad (1)$$

Where, V = volume of wear, s= sliding distance, k = dimensionless wear constant , F = Normal force H = Hardness factor

According to contact mechanics, it is also known that the contact radius, can be determined from the equation (2):

$$a = \sqrt[3]{\frac{3FR}{4E}} . \quad (2)$$

Where E represents Young's modulus at the point of contact, defined by equation (3)

$$\frac{1}{E} = \frac{1}{2} \left(\frac{1 - \nu_p^2}{E_p} + \frac{1 - \nu_d^2}{E_d} \right) \quad (3)$$

Where, Ep and Ed are the Young's modulus of pin and disc respectively, ν_p and ν_d are the Poisson's ratio for pin and disc respectively and R= effective radius which is defined as in equation (4):

$$\frac{1}{R} = \frac{1}{R_p} + \frac{1}{R_d} \quad (4)$$

3.2. Sound pressure.

To checking out the frictional noise, a specialized microphone, the GRAS 40PP CCP Microphone, is installed 10 cm from the pin. The tribometer was connected to a DAQ card, which was then connected to a computer for the recording of the sound pressure measurements as shown in figure 1 and used for signal expression. The sample's rate is 10 kHz, and its sensitivity is 47.46. The sound pressure level can be calculated from equation the below (5):

$$L = 10 \log_{10} \left(\frac{P}{P_R} \right) \quad (5)$$

Where: The sound pressure level in (dp.), Pr is the reference power (= 10-12 W) The acoustic power can then be calculated using the following equation (6):

$$P = \rho_0 c S \sigma V^2 \quad (6)$$

Where ρ_0 = air density, c = speed of sound in air, S = cross sectional surface area, σ = radiation efficiency (can be taken as 1), and V = vibrational velocity.

3. Results and Discussion

1.3. Influence of contact conditions on the friction coefficient

The frictional performance of three materials was investigated in a dry, as illustrated in Figure 3. The recorded data reveal that the coefficient of friction of the aluminium disc was higher compared to cast iron and mild steel. This preference may be evident thanks to the presence of graphite flakes in cast iron, which act as a solid lubricant, reducing the coefficient of friction [57]. While aluminium lacks these basic lubricating properties [58], in addition, mild

steel and cast iron are harder and more resistant to corrosion than aluminium, resulting in less deformation under stress. This minimal deformation reduces friction, while the softer metal, aluminium, undergoes greater deformation, which increases friction.

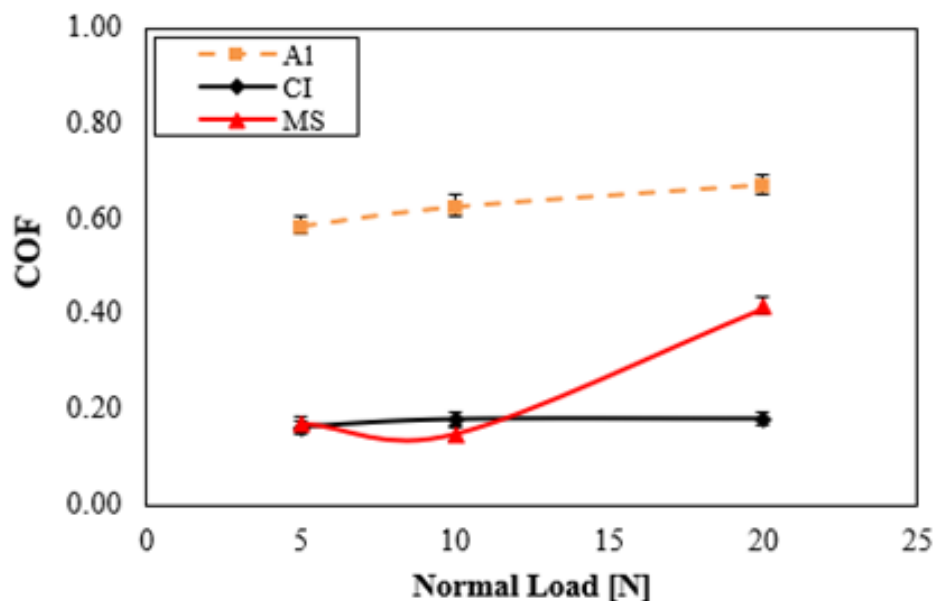


Figure 3. COF of different materials under dry condition with load 20 N.

The test data of various materials were evaluated in the lubrication condition, as indicated in Figure 4. The findings demonstrate that the presence of an oil layer significantly reduces the coefficient of friction. The results confirm that there is no significant difference between the different materials, and this may be due to a thin layer of lubrication, as complete lubrication ensures that direct contact between metals is prevented [59,60]. The lubrication-starved condition appears to be confined, where the properties of the crude play a role in reducing the coefficient of friction.

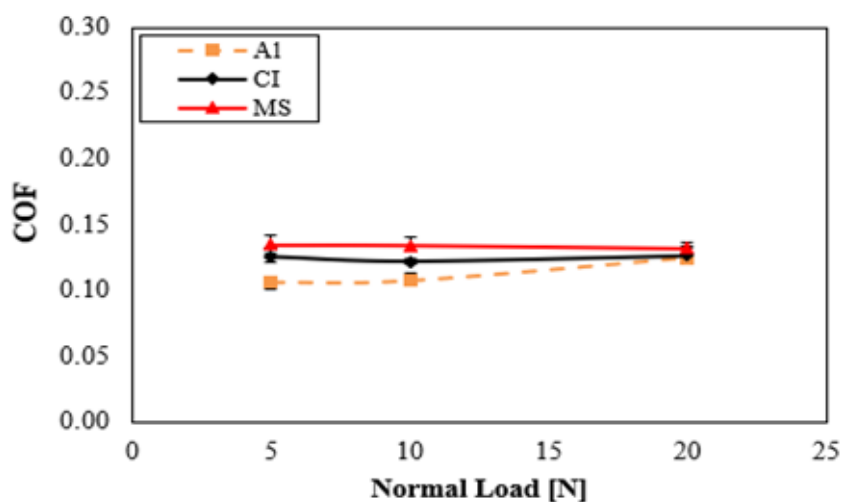


Figure 4. COF of different materials under lubrication condition and 20 N.

The wear rate of different materials was studied to assess their performance under different operating conditions. Figure 5 indicates the performance of aluminum under dry

operating conditions with different diameter loads. It has been observed that the wear rate is greater with a large load as the sliding distance is greater, which makes the disc more susceptible to weight loss. While Figure 6 shows a comparison between mild steel and aluminum under dry operating conditions with a 20 N load, the recorded data reveals that the corrosion rate of mild steel is clearly lower than that of aluminum. This could be because aluminum has a higher thermal conductivity than mild steel, which dissipates more heat during contact [61]. In addition, mild steel is harder and more resistant to wear than aluminum. Mild steel's high hardness means that it undergoes less deformation under load, reducing friction. In contrast, softer aluminum tends to deform more, which increases friction [62–64].

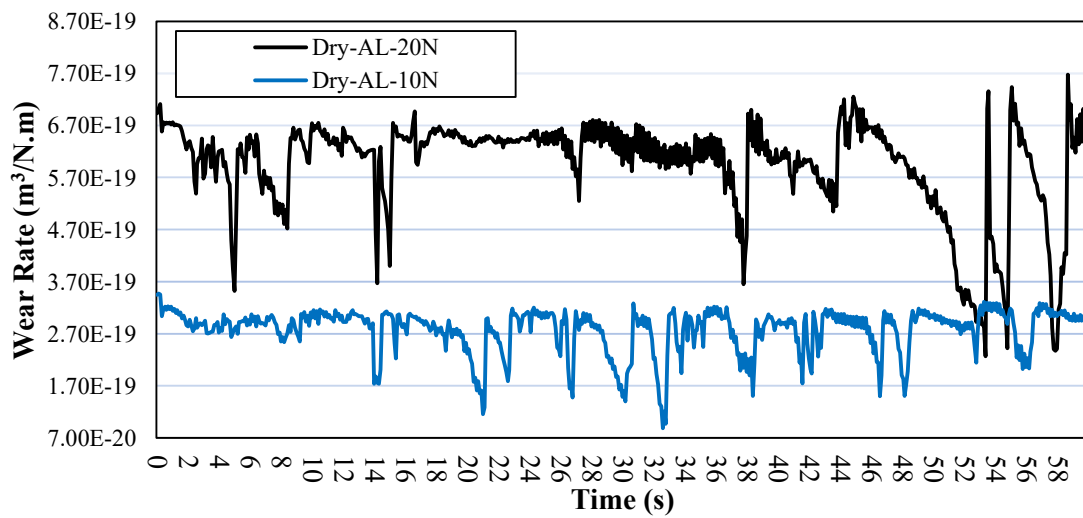


Figure 5. Wear Rate under Dry condition and different load – Aluminium.

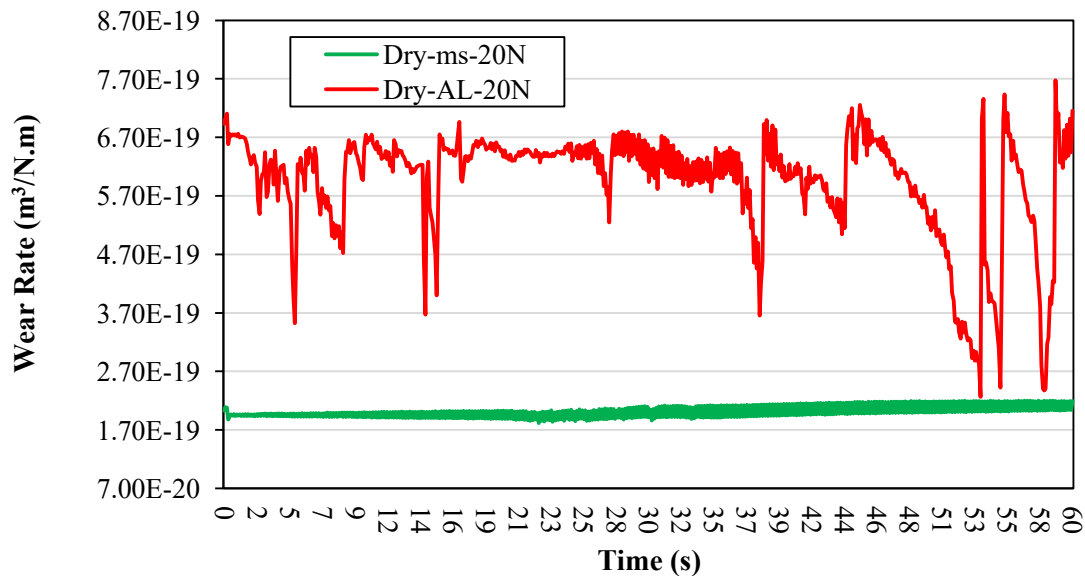


Figure 6. Wear rate under Dry condition for different from different material Mild steel (MS) and Aluminium (AL).

To complement the insight of the present study, the frictional sound level of mild steel was measured under dry and lubricating contact conditions. The results show that the sound pressure is much higher in the dry condition than in the lubricated condition, as shown in Figure 7. In dry conditions, where friction and surface interactions occur without lubricants, the sound pressure is significantly higher. This could be because, in the case of dry contact, the surfaces collide directly, resulting in relatively high noise. It can be said that surface roughness appears in this case as an effective factor in determining the resulting sound level. On the contrary, the presence of a lubricant layer limits this scenario and prevents metal-to-metal contact, giving a lower noise level. Therefore, in maintenance operations, noise technology is used as an indication of the occurrence of problems in the lubrication system of various parts.

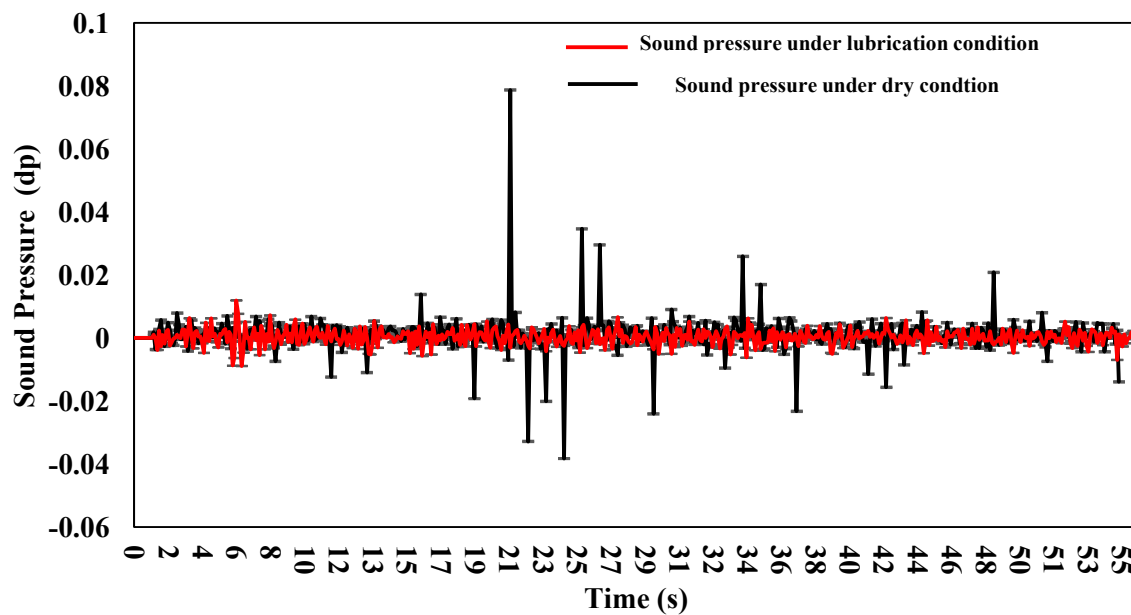


Figure 7. Sound pressure under dry and lubrication condition for Mild Steel

This study highlights the key role of using friction noise analysis as an effective tool for monitoring wear in industrial applications. The study explored the behaviour of frictional noise and wear rate under a variety of conditions, including dry and lubricated environments, variable loads, and a range of materials such as aluminium, cast iron, and mild steel. The recorded data confirmed a strong relationship between the acoustic data on frictional noise and wear rate. As wear progresses, noticeable changes in noise characteristics are observed, indicating that the presence of a lubricating layer reduces this scenario and prevents direct metal-to-metal contact, resulting in a lower noise level. Therefore, noise technology is used in maintenance operations as an indicator of problems in the lubrication systems of various parts.

4. Conclusion

The outcomes should adequately clarify the primary findings and their significance. Avoid providing new information or making predictions that are not supported by the results.

In dry conditions, the aluminium disc demonstrated higher coefficients of friction compared to cast iron and mild steel, potentially reflecting its absence of graphite flakes, which function as solid lubricants in cast iron. Under lubricated conditions, a layer of lube drastically decreases the coefficient of friction, and there seems to be no noticeable distinction between the materials tested, suggesting that complete lubrication eliminates direct metal contact. In environments with insufficient lubrication, the natural oil's characteristics nevertheless play a role in reducing friction, but this influence is restricted compared to completely lubricated scenarios. In dry conditions, frictional sound levels for mild steel are significantly higher due to direct surface impacts, but lubrication mitigates noise by preventing metal-to-metal contact. Monitoring noise levels can be a valuable indicator of lubrication concerns, as higher noise levels suggest issues with the lubrication system, making noise technology instructive for repairs and maintenance.

Further research efforts can enhance the creation of important, accurate, and reliable models for detecting and managing wear in various industrial sectors. This is especially accurate for scenarios requiring mechanical connections, where existing gaps and limitations can be effectively addressed. Investigating the relationships between wear, friction, and noise necessitates employing a variety of methodologies. It is vital to undertake more studies on how surface roughness, wear, and friction affect noise levels, particularly in lubricant-filled settings.

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