

Experimental Analysis of Wear Rate and Frictional Coefficient of Various Steel Material

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Abstract

This research study focuses on experimentally investigating the wear rate and frictional coefficient of different steel materials using a pin-on-disk testing machine. The tribological properties of steel materials play a crucial role in determining their performance and reliability in various applications. The objective of this study is to assess and compare the wear characteristics and frictional behavior of multiple steel materials under controlled testing conditions. The experimental setup involved employing a pin-on-disk testing machine, where a steel pin was brought into contact with a rotating steel disk. To ensure consistency, the pin and disk specimens were fabricated from various steel materials with uniform dimensions and surface finish. Several test parameters, such as load, sliding speed, and duration, were carefully selected to mimic real-world operating conditions. Throughout the experimental runs, the frictional forces and wear rates were continuously monitored and recorded. The wear rate was quantified by measuring the weight loss of the pin and disk specimens after each test run. Additionally, the frictional coefficient was calculated by dividing the frictional force by the applied load. By comparing these parameters among the tested steel materials, the researchers aimed to identify variations in their tribological performance. The results obtained from the experimental investigation indicated significant disparities in the wear rate and coefficient of friction among the tested steel materials. Certain steel materials exhibited lower wear rates and frictional coefficients, suggesting improved tribological properties compared to others. The observed differences in wear patterns and frictional behavior were thoroughly analyzed to gain insights into the underlying mechanisms responsible for the performance variations.

Keywords: wear rate, frictional coefficient, pin-on-disk testing machine, steel materials, wear resistance.

1. Introduction

The tribological properties of steel materials, which include friction, wear, and lubrication, play a crucial role in the performance and reliability of these materials in various engineering applications. It is important for steel materials to be able to withstand sliding or rubbing contact and maintain their integrity under different operating conditions. Therefore, investigating different steel materials to enhance their tribological properties is essential for advancing engineering design and manufacturing processes. Experimental techniques that simulate real-world conditions are used to evaluate the tribological behavior of steel materials. One such technique is the pin-on-disc machine, which allows for controlled testing and measurement of frictional forces and wear rates. The pin-on-disc machine simulates sliding or rubbing contact between a pin and a rotating disc, replicating the conditions experienced in practical applications. This study aims to analyze the effects of different steel materials on tribological properties using a pin-on-disc machine and provide insights into their potential for enhancing performance. By subjecting different steel materials to controlled loads and sliding speeds, their frictional behavior and wear characteristics can be evaluated. The study involves the selection of various steel materials, preparation of disc and pin specimens, and systematic testing under predetermined parameters. The primary objective of this study is to compare and analyze the wear rates and frictional coefficients exhibited by different steel materials. The wear rate is a crucial indicator of material loss due to rubbing contact, while the frictional coefficient represents the ratio of frictional force to applied load. By examining these tribological properties, valuable insights can be gained regarding the performance and suitability of different steel materials for specific applications. The outcomes of this investigation will assist in the selection and optimization of steel materials for applications where enhanced tribological properties are desired. Identifying materials with lower wear rates and frictional coefficients will enable engineers and designers to make informed decisions to improve system efficiency, reduce energy consumption, and extend component lifespan. Numerous research studies have been conducted to investigate the tribological properties of different steel materials using pin-on-disc machines. These studies have contributed to our understanding of how steel composition, microstructure, and surface characteristics influence friction and wear behavior. This literature review provides an overview of key findings in this field.

Ahmed et al. (2018) compared the tribological performance of various steel alloys using a pin-on-disc apparatus. They discovered that stainless steel alloys exhibited lower wear rates and friction coefficients compared to carbon steels. The presence of alloying elements like chromium and nickel contributed to improved tribological properties due to the formation of protective oxide layers.

Li et al. (2019) examined the effects of heat treatment on the tribological properties of high carbon steel using a pin-on-disc machine. They observed that quenched and tempered steel exhibited reduced wear rates and friction coefficients compared to untreated steel. Heat treatment resulted in the formation of a hardened surface layer, enhancing wear resistance.

Prakash et al. (2020) investigated the tribological behavior of surface-treated steel materials using a pin-on-disc apparatus. They explored the effects of plasma nitriding and diamond-like carbon (DLC) coating on friction and wear. Both surface treatments led to decreased wear rates and friction coefficients by creating a hard, low-friction surface layer.

Zhao et al. (2017) studied the impact of surface texturing on the tribological properties of steel using a pin-on-disc setup. They found that laser-induced surface texturing resulted in reduced friction and wear compared to a non-textured surface. The micro-dimples created by laser texturing acted as lubricant reservoirs, improving lubrication performance and reducing contact area.

Zhang et al. (2018) examined the tribological behavior of different steel materials under dry and lubricated conditions using a pin-on-disc machine. They discovered that the addition of solid lubricants, such as molybdenum disulfide, improved tribological properties by reducing friction and wear. The solid lubricant particles formed a protective film, reducing direct contact between the pin and disc.

2. Methodology

The following methodology is adopted for Investigation purpose.

1. Sample Preparation of selected materials.
2. Chemical Composition of Selected material.
3. Parameter Selection for experimentation.
4. Experimentation on experimental setup.
5. Design of Experiments and Analysis of Variance
6. Results and Conclusions

2.1 Material Selection & Sample Preparation:

For the experimental purpose of investigating the enhancement of tribological properties, four types of steel grades were selected: (1) Mild Steel, (2) D2 Steel, (3) 316 Stainless Steel, and (4) 304 Stainless Steel. Each of these steel grades offers distinct characteristics and properties that can affect their tribological behavior. By studying these different steel materials, a comprehensive understanding of their performance in terms of friction and wear can be achieved. Mild Steel: It also called as low carbon steel, is a common and widely used steel grade due to its affordability and ease of manufacturing. It has relatively low carbon content, typically ranging from 0.05% to 0.25%. Mild steel exhibits moderate strength and good machinability but is generally less resistant to wear and corrosion compared to other steel grades. D2 Steel: It is a high-chromium, high-carbon tool steel that offers very good wear resistance and good toughness. It contains around 1.5% carbon and significant amounts of chromium and vanadium, providing enhanced hardness and abrasion resistance. D2 steel is commonly used in various applications where resistance to wear higher and better dimensional stability are needed, such as cutting tools and punches. 316 Stainless Steel: It is a corrosive resistant austenitic stainless steel alloy containing molybdenum. It is widely used in various industries, including marine, chemical, and medical, due to its superior corrosion resistance, high temperature strength, and excellent mechanical properties. 316 stainless steel exhibits good wear resistance and can maintain its properties even in aggressive environments. 304 Stainless Steel: It is another widely used austenitic stainless-steel grade. It is having a higher percentage of chromium (18%) and nickel (8%) compared to 316 stainless steels. 304 stainless steel offers very good resistance to corrosion, high formability, and excellent mechanical properties. While it may have slightly lower wear resistance compared to 316 stainless steel, it is suitable for many applications requiring strength, durability, and resistance to various environmental conditions.

2.2 Chemical Composition of Selected Material.

Chemical tests is conducted to verify the authenticity and composition of the materials used in this experiment. The tests confirmed the legitimacy of the materials and provided the weight percentage composition of alloying elements such as carbon, nitrogen, manganese, etc. Based on the test reports, the materials used in the experiment were found to be authentic with known compositions. The chemical composition of the materials is presented in Table 1, which includes the chemical test report of Mild Steel, D2 Steel, SS316 Steel, and SS304 Steel.

Table 1. Chemical composition of different type Steels

Sample Material	Mild Steel	D2 Steel	SS316	SS304
	Steel Steel			
C%	0.15	1.29	0.034	0.037
S%	0.010	0.006	0.009	0.016
P%	0.012	0.011	0.027	0.031
Si%	0.11	0.34	0.35	0.32
Mn%	0.78	0.44	1.44	1.84
Ni%	0.10	---	9.60	7.74
Cr%	0.30	11.71	17.54	18.74
Mo%	0.002	0.75	1.81	---
V%	0.002	0.80	---	---
Cu%	0.028	---	---	---

2.3 Pin-On-Disk Machine & Experimental Setup

The Pin-on-Disk machine is extensively utilized for evaluating and measuring the tribological properties of industrial materials. It consists of several components, including a rotating disk, a specimen (pin) holder, a lever mechanism, and weights.

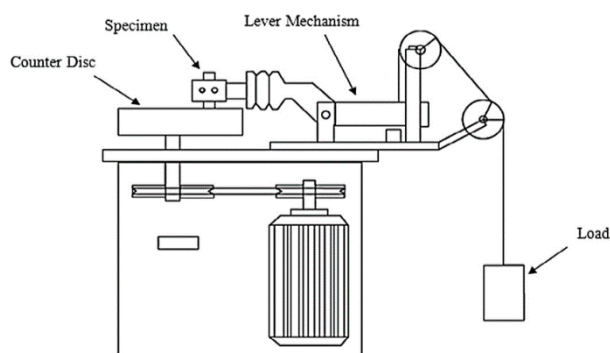


Figure1. Pin-on-Disk Machine set up

The workflow for a Pin-on-Disk machine:

1. The Pin-on-Disk machine is initiated by setting the disk in motion using a motor with adjustable RPM (Revolutions per Minute), allowing for precise control over the rotational speed based on the experimental requirements.
2. The specimen, representing the material being tested, is securely held by the specimen holder and brought into contact with the rotating disk.

3. The pressure applied by the specimen onto the disk is determined by the application of weights or loads through the lever mechanism. This mechanism allows for the adjustment of the contact pressure between the pin and the disk.
4. Once the setup is complete, the disk starts rotating, and the physical outputs generated during this process are converted into electronic signals.
5. These electronic signals are then transmitted to advanced software that analyzes and processes the data. The software calculates and provides results, revealing the expected tribological properties of the material under investigation.

The table 2 shows the general specifications of a pin-on-disk machine:

Table 2. Specifications of a pin-on-disk machine

Sr.No.	Specification	Description
1	Speed of disc	Ranging from 200 to 2000 rpm
2	Load	From 0 to 20 Kg
3	Rate of wear	Plus/minus 2 mm
4	Temperature	Heating temp. of pin - 200° C
5	Chamber heating temperature	200°C
6	Diameter of wear track	50 m to 100 mm

2.4 Experimentation



Figure 2 Experimentation Setup

To prepare the specimens for examination, the following procedure is implemented:

A. Sample Preparation

- The raw materials for the specimens, including Mild Steel, D2 Steel, SS316 Steel, and SS304 Steel, are collected.
- The raw material is processed using a lathe machine.
- The lathe machine is used to turn the raw material into spheres with a diameter of 10mm and a length of 50mm, as depicted in the accompanying 3D figure.

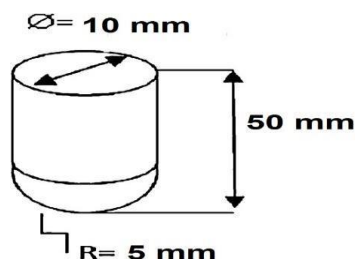


Figure.3. Pin fabricated from steels

• Once the specimens have been prepared, the next step is to place each specimen in the pin holder. The pin holder is then positioned against the rotating disk. At this point, the setup is ready, and the experimentation is commenced.

B. Selection of material load and speed based on application

Table 3. Steel Selected for different application

Sr. No.	Mild Steel	Nut- Bolt application
1	SS304 & SS316	Food processer grinder vessel.
2	D2 Steel	Drilling machine drill tool

C. Experimental Design Method

The design of experiments (DOE) is indeed crucial for understanding and optimizing processes. Traditional DOE approaches can be complex and time-consuming, particularly when dealing with a large number of processing parameters. However, the Taguchi method offers a solution by using orthogonal arrays to efficiently study the entire parameter space with a limited number of experiments. The primary focus of the Taguchi method is to reduce process variation and achieve robust designs. It aims to produce high-quality products while minimizing costs for suppliers. The method was developed by Genichi Taguchi, who introduced a systematic approach for designing experiments to investigate the impact of various parameters on the mean and variance of a process performance characteristic. By utilizing orthogonal arrays, the Taguchi method allows for efficient experimentation, as it enables a comprehensive exploration of parameter combinations while minimizing the number of experiments required. In essence, the Taguchi method provides a structured approach to experimental design, facilitating the systematic analysis of process parameters and their effects on process performance. By using orthogonal arrays, the method allows for an effective exploration of parameter spaces with fewer experiments. This makes the Taguchi method a valuable tool for optimizing processes and improving product quality while reducing time and resource requirements.

Table.4. Selection of experimental process parameters and its levels

Sr. No.	Parameters	Levels
1	Load in N	60 80
2	Speed in RPM	400 600

Table.5. DOE using orthogonal array for all Materials

Expt.	NoLoad (N)	Speed (RPM)
1	60	400
2	60	600
3	80	400
4	80	600

1. Disk cleanliness: The rotating disk is cleaned before starting the experiment. Any contaminants on the disk surface could potentially affect the frictional interactions between the disk and the specimen.
2. Specimen contact: It is essential to ensure proper contact between the specimen and the disk surface. This ensures reliable data collection regarding the tribological properties of the materials under investigation.
3. Motor power supply: The motor responsible for rotating the disk should be connected to a stable power supply. This ensures consistent and controlled rotational speed throughout the experiment.
4. Load application: The load or weight applied to the specimen should be free from any slag or unwanted materials. This ensures accurate and precise measurement of the frictional forces and wear characteristics of the materials.
5. Skilled personnel: The individual responsible for operating and handling the equipment should possess the necessary skills and proficiency in conducting the experiments. This ensures the proper setup of the apparatus and minimizes the chances of errors or discrepancies.

Additionally, the experiments are performed at a constant room temperature to maintain Consistent testing conditions throughout the study.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In Case I, the experiment was conducted using Mild Steel as the specimen, and the following parameters were set:

- Load: 60 N
- RPM: 100.00
- Duration: 120 seconds

The experiment results obtained from the software are presented in a graphical representation, which visually depicts the relevant data and findings.



Figure.4. Graphical Representation of Wear rate, CoF and Friction Force verses time

In Case II, the experiment was performed using D2 Steel as the specimen, and the following parameters were applied:

- Load: 60 N
- RPM: 100.00
- Duration: 120 seconds

The results obtained from the experiment are presented in a graphical representation, which provides visual insights into the data and findings



Figure 5. Graphical Representation of Wear rate, CoF and Friction Force verses time

In Case III, the experiment was conducted using SS316 steel as the specimen, with the following parameters:

- Load: 60 N
- RPM: 400.00
- Duration: 120 seconds

The experimental results obtained from the software are presented in a graphical representation



Figure 6 Graphical Representation of Wear rate, CoF and Friction Force verses time

In Case IV, the experiment was conducted using SS304 steel as the specimen, and the following parameters were set:

- Load: 60 N
- RPM: 100.00
- Duration: 120 seconds

The experimental results obtained from the software are displayed in a graphical representation.

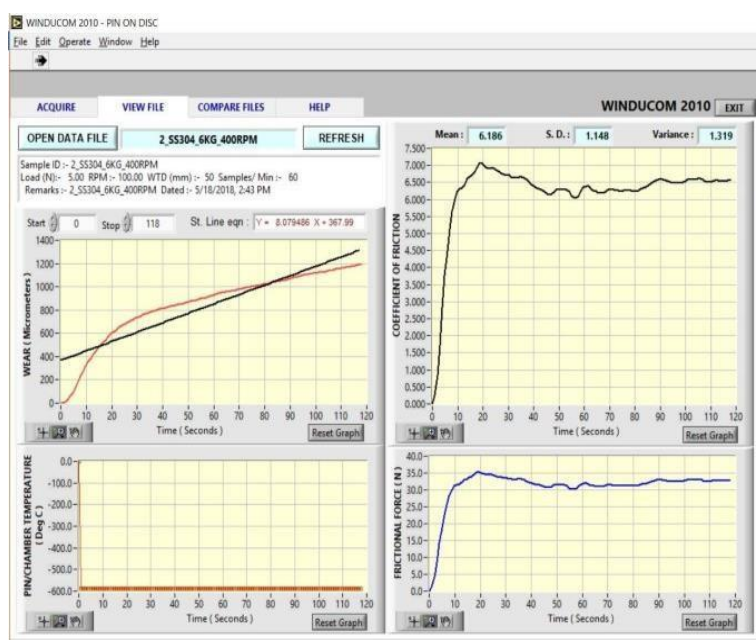


Figure 7 Graphical Representation of Wear, Coefficient of Friction and Frictional Force verses Time

To analyze and discuss the results of the experiments, it is necessary to compare the graphs generated by the sophisticated software. The graphs can be compared based on different parameters, including "Wear rate vs. Time," "CoF vs. time," and "Friction Force vs. time."

A. Wear rate vs Time

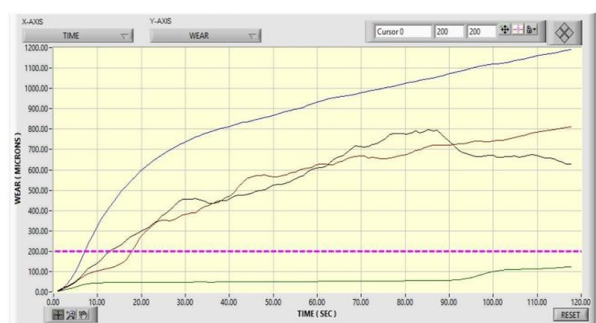


Figure 8. Comparison of Wear vs. Time of all Steels.

It is important to note that the color code used in the subsequent graphs will be explained below.

Table 6 Color coding of material

Sr.No.	Material	Color
1	Mild Steel	Black
2	D2 Steel	Green
3	SS316	Red
4	SS304	Blue

Based on the Wear vs Time graph provided, it is evident that D2 steel exhibits the highest wear resistance among the tested materials. This observation aligns with the understanding that the addition of carbon in steel enhances its hardness and wears resistance. However, it is important to understand that wear resistance is influenced by factors other than carbon content. In contrast, SS304 steel, this has a significantly lower carbon composition, demonstrates the highest wear rate among the tested materials. This indicates that the lower carbon content in SS304 steel leads to reduced wear resistance.

B. CoF vs Time

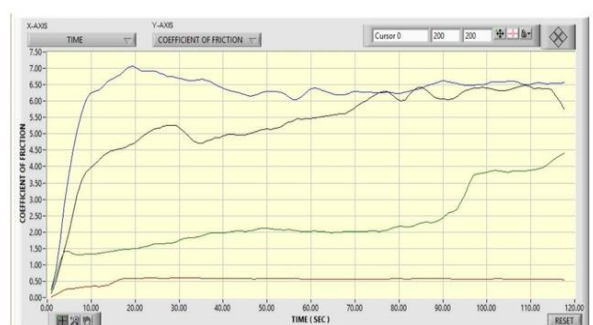


Figure 9. Comparison of CoF vs. Time of all Steels.

Based on the Coefficient of Friction vs. Time graph provided, it is apparent that SS316 steel exhibits the lowest coefficient of friction among the tested materials. Conversely, SS304 steel demonstrates the highest coefficient of friction, indicating increased resistance to relative motion. Mild steel has a higher Coefficient of Friction compared to D2 steel, which falls in the moderate range.

C. Frictional Force vs Time

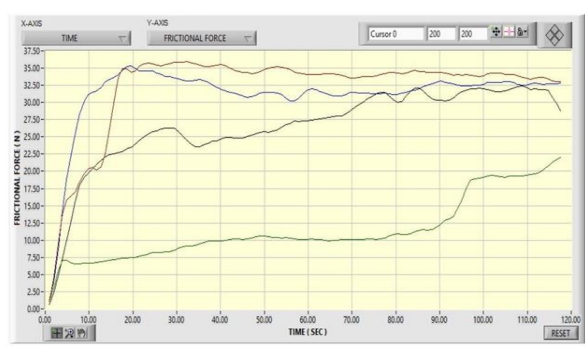


Fig.10. Comparison of Friction Force vs. Time of all Steels

The graph replicates the (CoF) vs. Time graph. This relationship is expected since the frictional force is directly proportional to the coefficient of friction, assuming the load is constant in all cases. The equation that relates the frictional force (F_f) and the (CoF) is as follows:

$$\text{Frictional force} = \text{CoF} \times \text{Normal Force}$$

Where the normal force represents the applied load. Since the load is kept constant for all the experiments, the resulting frictional forces are directly proportional to the coefficient of friction.

Table.7. Carbon percentage for 60N Load.

Material	MildSteel	D2	SS316	SS304
Carbon %	0.15	1.29	0.034	0.037
Wear	626.98	124.31	1812.42	1189.98

4. Conclusion

From the performed experiments and analysis, it is concluded that

1. Increasing the carbon content in steel improves its wear resistance. The wear resistance is affected by other elements like manganese (Mn) and nickel (Ni) as well.
2. The CoF is primarily decided by the type of material and is not significantly affected by external factors such as RPM and applied load.
3. Frictional forces, on the other hand, do vary according to external factors such as RPM and applied load. Changes in RPM and load can result in proportional changes in wear losses.

These conclusions highlight the importance of carbon content in enhancing wear resistance, the independent nature of CoF and the influence of external factors on friction forces. For specific details on carbon percentages for the different materials and load cases, please refer to Table 7.

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