Politecnico di Torino

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SURFACE SCIENCE and TECHNOLOGY

Lab Work

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Research: Friction and wear testing

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Master of Science in Materials Engineering for Industry 4.0

QUESTION 1

How tribological testing at the lab scale can aid the design of surface treatments for structural or anti-wear purposes? Briefly describe the pin on disc and the disc on disc test methods, which different wear mechanisms are reproducible? Use literature references if needed

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Tribological testing at the lab scale is very significant for aiding the design of surface treatments for structural or anti-wear purposes in different ways. Firstly, it helps in understanding friction and wear properties. Tribological testing allows us to measure and evaluate the friction coefficients and wear rates of different surface treatments under controlled conditions. It also helps in the optimization of material selection. By subjecting surface-treated materials to tribological tests, we can determine which materials offer the best wear resistance thus helping in the selection of materials for specific applications.

It is known that, tribological testing validates the performance of surface treatments by simulating real-world conditions, ensuring that the treatments meet design requirements for structural integrity and wear resistance. Additionally, data from tribological tests can guide the refinement of surface treatment designs, leading to enhancements in durability, anti-wear properties, and overall performance. . Through tribological testing, we can estimate the service life of components with specific surface treatments thus aiding in the prediction of maintenance schedules and replacement cycles .

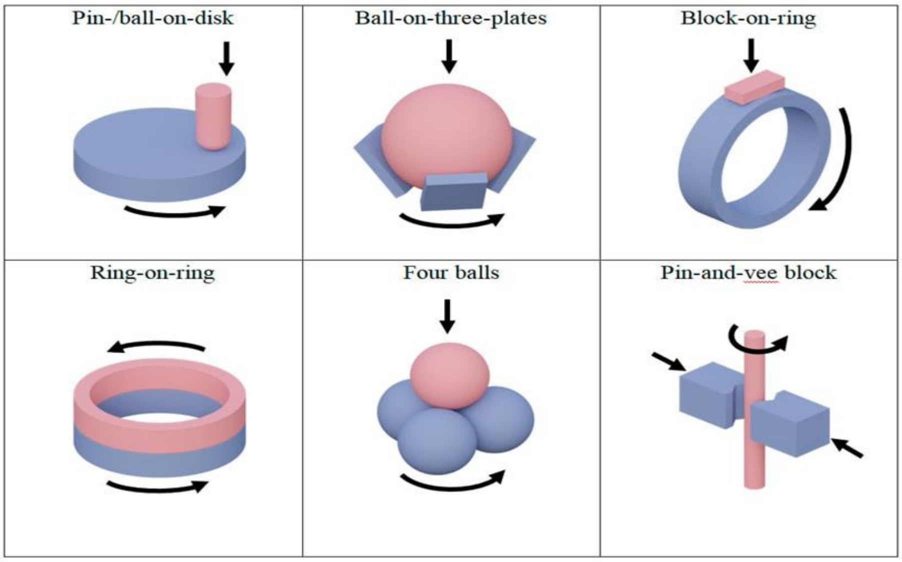

Figure 1. Tribological Test Methods.

DESCRIPTION OF DISK-ON-DISK TEST METHOD.

Disk-on-disk test is a method used to characterize the friction and wear properties of materials. It involves two disks in contact with each other, with one disk rotating against the other under a given load. The applied normal load, rotational speed, environmental conditions (such as temperature, pressure, presence of a lubricant), friction forces, and wear rates are typically measured and controlled during the test (8). The test typically allows for the evaluation of different motion modes, including unidirectional, fretting modes, and complex motion patterns (4). It is known that, the choice of disk geometry and materials is crucial in approximating the actual tribological contact under investigation. Additionally, other factors such as alignment, material choice, and placement of the disks should also be carefully considered to ensure accurate and meaningful test results.

DESCRIPTION OF PIN-ON-DISC TEST METHOD.

Pin on disc test is a method of characterizing the coefficient of friction, frictional force, and rate of wear between two materials (1). Pin on disc tribometers are the most common types of tribometers being used to investigate the friction and wear properties. A typical pin on disc tribometer consists of a stationary pin and a rotating disc. As per ASTM G 99 standards a pin diameter ranges between 2mm to 10 mm and a typical disc diameter range between 30 to 100 mm. The thickness of the disc is generally between 2 to 10mm. The surface roughness also plays a major role in controlling the wear, and hence, ground surface roughness (average) of 8µm or less is recommended. Additionally, pins having any sub surface defects should not be used during the tribo test.A schematic diagram of a pin on disc tribometer is shown in Figure 2.

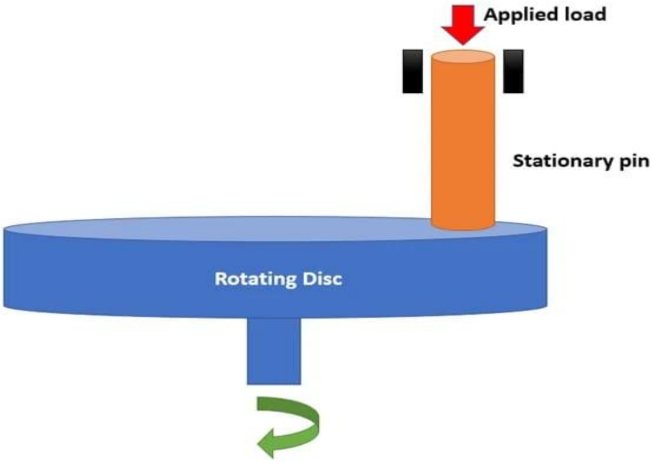

Figure 2: A typical schematic diagram of a pin on disc tribometer

A normal load is applied on the pin and the friction readings are recorded using a load cell. The wear rate is recorded using a Linear Variable Differential Transformer (LVDT). The pins attached are generally hemispherical, however flat faced pins are also used. The pins can be of varied shapes flat, triangular. However, the most commonly used pins are cylindrical or spherical. The principle of the pin-on-disk wear test is shown in Figure 3(a). The main advantage of using a pin on disc is that a variety of materials can be tested. The only requirement is that the specimen is to be made as per the requisite dimensions and it must withstand the stresses which the pins withstand during the tribo-tests. The material properties such as the indentation hardness, microstructures, compositions, surface finish, treatments (process) and specimen dimensions are taken into consideration during the tests. The data acquisition system records the frictional force as a function of time or number of revolutions, although it is often recalculated so that the coefficient of friction is displayed on the same axes. A typical example of the acquired data is shown in Figure 3(b).

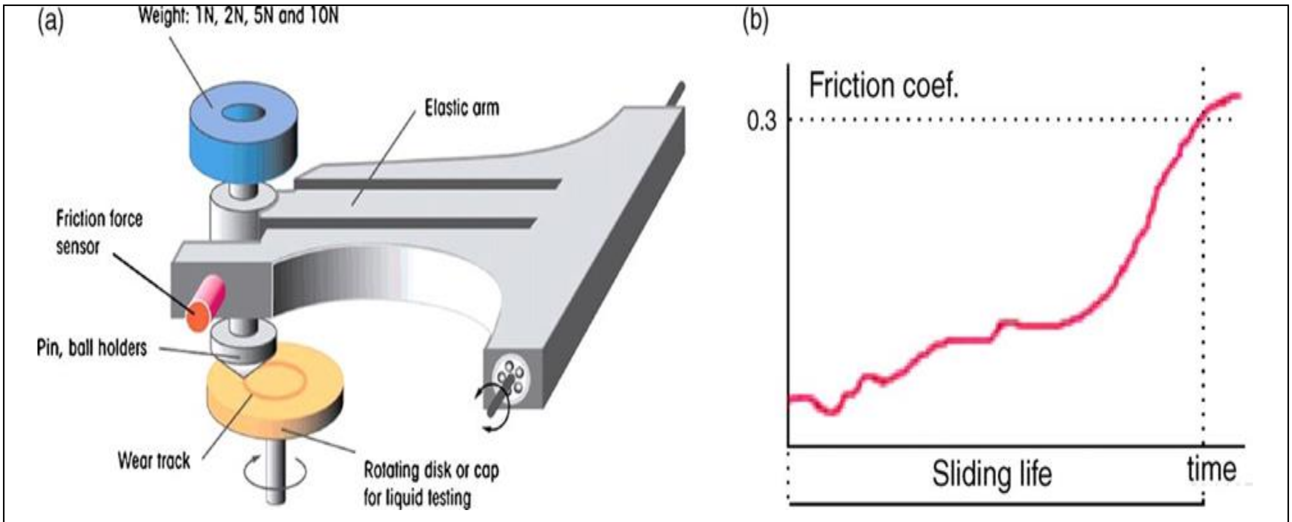

Figure 3. Principle of the pin-on-disk wear test (a) and typical example of test data (b) from which the friction coefficient between the coating and the static partner (usually a ball) can be assessed.

Wear mechanisms that are reproducible include:

- Corrosive wear
- Abrasive wear
- Fatigue wear
- Erosive wear
- Fretting wear
- Adhesive wear
- Microfracture and abrasion
- Wear influenced by the design of design of the testing machine
-

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QUESTION 2: For Case study_1, about pin on disc testing of PVD coatings, make a short report of the results obtained. Follow the questions reported in the presentation and use literature references if needed.

Insert text (4000 characters, no spaces) and images

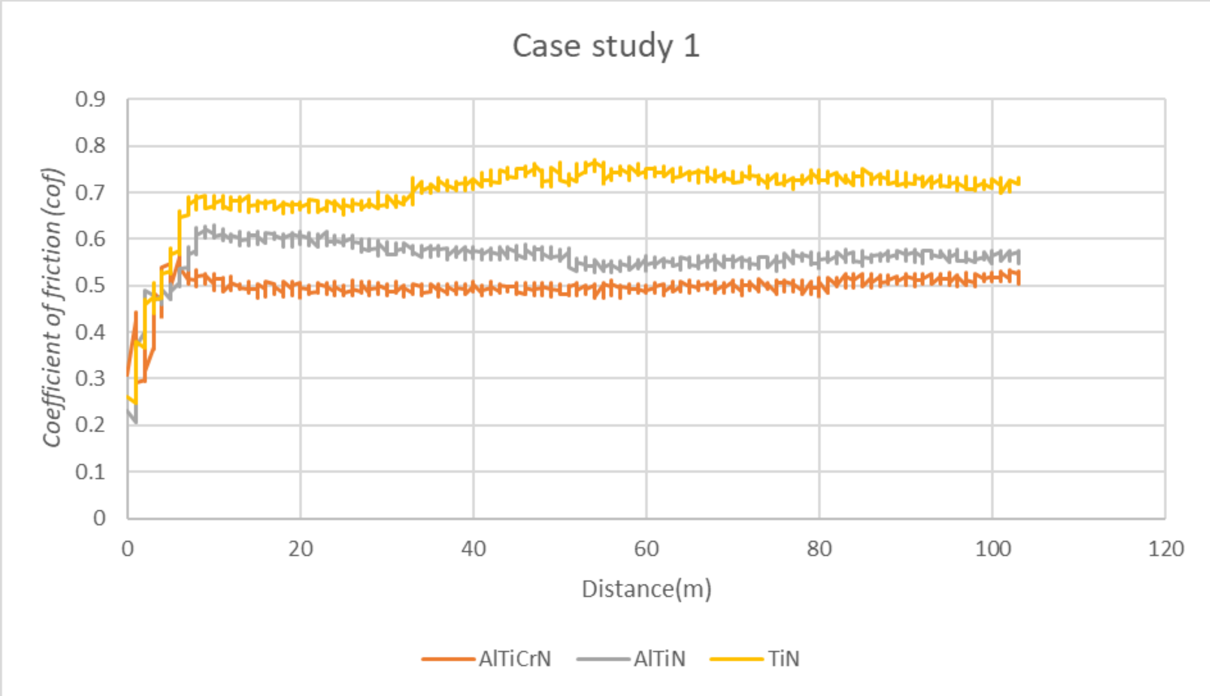

Figure4: The graph presents the evolution of the coefficient of friction (CoF) for AlTiCrN, AlTiN, and TiN over 0 to 100 meters.

In the initial phase (0-10 meters), all materials exhibit a steep increase in CoF, known as the running-in phase. This phase is characterized by surface asperities interacting and conforming to each other, resulting in high initial friction. AlTiCrN stabilizes around a CoF of 0.45, AlTiN around 0.55, and TiN around 0.70.

During the stabilization phase (10-100 meters), AlTiCrN demonstrates the most stable performance with minimal fluctuations, AlTiN exhibits moderate stability, and TiN shows the most fluctuations.

Comparatively, AlTiCrN has the lowest CoF and the most stable performance, making it ideal for high-performance applications where minimizing friction and wear is paramount. AlTiN offers a balance between wear resistance and friction, making it suitable for a variety of applications. Despite having the highest CoF, TiN is valuable for applications that prioritize high hardness and oxidation resistance over friction reduction.

In terms of material properties, AlTiCrN likely has high hardness and excellent oxidation resistance, contributing to its low wear rate and suitability for high-temperature applications. AlTiN has high hardness and good oxidation resistance, making it effective in moderately high-temperature environments. TiN has very high hardness and decent oxidation resistance, making it suitable for standard industrial applications.

In conclusion, understanding these frictional behaviors aids in selecting the appropriate material for specific industrial applications, optimizing performance, and extending the lifespan of tools and components.

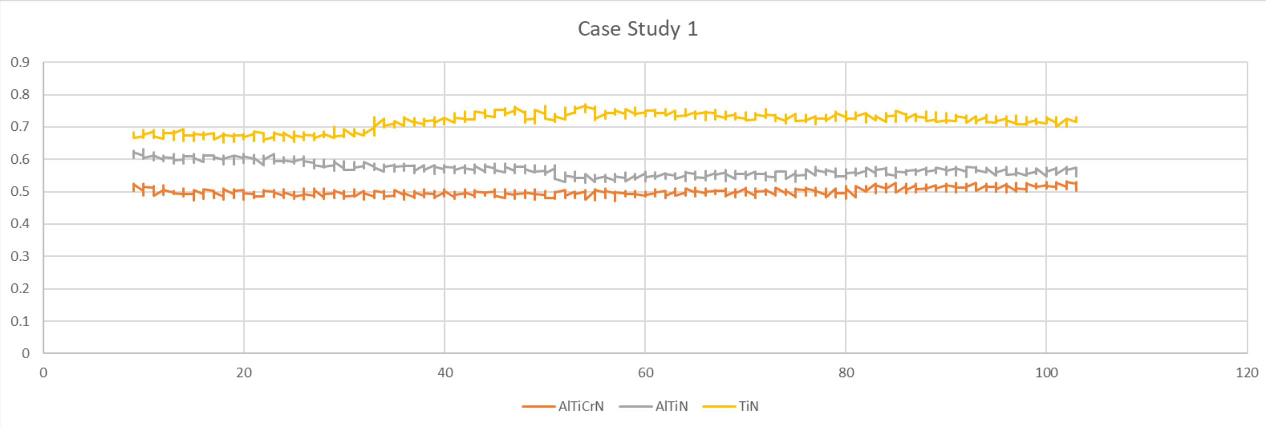

Figure5:The graph you provided is a study of how the coefficient of friction (cof) varies with distance for three distinct materials: AlTiCrN, AlTiN, and TiN. Here's a simplified breakdown:

- Distance (X-axis): This represents the length over which the frictional coefficient is measured, extending from 0 to 110 meters.
- Coefficient of Friction (Y-axis): This measures the frictional resistance encountered by each material, with values between 0.4 and 0.8.

Regarding the materials:

- AlTiCrN (Orange Line): AlTiCrN exhibits the lowest frictional resistance among the tested materials, with its cof fluctuating around 0.5 across the measured distance.
- AlTiN (Green Line): AlTiN shows a moderate cof, consistently around 0.6, placing it between AlTiCrN and TiN in terms of frictional resistance.
- TiN (Blue Line): TiN starts with a cof slightly below 0.7 and shows a minor increase to about 0.75 over the distance, indicating it has the highest frictional resistance among the tested materials.

Some general observations:

- The cof for all three materials fluctuates, but the overall trend remains relatively stable for each material.
- The differences in frictional resistance are clear, with TiN having the highest, AlTiN in the middle, and AlTiCrN the lowest cof.

Potential implications:

- AlTiCrN could be the preferred choice for applications where lower frictional resistance is required, potentially leading to less wear and tear.

- TiN might be suitable for applications where a higher level of friction is acceptable or even beneficial.
- AlTiN provides a balance between the two, making it suitable for situations where a moderate level of friction is desired.

This analysis aids in understanding how these coatings/materials perform under frictional conditions over a certain distance, guiding the selection of materials based on specific application needs.

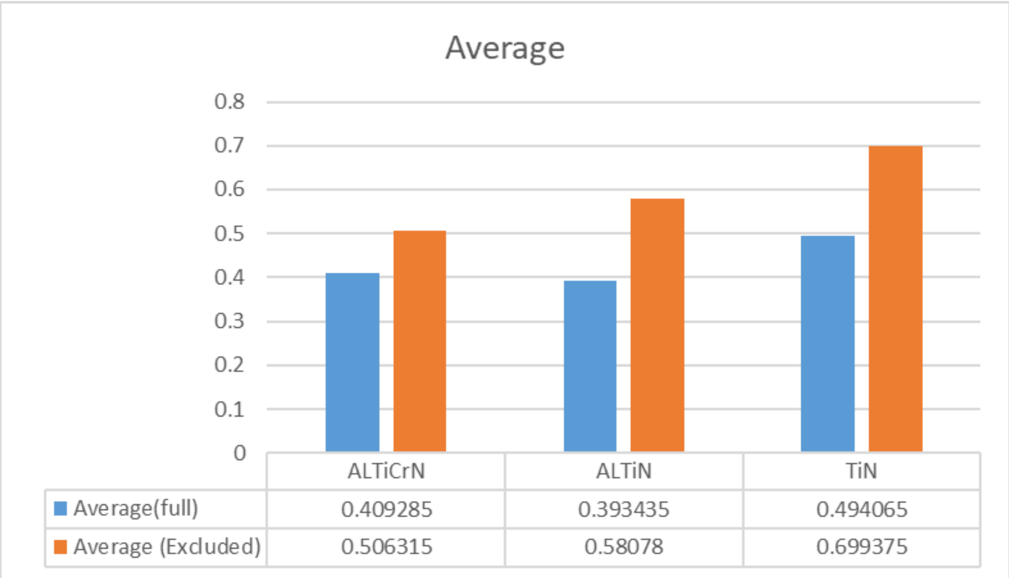

Figure6: The bar chart comparing the average coefficient of friction (CoF) for three different materials: AlTiCrN, AlTiN, and TiN. The chart presents two sets of data for each material: "Average (full) and average (Excluded).

1. AlTiCrN: The "Average (full)" CoF is approximately 0.409, and the "Average (Excluded)" CoF is approximately 0.506. This indicates that when certain data points are excluded, the average CoF for AlTiCrN increases.
2. AlTiN: The "Average (full)" CoF is approximately 0.393, and the "Average (Excluded)" CoF is approximately 0.581. Similar to AlTiCrN, the average CoF for AlTiN also increases when certain data points are excluded.
3. TiN: The "Average (full)" CoF is approximately 0.494, and the "Average (Excluded)" CoF is approximately 0.699. Again, the average CoF for TiN increases when certain data points are excluded.

From this data, it appears that all three materials show an increase in the average CoF when certain data points are excluded. This could suggest that these excluded data points have lower CoFs, and their exclusion results in a higher average.

It's important to note that the choice of material for a specific application would depend not only on the average CoF but also on other factors such as the material's hardness, thermal stability, and oxidation resistance. Therefore, a comprehensive evaluation considering all these factors would provide a more definitive conclusion.

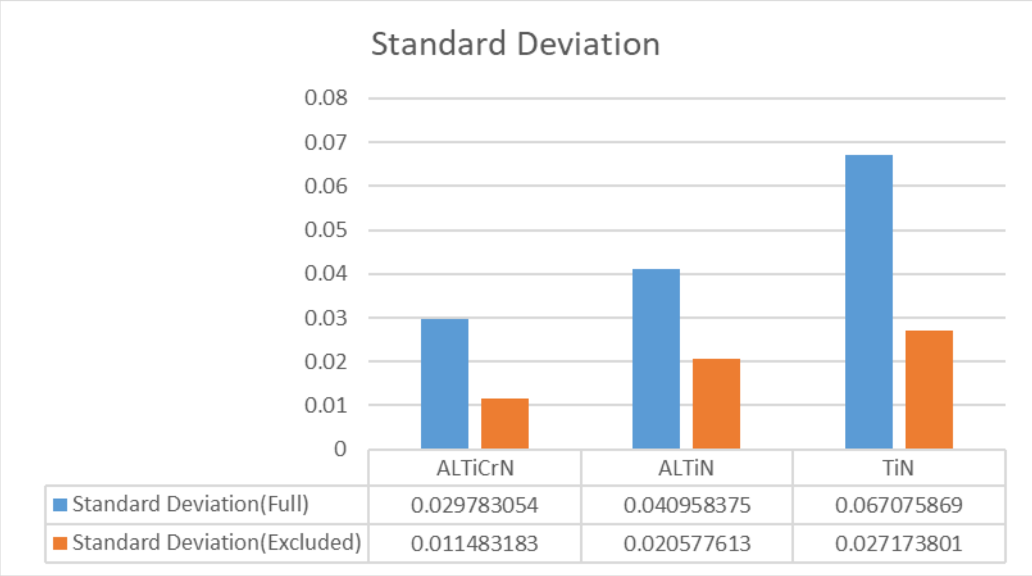

Figure7: The bar chart titled "Standard Deviation" provides a comparative analysis of the standard deviations for three different materials: AlTiCrN, AlTiN, and TiN under two conditions: "Full" and "Excluded".

1. AlTiCrN:
   - Standard Deviation (Full): This value represents the dispersion of the full dataset for AlTiCrN. The value is 0.029783054, indicating a relatively low spread of data around the mean.
   - Standard Deviation (Excluded): This value, 0.011483183, represents the dispersion of the dataset for AlTiCrN when certain data points are excluded. The reduction in standard deviation suggests that the excluded data points were likely outliers that contributed to a higher dispersion in the full dataset.

2. AlTiN:
   - Standard Deviation (Full): The full dataset for AlTiN has a standard deviation of 0.040958375, which is higher than that of AlTiCrN, indicating a greater spread of data.
   - Standard Deviation (Excluded): The standard deviation reduces to 0.020577613 when certain data points are excluded, again suggesting the presence of outliers in the full dataset.
3. TiN:
   - Standard Deviation (Full): The full dataset for TiN shows the highest standard deviation of 0.067075869 among the three materials, indicating the greatest variability in measurements.
   - Standard Deviation (Excluded): Even after excluding certain data points, TiN still has the highest standard deviation (0.027) among the three materials, suggesting inherent variability in the material's properties.

Geometrical Configuration:

At the start of the test, the contact between the AISI 51200 steel pin and the WC-6Co disc is a point contact. This is because the pin, which is typically spherical or cylindrical, has a small contact area on the flat disc surface. The point contact leads to high contact pressure in the initial stages.

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Mechanical Loads/Stresses:

The mechanical loads and stresses at the beginning of the test are significant due to the point contact. The high contact pressure can lead to high stresses both at the surface and beneath the surface of the materials.

1. Surface Stresses: The surface stresses are primarily due to the direct contact and friction between the pin and the disc. These stresses can lead to surface deformation and wear, especially in the high-pressure contact area.
2. Subsurface Stresses: Beneath the surface, the material experiences compressive stresses due to the contact pressure. These subsurface stresses can lead to plastic deformation and can affect the material's fatigue life.

It's important to note that the exact values of these stresses would depend on factors such as the applied load, the material properties of the AISI 51200 steel pin and the WC-6Co disc, and the test conditions.

As the test progresses and the surfaces start to conform, the contact area increases, leading to a decrease in the contact pressure and surface stresses. However, the friction between the surfaces can lead to an increase in temperature, which can affect the material properties and the wear behavior.

This analysis provides a detailed understanding of the pin-disc contact at the beginning of the pin-on-disc test. It helps in predicting the wear behavior and life of the materials under different operating conditions. However, for a more accurate analysis, experimental data and material-specific information would be required.

Surface:
At the beginning of the pin-on-disc test, the high contact pressure at the point of contact results in localized Hertzian stresses at the surface of both the AISI 51200 steel pin and the WC-6Co disc. Due to the higher hardness of WC-6Co compared to AISI 51200 steel, the steel pin is more susceptible to plastic deformation at the contact surface. The initial contact may also lead to adhesion between the asperities of the two surfaces, contributing to friction and wear.
Sub-Surface:
Beneath the surface, the stress distribution is not uniform. The maximum shear stress occurs slightly below the surface of the pin, which is a potential site for crack initiation and fatigue failure. Despite its higher hardness, the stress field in the WC-6Co disc is more localized, but it can still lead to microstructural changes and eventual surface damage.
Evolution of Contact:
As the test progresses, the contact between the pin and disc evolves. The initial point contact gradually transforms into a larger area of contact as the pin wears and the surfaces conform to each other. This leads to a decrease in contact pressure and a redistribution of stress.
EDS Analysis and Oxygen Content in Wear Debris:
Energy-dispersive X-ray spectroscopy (EDS) is a powerful tool for analyzing the elemental composition of wear debris. The different oxygen content in the wear debris could be due to several factors. One possibility is the formation of oxides during the wear process. The friction and heat generated during the test can lead to oxidation of the materials, especially if the test is conducted in an oxygen-containing environment.
The AISI 51200 steel and WC-6Co may have different affinities for oxygen, leading to different amounts of oxides in the wear debris. For instance, if the steel has a higher affinity for oxygen, it might form more oxides, resulting in a higher oxygen content in the wear debris.

Another possibility is the presence of oxygen in the coatings or treatments applied to the materials. If one of the materials has a coating or treatment that contains oxygen, it could contribute to the oxygen content in the wear debris.
These are just hypotheses and would need to be confirmed with further testing and analysis. For a more accurate interpretation, additional information about the test conditions, the materials, and the coatings or treatments used would be helpful.

Absolutely, here's a more detailed explanation:
Based solely on these results, the AlTiCrN coating appears to be the most effective for dry cutting of hard steels.
Reasoning:

- Lower Coefficient of Friction (CoF): AlTiCrN exhibits a lower average CoF of 0.50076 compared to the other two coatings, AlTiN and TiN. A lower CoF indicates less friction during the cutting process. The benefits of reduced friction are manifold:
    - Extended Tool Life: Lower friction reduces the wear and tear on the cutting tool, thereby extending its operational life. This is particularly important in industrial applications where tool replacement can be costly and time-consuming.
    - Improved Surface Finish: With less friction, the tool can cut more smoothly, resulting in a better surface finish on the workpiece. This can improve the quality of the final product and reduce the need for additional finishing processes.
    - Decreased Cutting Force Requirement: Less friction means less resistance to the cutting motion, which in turn means less force is required to perform the cut. This can lead to energy savings and less strain on the machinery, potentially extending the lifespan of the equipment and reducing maintenance costs.

Conclusion:
Based on the average CoF and the standard deviation, AlTiCrN seems to be the best choice among the three coatings for dry cutting of hard steels. However, it's important to note that these results are based solely on friction performance. Other factors such as the hardness of the steel, cutting speed, feed rate, and cooling conditions can also significantly impact the effectiveness of the coating. Therefore, a more comprehensive evaluation considering all these factors would provide a more definitive conclusion. For instance, a coating that performs well under high-speed conditions might not perform as well under slower speeds, and vice versa. Similarly, a coating that excels in dry cutting might not be the best choice for wet cutting, where cooling lubricants are used. Therefore, the selection of the coating should always consider the specific requirements of the application

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QUESTION 3: For Case study_2, about block on ring testing in steel vs steel lubricated contact, make a short report of the results obtained. Follow the questions reported in the presentation and use literature references if needed.

Insert text (5000 characters, no spaces) and images

In the second case study, a block-on-ring configuration was created by replacing the upper disc with a stationary block. A steel block was kept stationary while a steel ring was rotated at a controlled speed, achieving pure sliding conditions. A load of 100kg or 200kg was applied to the block in contact with the ring, rotating at 100 RPM. This case stude our pupose is to determine the differences in the effect of the lubrication properties of both synthetic oil and mineral oil on the coefficient of friction for the steel sample.(COF)

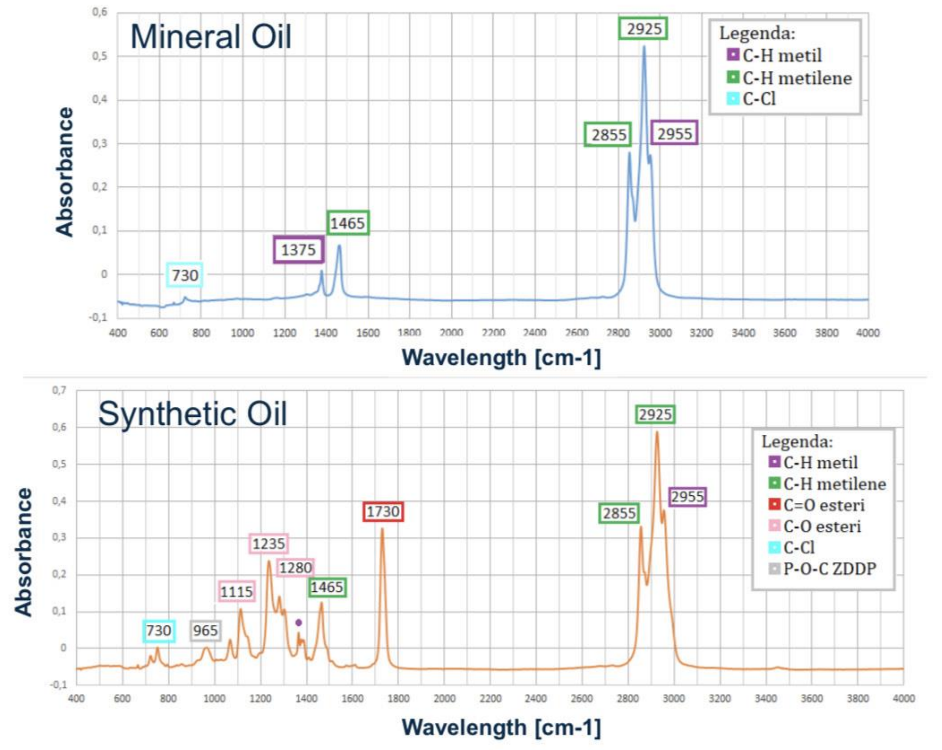

Figure8

The FTIR graphs show the differences between mineral oil and synthetic oil by measuring how they absorb infrared light at different wavelengths

Mineral Oil - Few Peaks: Mainly shows absorption at specific wavelengths indicating simple chemical bonds.
Synthetic Oil - More Peaks: Shows additional peaks indicating more complex chemical structures with additional functional groups.
Differences: - Mineral oil is Simpler structure with fewer chemical bonds but synthetic oil is more complex structure with more types of chemical bonds.

For more details:

The mineral oil lubricant shows fewer significant peaks in the range of 2800 – 3000 cm^{-1}, indicating the presence of C-H stretching in methyl and methylene groups. Similarly, synthetic oil exhibits peaks in the 2800 – 3000 cm^{-1} range due to Carbon-Hydrogen (C-H) stretching. The peak near 1730 cm^{-1} signifies C=O stretching, indicating the presence of ester groups. Additionally, the peak around 1235 cm^{-1} represents P-O-C bonds from ZDDP (Zinc DialkylDithiosphosphate), a common anti-wear additive. In summary, the FTIR spectra confirm the presence of hydrocarbons in both mineral and synthetic oils.

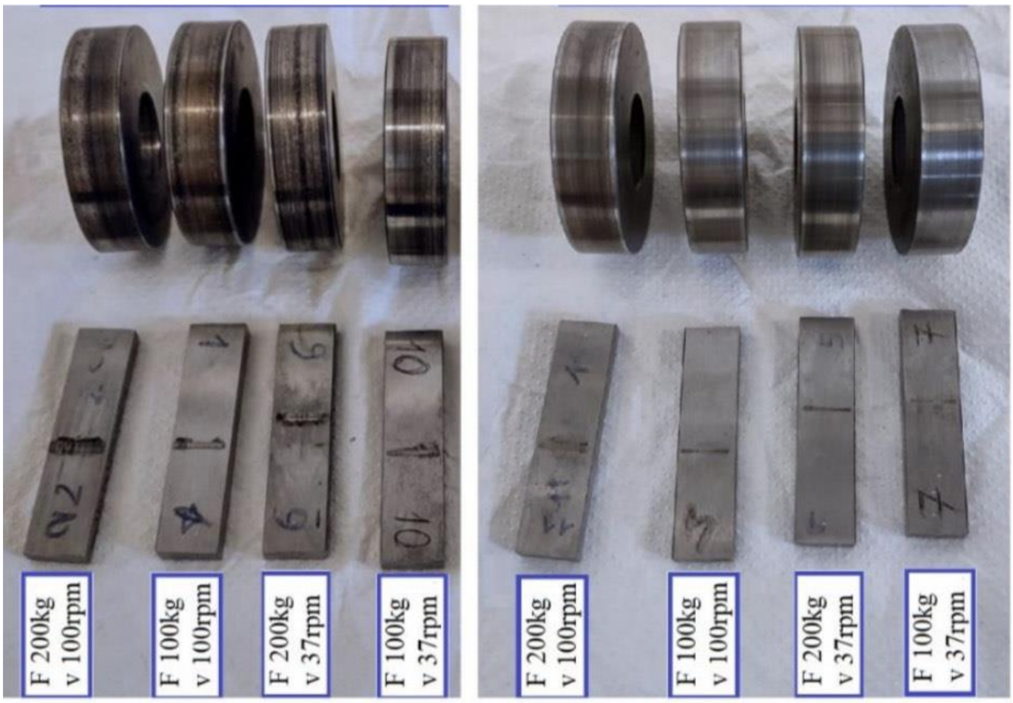

Figure9:This image exhibits the specimens subsequent to tribological evaluation. As is evident, two distinct lubricants were utilized: 1. Mineral oil and 2. Synthetic oil. The illustration facilitates a comparative analysis of their performance.

The friction coefficient for a tribopair consisting of:
1. a ring made of AISI 4140 steel (40 HRC)

2. a block made of AISI 51200 steel (60 HRC)

Diagrams:

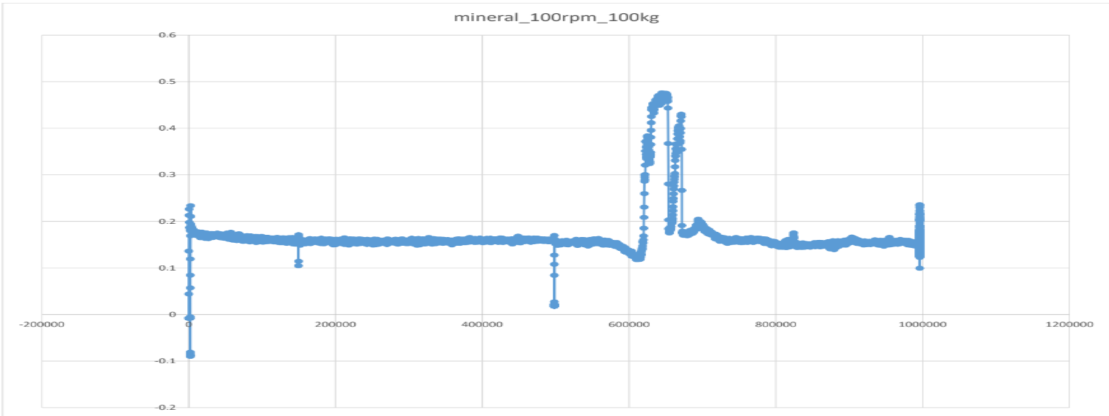

Figure10) Mineral-100 rpm-100kg

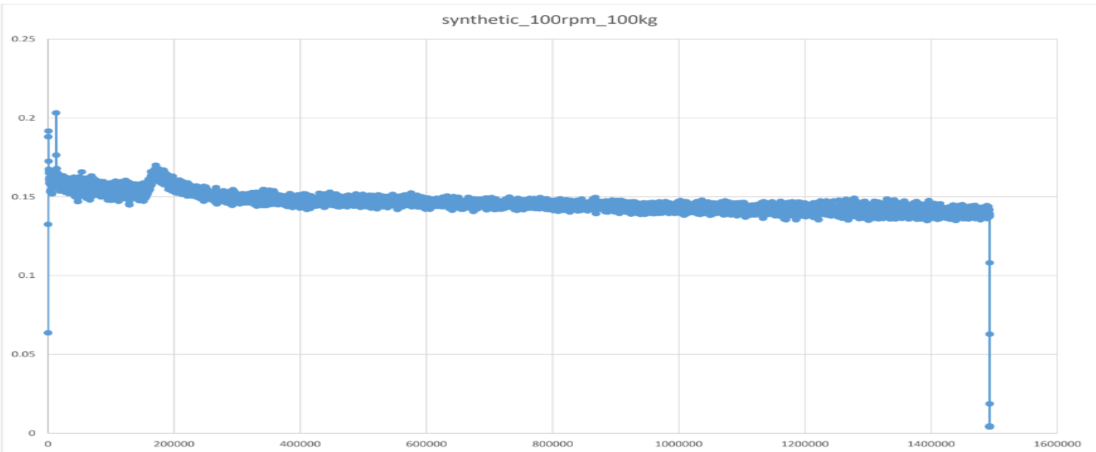

Figure11) Synthetic -100rpm -100kg

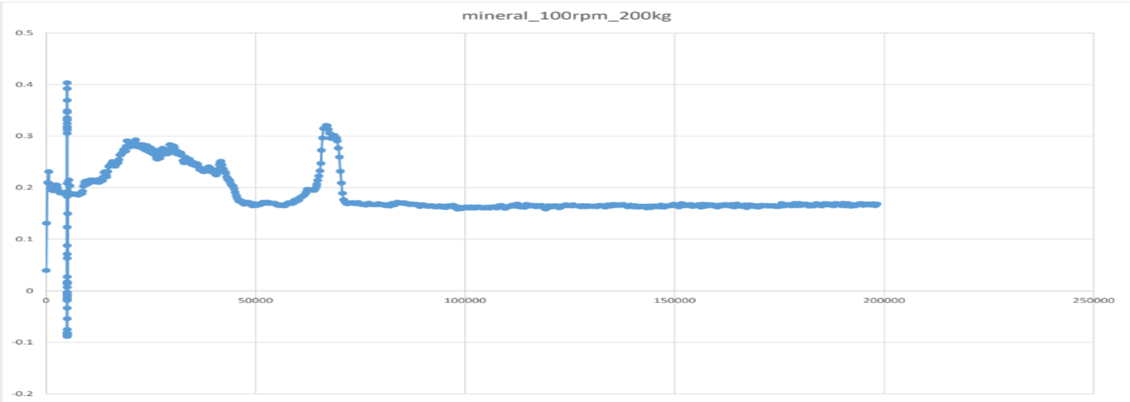

Figure12) Mineral-100rpm-200kg

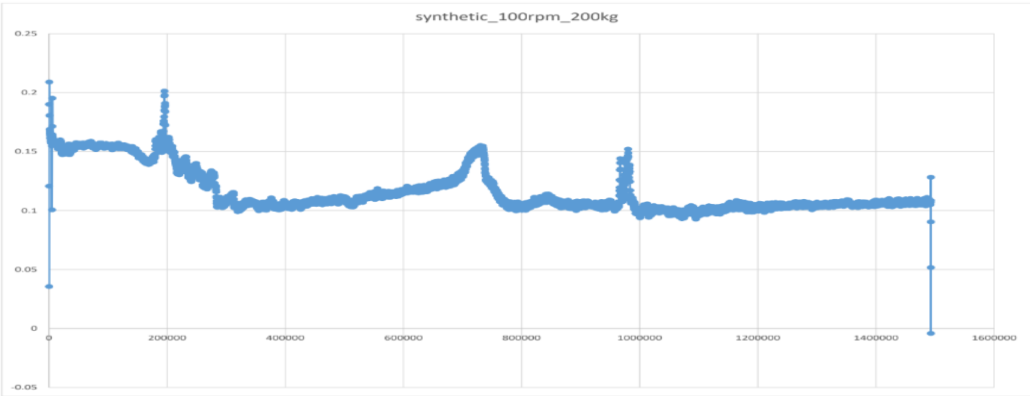

Figure13) Synthetic-100rpm-200kg

These four diagrams illustrate the performance of two different lubricants—mineral oil and synthetic oil—under identical rotational speed (100 rpm) but varying loads (100 kg and 200 kg).

The Holm-Archard equation is a fundamental concept in surface engineering and tribology. It provides insights into material removal during sliding processes. Let's break it down: Coefficient of Friction (CoF): This parameter represents the resistance encountered when two surfaces slide against each other. When the CoF is higher, more material is removed due to increased frictional forces. Hardness: The hardness of a material affects its wear resistance. Softer materials tend to wear more quickly, resulting in greater material removal. Applied Force: Higher forces lead to more severe wear and material loss during sliding. Sliding Distance: Longer sliding distances cause more material to be removed. In summary, the Holm-Archard equation helps us understand how these factors influence material removal. Based on these principles, we investigated two images to categorize whether they represent mineral-based lubricants or synthetic ones.

$$V = K\frac{Fn}{H}d$$

Synthetic Oil:

100kg: V =$KFN\ H\ d$ = 0.144 * 12732.41$*FN\ H$ = 1833.47 $FN\ H$

200kg: V =$KFN\ H\ d$ = 0.110 * 12732.41$*FN\ H$ = 1400.57 $FN\ H$

Mineral Oil:

100kg: V =$KFN\ H\ d$ = 0.159 * 12732.41$*FN\ H$ = 2024.45 $FN\ H$

200kg: V =$KFN\ H\ d$ = 0.165 * 12732.41$*FN\ H$ = 2100.85 $FN\ H$

delve into the initial conditions of the ring-on-disc contact using Hertzian contact theory. This detailed approach will help us analyze the mechanical loads and stresses both at the surface and beneath it for a 40 mm diameter disc. Finally, we'll utilize the Hertzwin software to obtain the equivalent von Mises stress and its location.

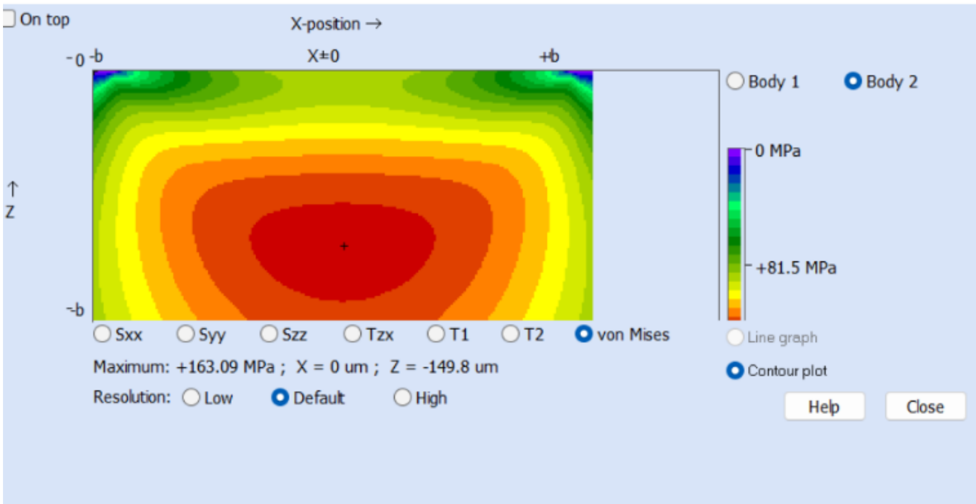

Figure14)contact in static condition

body	Material	Young's modulus E (GPA)	Sigma max(Mpa)	Poisson's ratio
1	AISI 52100(100Cr6)	210	2300	0.30
2	Wc-Co6	700	3000	0.21

Table1) pin and disc material properties

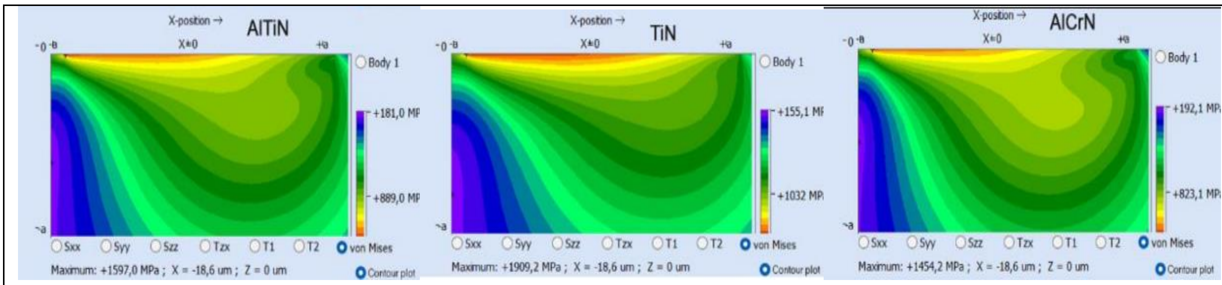

Figure15) Equivalent stress distribution graphs

the pressure distribution is influenced by the varying COF, as can be seen in Figure15. As the COF increases so do the shear stresses parallel to the surface causing the deformation and the potential formation of cold welds breaking in different modes. In this conformal dynamic state, the stress distribution is influenced by several factors.

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https://www.tribonet.org/wiki/pin-on-disk-test/

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