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DEVELOPMENT OF A MULTIFUNCTIONAL TRIBOMETER
DESIGN CONCEPT

Gencaga Pürçek
Harun Yanar
UTS Engineering Inc., Trabzon Technology Development Region, Trabzon,Turkey
Karadeniz Technical University, Trabzon, Turkey

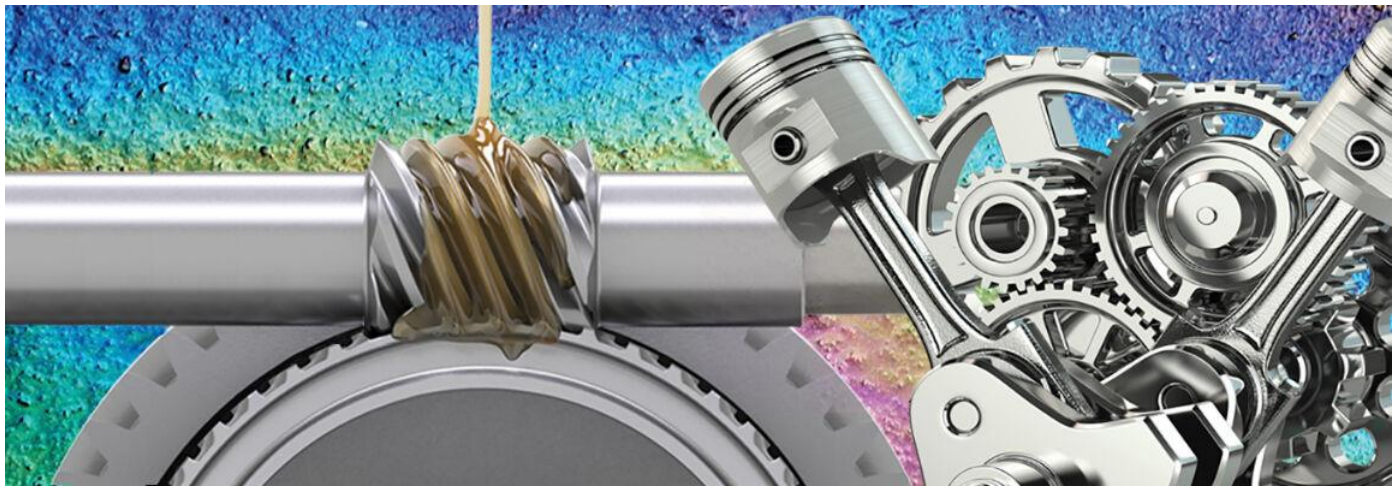
TRIBOLOGY- In General

- Tribology is the science and technology that investigates the interaction of surfaces in relative motion in the form of **friction, wear, lubrication** and other design aspects of materials sciences.

- The word “Tribology” comes from the Greek word tribos meaning rubbing, translating the word literally into the “science of rubbing”.

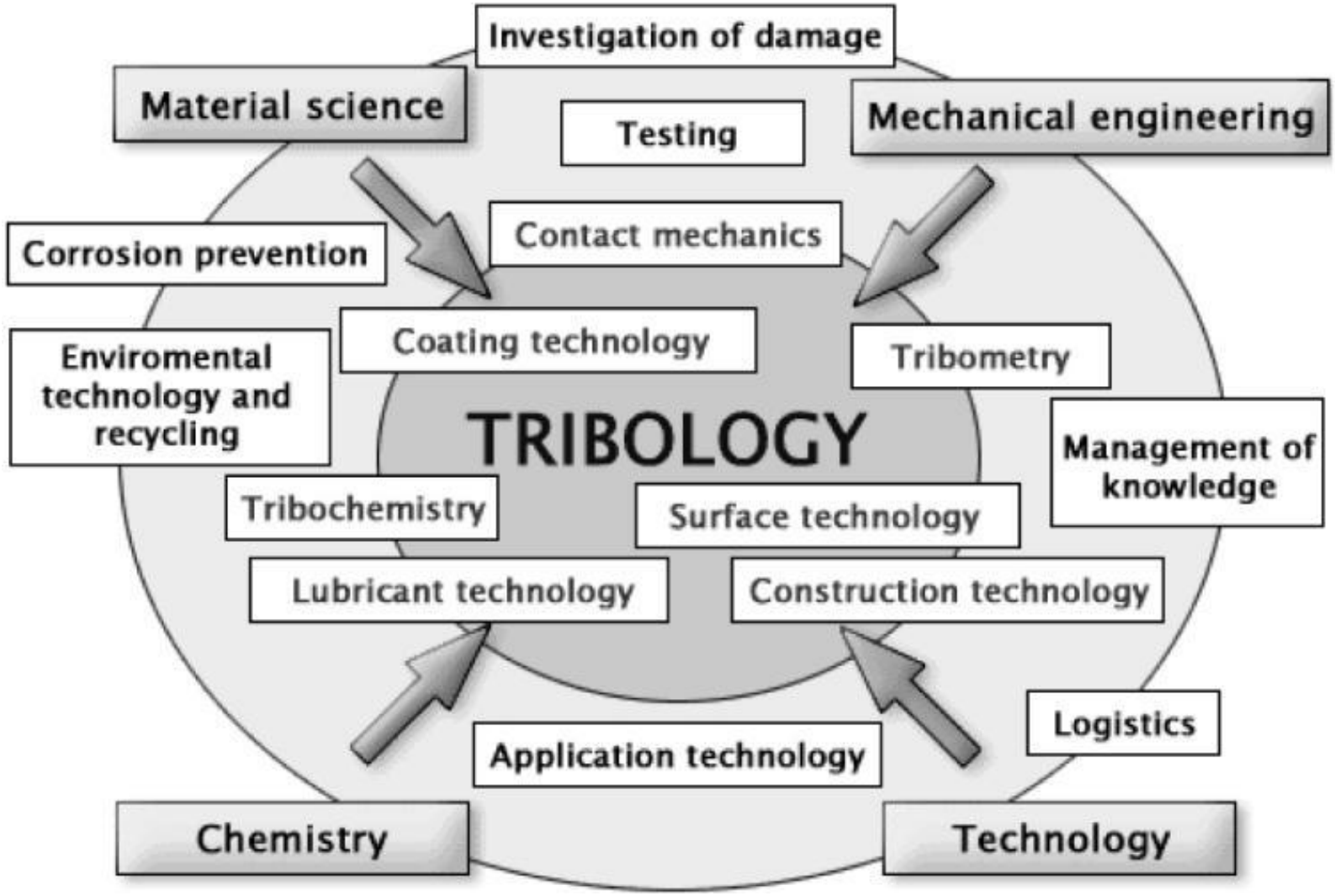
- The study of the concept dates to Leonardo da Vinci and his studies on the laws of friction.

- The word of “Tribology” was used first by Peter H. Jost, a British mechanical engineer in 1966.



TRIBOLOGY- In General

The work of the tribologist is truly interdisciplinary, embodying physics, chemistry, mechanics, thermodynamics, and materials science, and encompassing a large, complex, and interwinded area of machine design, reliability, and performance where relative motion between surfaces is involved.



Tribology-In General

Tribology is also in Virtually every Area of Engineering and Industry

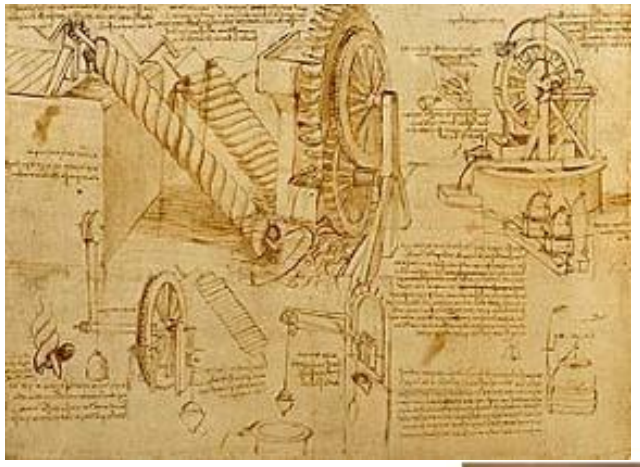
- Aerospace
- Agriculture
- Automotive
  - Engine: Piston ring/cylinder, Bearings, valve seats, injectors
  - Brakes/clutch
  - Tooling/Machining/Sheet metal forming
- Coatings Providers
  - Low Friction
  - Wear Resistant
    - Thin Films or Hardfacings
- Cosmetics/Personal Care
- Dental Implants
- Energy
  - Nuclear
  - Wind
  - Fossil
  - Solar
- Fabric/Clothing
- Flooring
- Food Processing
- Highway/Transportation Depts.
- Lubricant Manufacturers
- Medical Diagnostics
- Medical Implants
- Military
- Pharmaceutical
- Shoe Manufacturers
- Sports Equipment Companies
- Universities/Educators
  - Mechanical Engineering
  - Materials Science Engineering
  - Physics
  - Chemistry

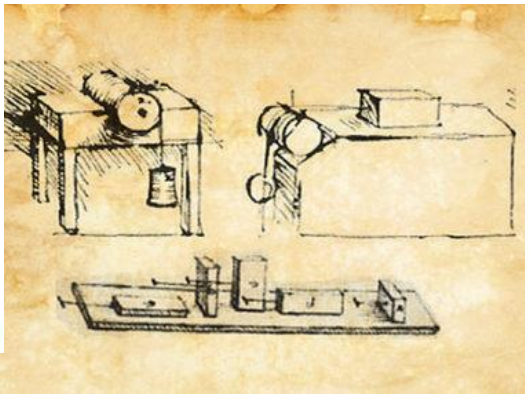
Tribometer/Tribotester

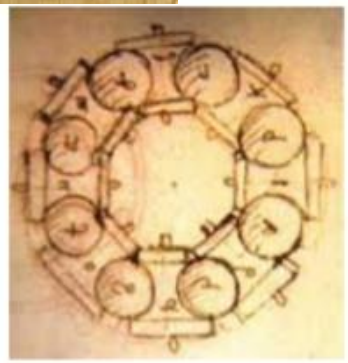
A tribometer (or tribotester) is a generic name given to a machine or device used to perform tests and simulations of wear, friction and lubrication.

It was the renaissance engineer-artist, Leonardo da Vinci (1452-1519), discovered that the tangential force of friction between moving solid bodies is proportional to the normal force. His notebooks show many designs for moving parts and machines that show a remarkable similarity to those in use today

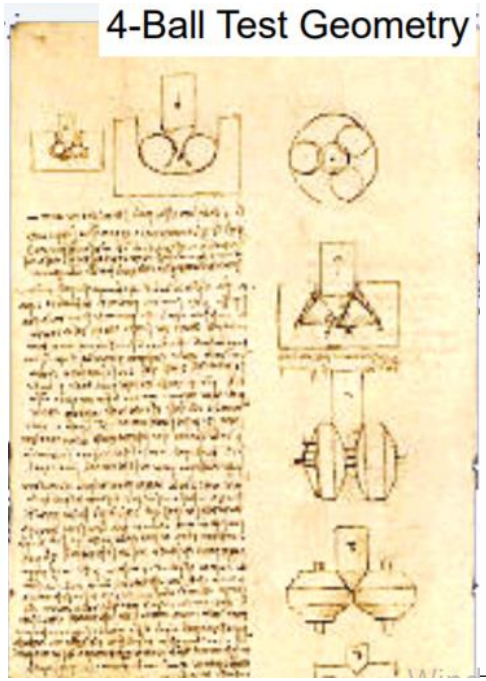
Leonardo Da Vinci







Ball Bearing



Tribometer/Tribotester

Tribometers are developed and used for a variety of purposes, including but not limited to:

- **simulate the tribocontact situation in a particular machine**
- **evaluate candidate-bearing materials for a friction-critical application**
- **evaluate lubricants for a particular application**
- **qualify lubricants for use on the basis of established criteria**
- **monitor surface contamination on a product**
- **acquire nontribosystem-specific (generic) friction data as a means to compare and develop new materials, coatings, or lubricants**
- **investigate the fundamental nature of friction of solids or lubricated solids**

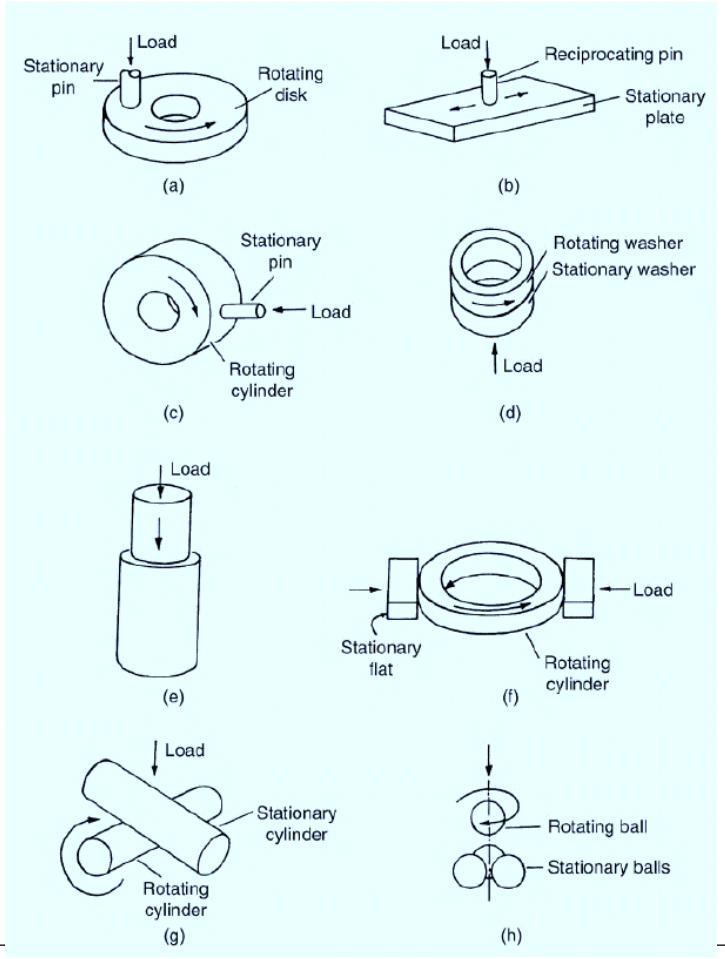
Tribometer/Tribotester

Since **tribological problems** are present in almost any field of engineering, a wide range of tribometers are in use to mimic all kinds of situations encountered in the real life applications.

Despite the widespread availability of commercial tribometers, researchers continue designing specific tribometers. This is needed to provide certain testing conditions, specific component simulations, or specimen dimensions that are not readily available.

Schematic illustrations of typical interface geometries used for sliding friction and wear tests:

(a) pin-on-disk,
(b) pin-on-flat,
(c) pin-on-cylinder,
(d) thrust washers,
(e) pin-into-bushing,
(f) rectangular flats on rotating cylinder,
(g) crossed cylinders,
(h) four-ball.



Tribometer/Tribotester

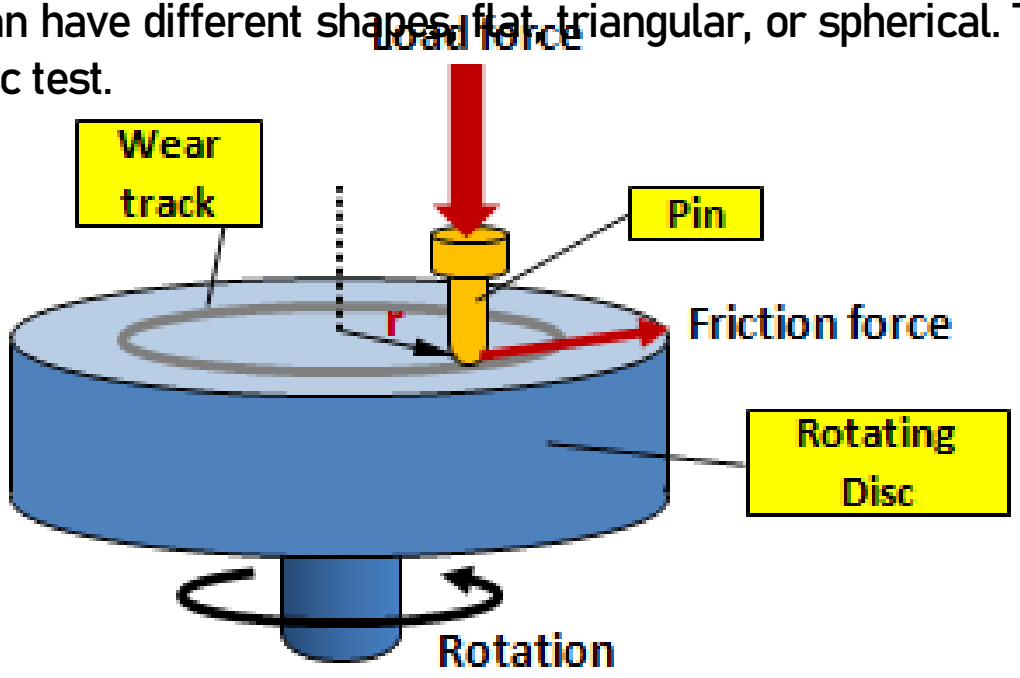
Some details of typical test geometries for friction and wear testing

Geometry[a]	Type of contact	Type of motion
1. Pin-on-disk (face loaded)	Point/conformal	Unidirectional sliding, oscillating
2. Pin-on-flat (reciprocating)	Point/conformal	Reciprocating sliding
3. Pin-on-cylinder (edge loaded)	Point/conformal	Unidirectional sliding, oscillating
4. Thrust washers (face loaded)	Conformal	Unidirectional sliding, oscillating
5. Pin-into-bushing	Conformal	Unidirectional sliding, oscillating
6. Flat-on-cylinder (edge loaded)	Line	Unidirectional sliding, oscillating
7. Crossed cylinders	Elliptical	Unidirectional sliding, oscillating
8. Four balls	Point	Unidirectional sliding

TYPES OF TRIBO-TESTING MACHINES

❖ Pin on Disc/Ball on Disc

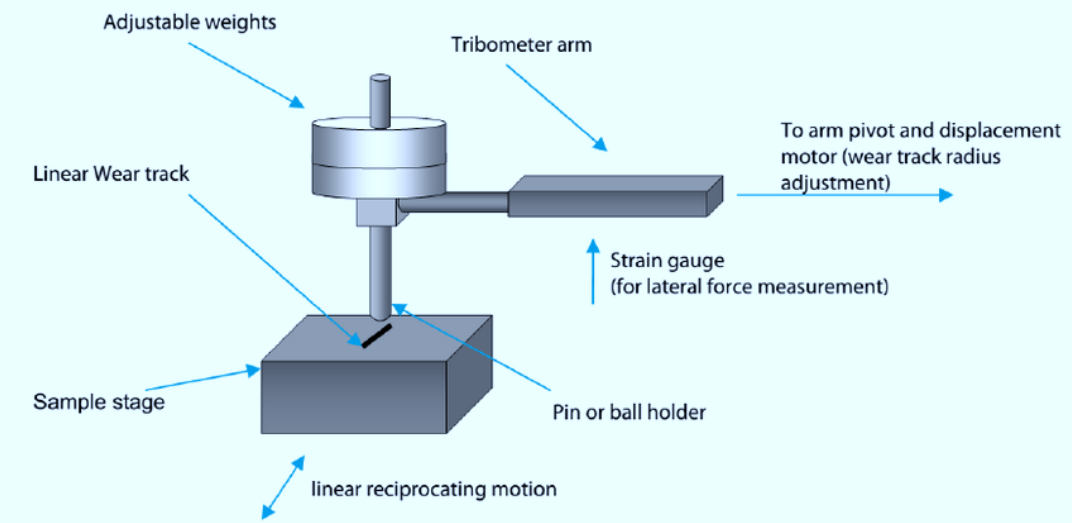
- Ability to perform tests according to ASTM G-99 standard. Test options according to DIN 50324, ASTM D3702, ASTM D2266, ASTM D4172, ASTM G132 standards
- Pin in Disc tribometers are probably most known and extensively used devices in tribology.
- The tribometer consists of a stationary pin and a rotating disc.
- Pin is loaded by a dead weight or actively controlled systems.
- Pin can have different shapes, flat, triangular, or spherical. The latter case it is called ball on disc test.



Classification and types of tribometers

❖ Linear Reciprocating (Pin/Ball on Flat)

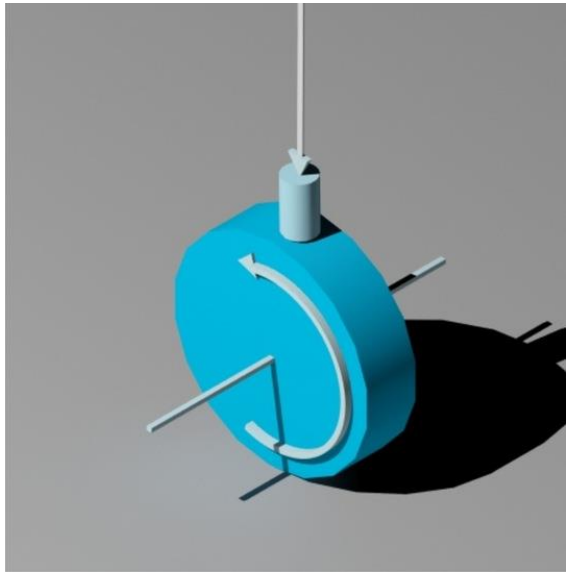
- This is used to conduct the reciprocating tests according to ASTM G-133 .
- A flat moves relative to a stationary pin/ball in reciprocating motion. In some cases, the flat is stationary and the pin reciprocates.
- The pin can be a ball, a hemispherically tipped pin, or a flat-ended cylinder. By using a small oscillation amplitude at high frequency, fretting wear experiments can be conducted.
- It is possible to perform dry and lubricated tests.
- Different types of contact geometries are possible such as Ball-on-disc, ball-on-plate, cylinder-on-disc, cylinder-on-plate and disc-on-disc.
- Load, Frequency, Stroke and Temperature can be varied according to requirements.

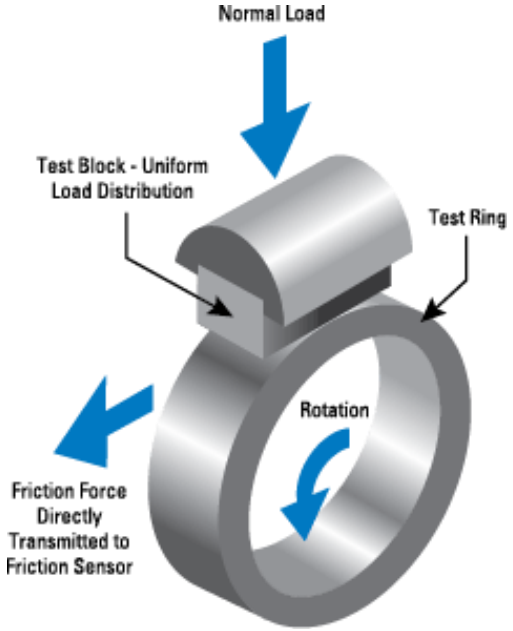


Classification and types of tribometers

❖ Pin-on-Cylinder (Edge Loaded) and Block-on-Ring

- The pin-on-cylinder tester is similar to the pin-on-disk, except that loading of the pin is perpendicular to the axis of rotation or oscillation. The pin can be flat or hemispherically tipped
- Block-on-Ring (ASTM G77) test is a widely used technique that evaluates the sliding wear behaviors of materials in different simulated conditions, allows reliable ranking of material couples for specific tribological applications.
- Possibility to perform the friction and wear tests in dry and oily environments with line and superficial (conforming) contact, such as plain bearings, gears, cranks, connecting rods and cam mechanisms.

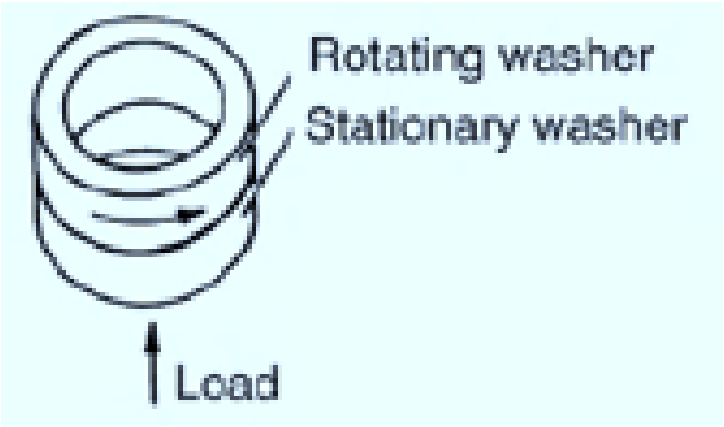


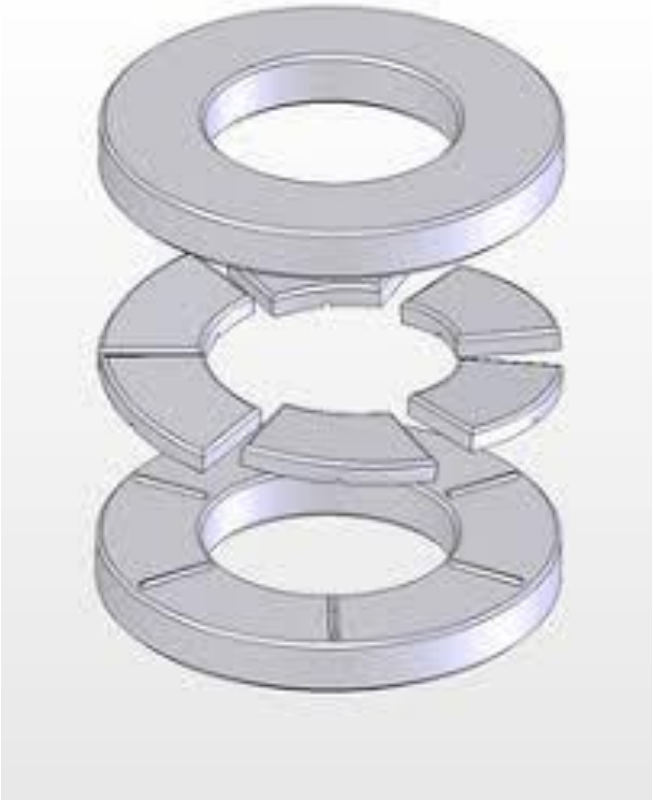


Classification and types of tribometers

❖ Thrust Washers (Face Loaded)

- In the thrust-washer tester, the flat surface of a washer (disk or cylinder) rotates or oscillates on the flat surface of a stationary washer.
- The testers are face loaded because the load is applied parallel to the axis of rotation.
- This configuration is most common for testing materials for low-stress applications, such as journal bearings and face seals.

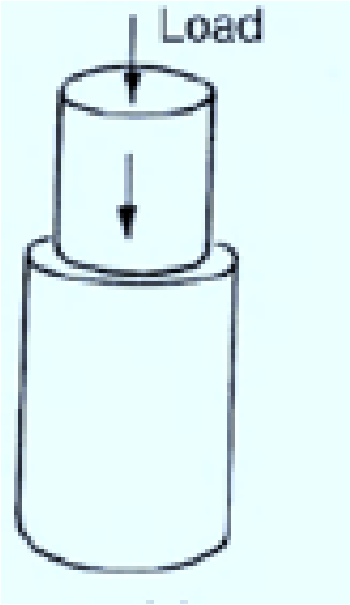


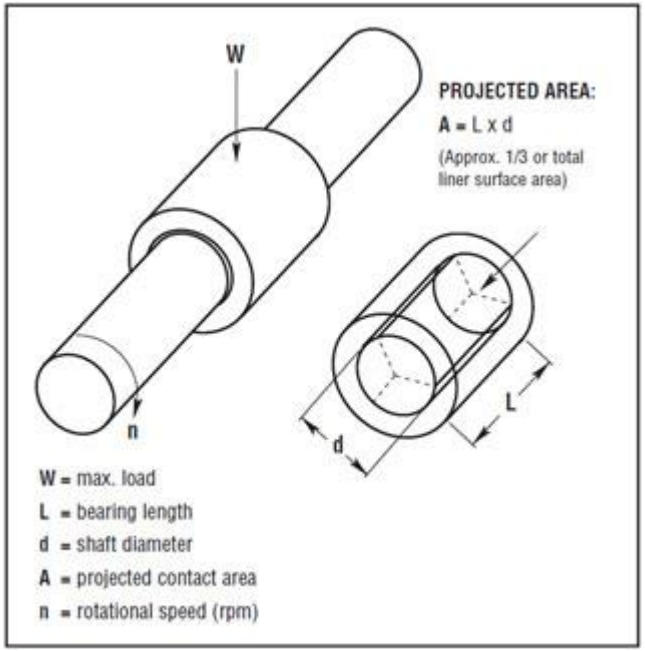


Classification and types of tribometers

❖ Pin-into-Bushing (Edge Loaded)

- In the pin-into-bushing test apparatus, the axial force necessary to press an oversized pin into a bushing is measured.
- The normal (axial) force acts in the radial direction and tends to expand the bushing; this radial force can be calculated from the material properties, the interference, and the change in the bushing's outer diameter.

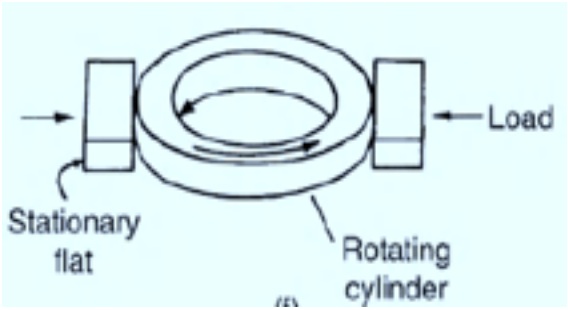




Classification and types of tribometers

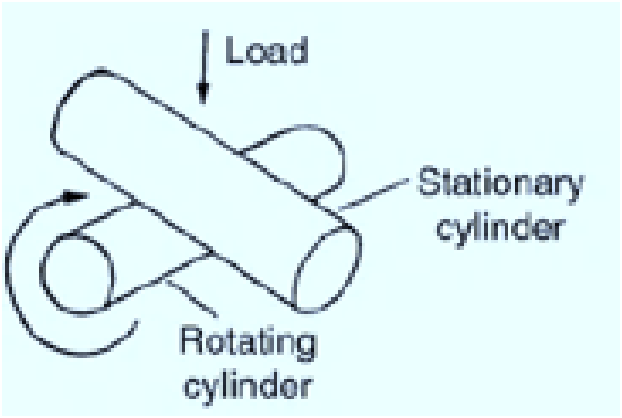
❖ Rectangular Flats on a Rotating Cylinder (Edge Loaded)

➢ In the rectangular-flats-on-a-rotating-cylinder tester, two rectangular flats are loaded perpendicular to the axis of rotation or oscillation of the disk.



❖ Crossed Cylinders

➢ The crossed-cylinders tester consists of a hollow (water-cooled) or solid cylinder as the stationary wear member and a solid cylinder as the rotating or oscillating wear member that operates at 90◦ to the stationary member.



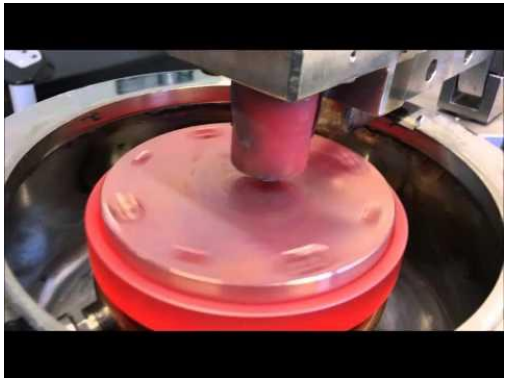
Classification and types of tribometers

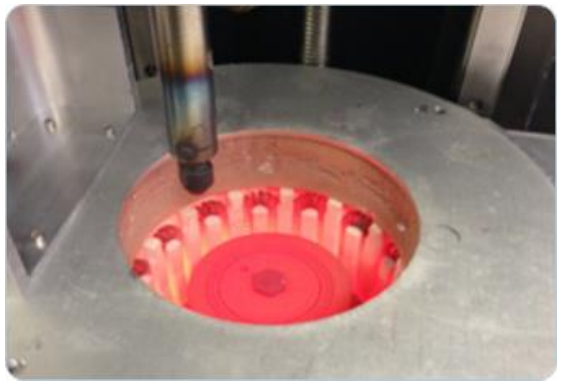
❖ High Temperaure/Low Temperature Tribometer

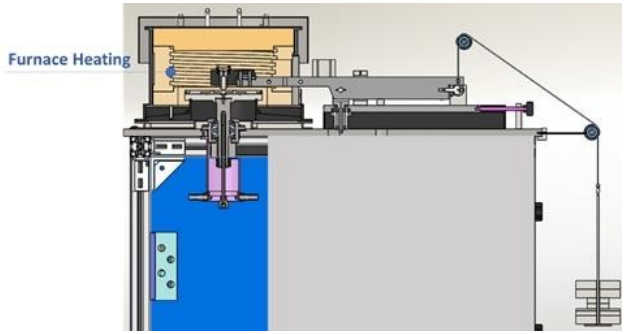
- High Temperature Tribometers are used for analysis of friction and wear properties at elevated temperatures, as high as 1200-1500oC like internal combustion engines, steam turbines, jet engines and power plants, as well as the tribological behavior of the materials to be used in such systems.

- This kind of tribometers generally use a furnace or insulated chamber equipped with heating coils to obtain high temperatures.

- Low temperature Tribometer are used for analysis of friction and wear properties of materials at very low temperatures down to -120 oC. These are generally used for testing materials used in space applications or for very low temperature regions (pipelines in polar regions). These kind of tribometers generally use liquid nitrogen or liquid helium to cool the interface.



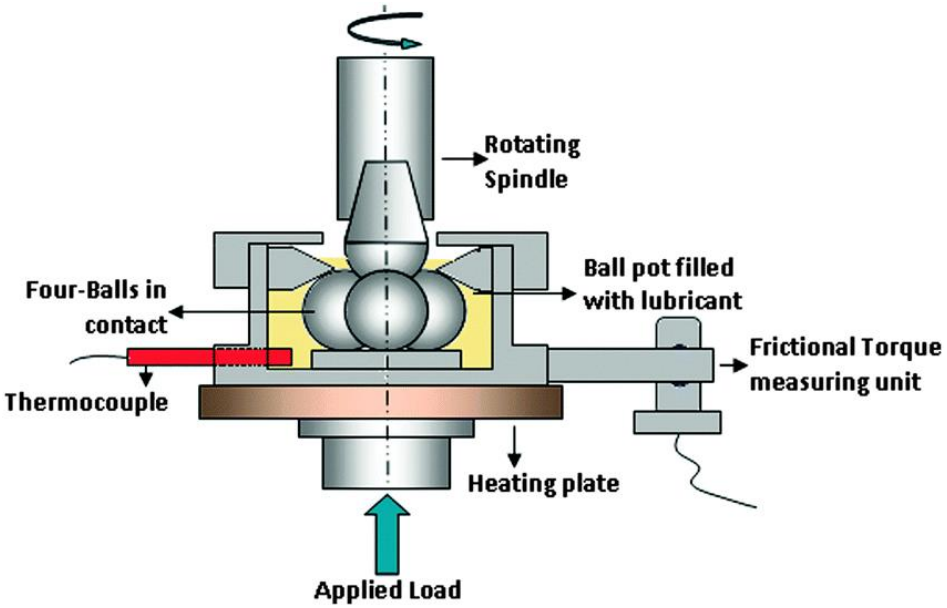


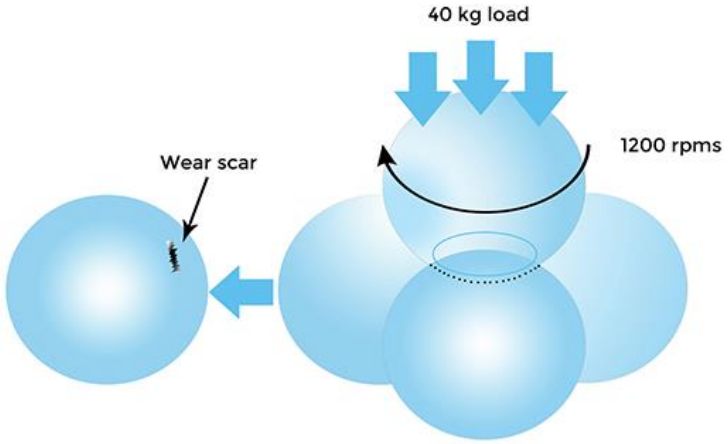


Classification and types of tribometers

❖ Four Ball Tester

- The test is used to determine the characteristics of lubricating oils and greases in sliding applications.
- The test consists of rotating a ball under load against three stationary balls in lubricated conditions.
- Measurements are taken at the various speeds, temperatures, and duration as specified by published standards.
- The lubricant comparisons can be made based upon scar diameters incurred from wear tests.



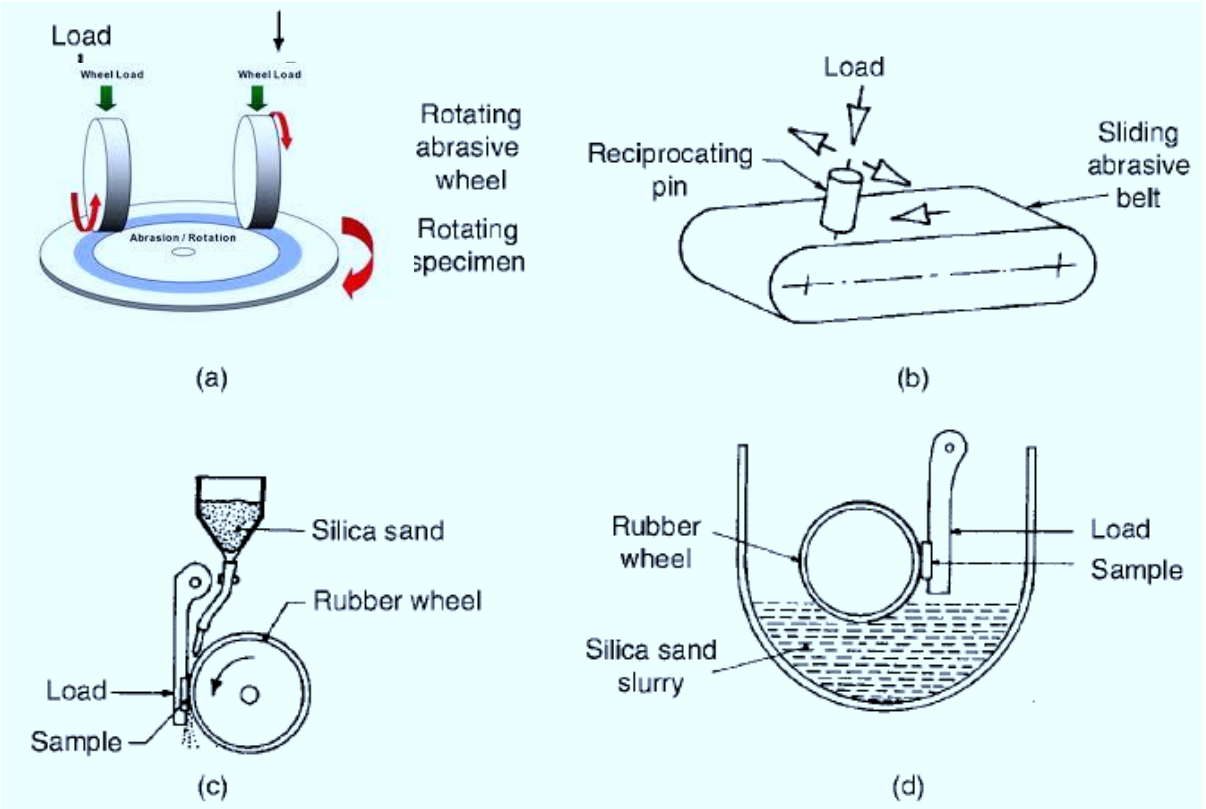


Classification and types of tribometers

❖ Abrasion Testers

- Abrasion tests include two-body and three-body tests.
- In a two-body abrasion test, one of the moving members is abrasive.
- In a three-body abrasion test, abrasive particles are introduced at the interface.

- Abrasion tests can be conducted using any of the test geometries, with one of the surfaces being made of abrasive material or in the presence of abrasive particles.



Schematic illustrations of abrasion test apparatuses:

a) Two abrading wheels weighted on test specimen driven in opposite directions in the Taber abrasion tester,
b) Abrasive belt tester
c) Dry-sand abrasion tester,
d) Wet-sand abrasion tester.

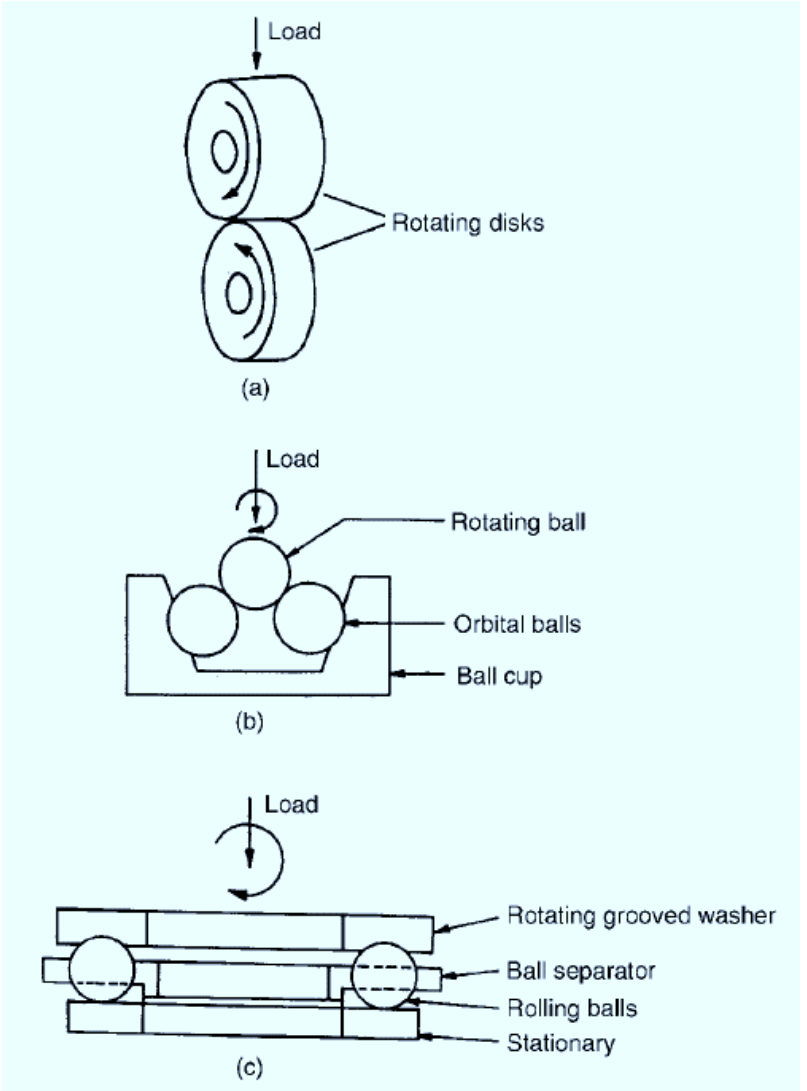
Classification and types of tribometers

❖ Rolling-Contact Fatigue Tester

A number of rolling-contact fatigue (RCF) tests are used for testing materials and lubricants for rolling-contact applications such as antifriction bearings and gears.

Schematic diagram of three types of rolling-contact fatigue tester

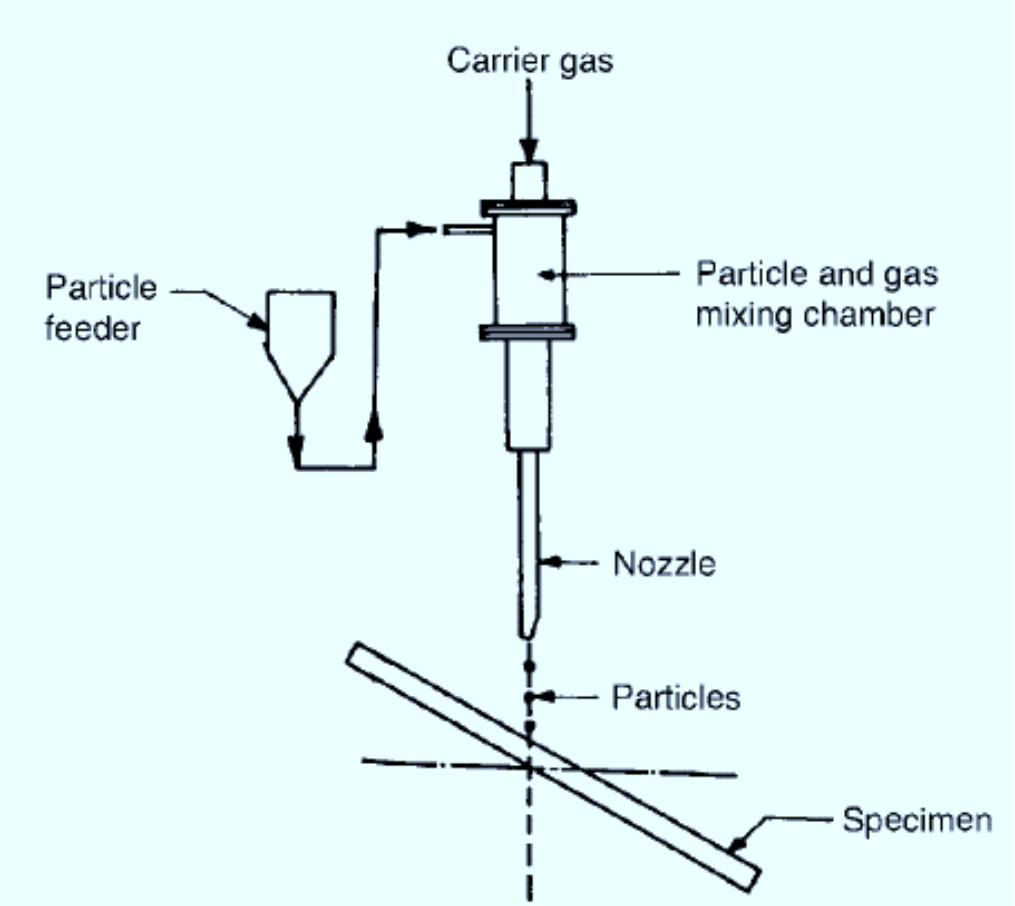
(a) Disk-ondisk,
(b) Rotating four ball,
(c) Balls-on-flat.



Classification and types of tribometers

❖ Erosion Tester

- Erosion testing is generally conducted at room temperature using an air-blast tester
- The tester is operated by feeding the eroding particles from a vibrating hopper into a stream of gas.
- A known amount of eroding particles is directed onto one or more test specimens.
- The weight loss of the test specimens is used as a measure of erosive wear

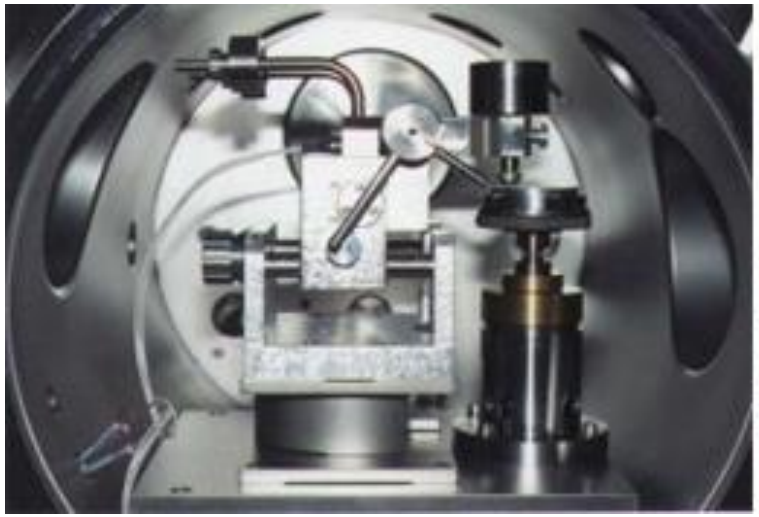


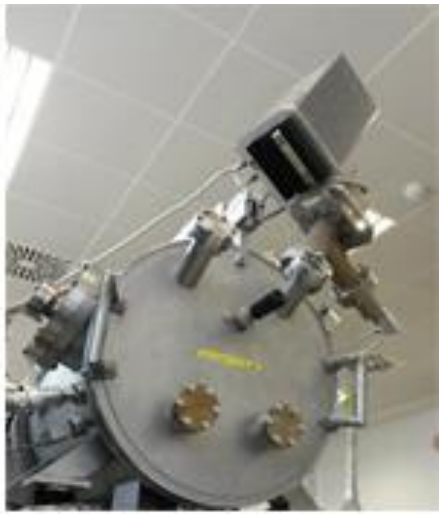
Classification and types of tribometers

❖ Vacuum Tribometer

- Some devices are needed to test of some critical equipment with moving parts that work under vacuum conditions (machines operating in harsh conditions, such as space, tools in the semiconductor industry, scanning electron microscopy or cryo pumps, etc.).

- Vacuum Tribometer are designed to provide controlled vacuum conditions for friction and wear studies.

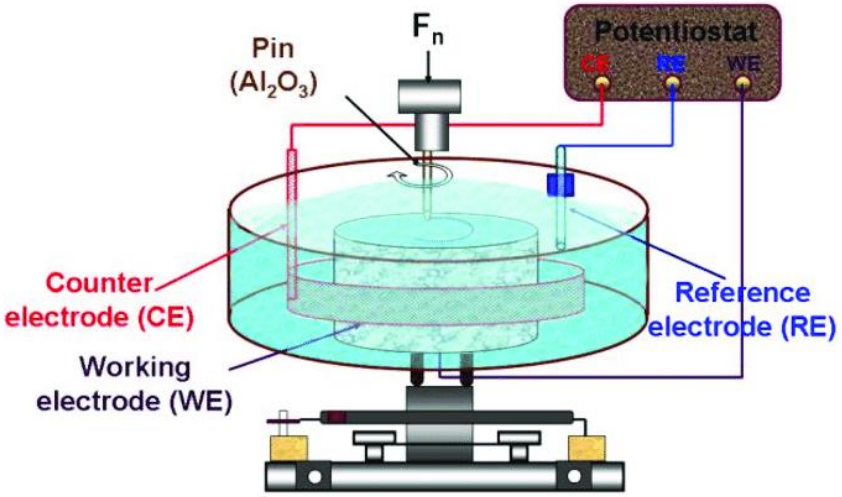


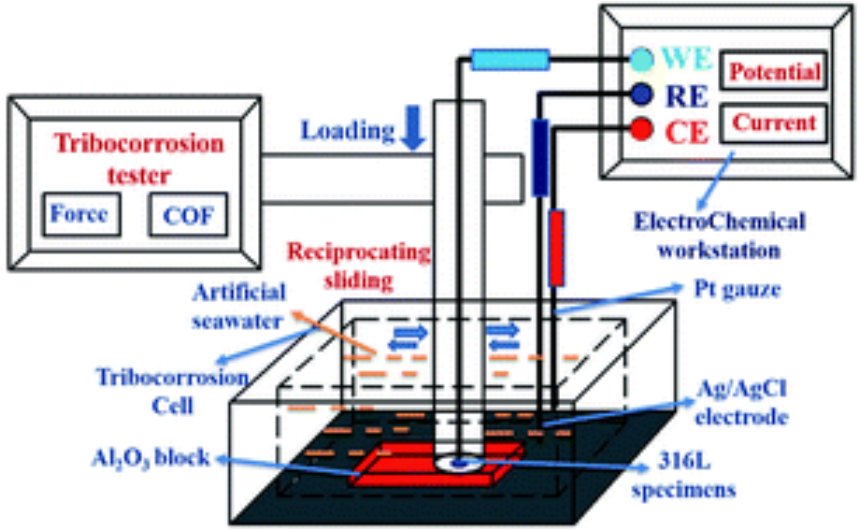


Classification and types of tribometers

❖ Tribocorrosion test systems

- Tribo-corrosion is a surface degradation process that occurs simultaneously with tribological processes and corrosion effects.
- Tribo-corrosion test is a test method to be used for evaluating the combined effect of friction / wear and corrosion.
- If there is corrosion cell that can be adapted to the rotational movement module, friction and wear can be characterized for different natural corrosive environments (salt water, body fluid, acidic solutions etc.).
- A modernized module with reciprocating motion system can make the electro-tribocorrosion tests by the addition of potansiyostat.
- The module is made of corrosion-resistant material. For the removal of the heat generated during tribo-corrosion tests, a constant temperature bath with a water circulation system is provided.

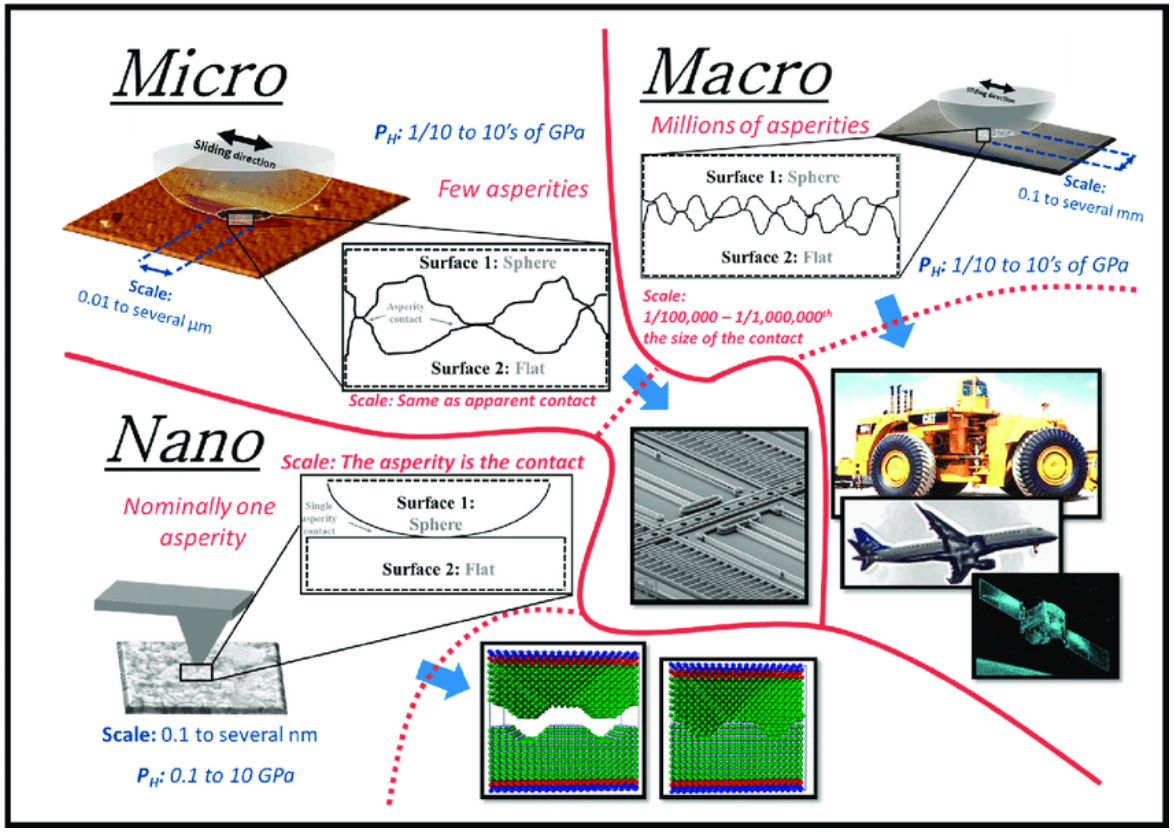




Classification and types of tribometers

❖ Micro/Nano Tribometer

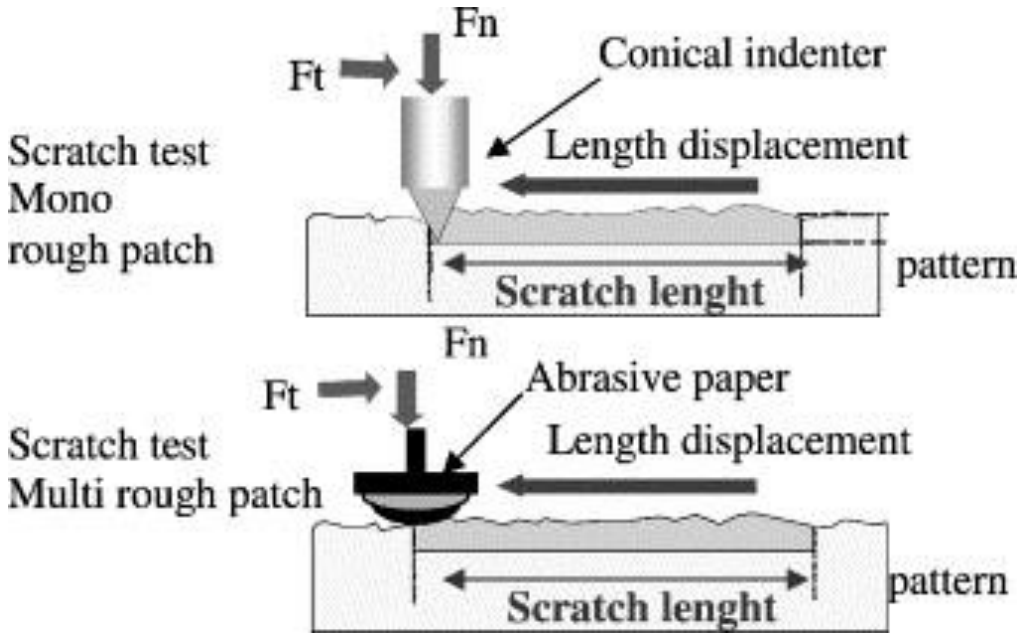
- Such tribometers or test divices are used to investigate tribological properties of a wide range of surfaces and interactions at small scales (atomic level).
- Typically the applied forces are small, leading to small friction forces which are difficult to measure.
- Specific devices are needed to perform such tests.

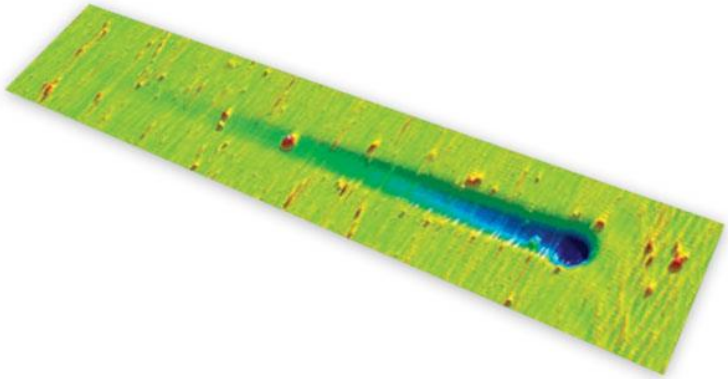


Classification and types of tribometers

❖ Scratch Test Instrument

- Scratch test instrument is a simple for evaluating adherence characterization and scratch resistance for thin coatings and bulk materials.
- A stylus with well-defined tip geometry is moved over a specimen surface with load until failure occurs at critical load or loads.
- It also can be combined with inline profile characterization.

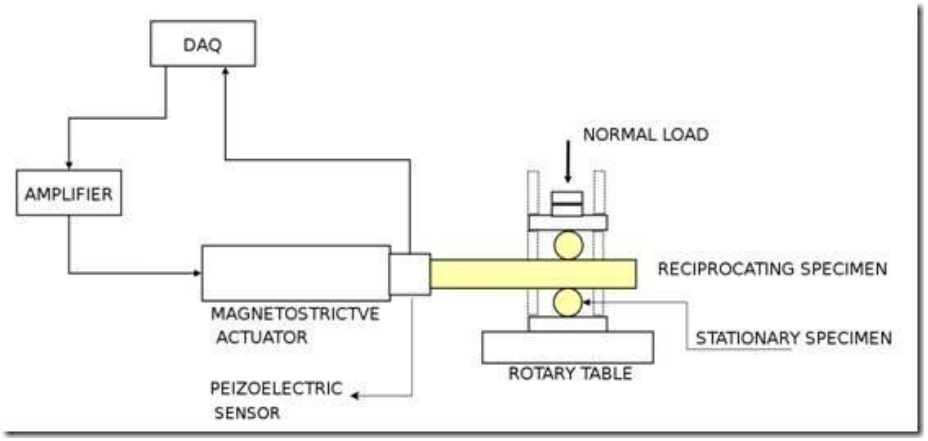


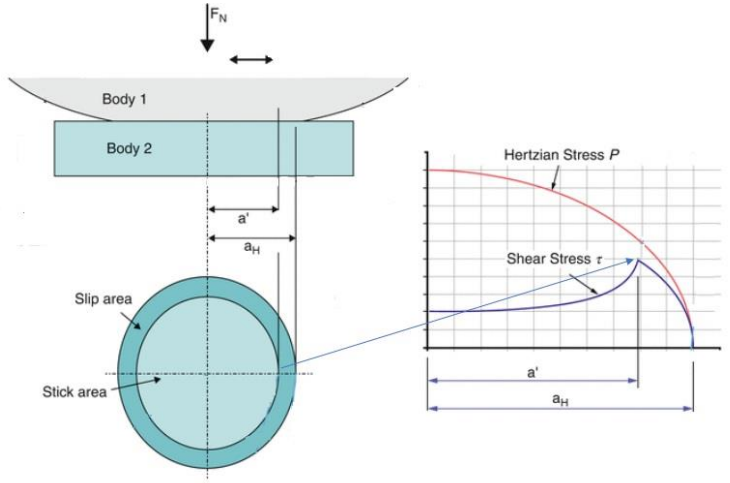


Classification and types of tribometers

❖ Fretting Tester

- Fretting is a specific wear type which is characterized by low amplitude oscillating sliding between bodies, which are nominally at rest.
- The amplitude of sliding may vary from tens of mircons (in bolted joints, electrical contacts) to tens of nanometers (in MEMS).
- Fretting tribometers are therefore specific machines designed for low amplitude reciprocating motion.
- Fretting typically appears as pits or grooves surrounded by corrosion products.
- Fretting is usually accompanied by corrosion (in a corrosive environment).

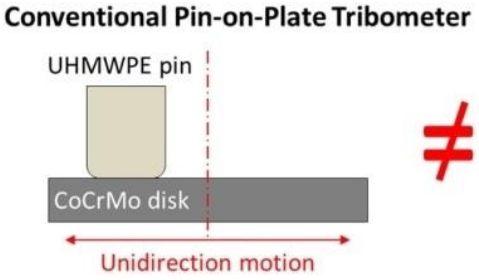




Classification and types of tribometers

❖ BioTribometer

- Bio Tribometers are used to mimic situations encountered in biological environments such as artificial joint replacements.
- Behavior of the materials used in these devices can be tested (in accelerated manner) with such tribometers.
- Materials like UHMWPE, Al2O3, Polycarbonate urethanes (PCU),Ti-6Al-4V are used to replace acetabular cup, femur head, meniscus and tibia (epiphysis), respectively.



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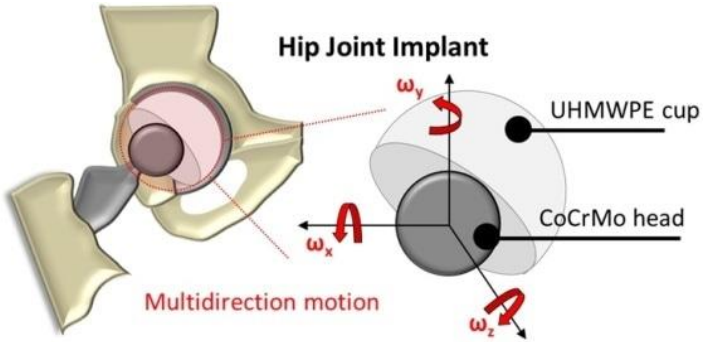
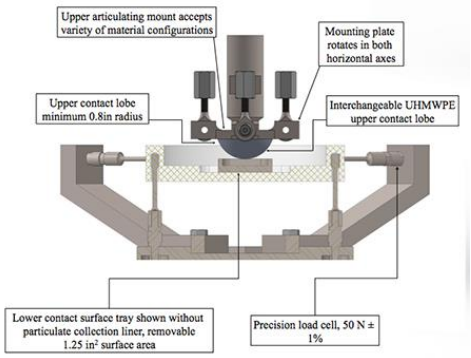
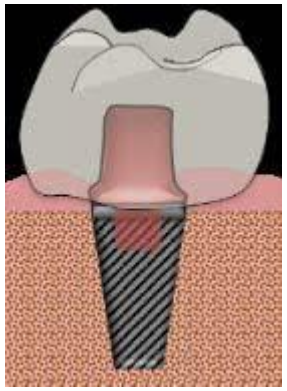
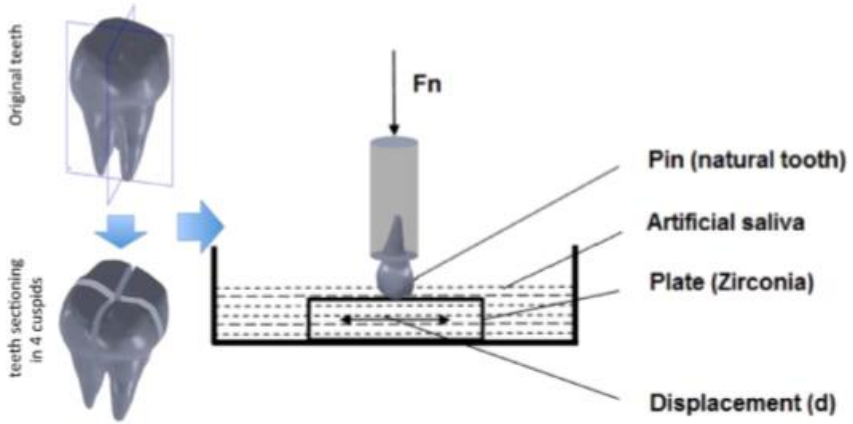








Design of a new multifunctional tribometer

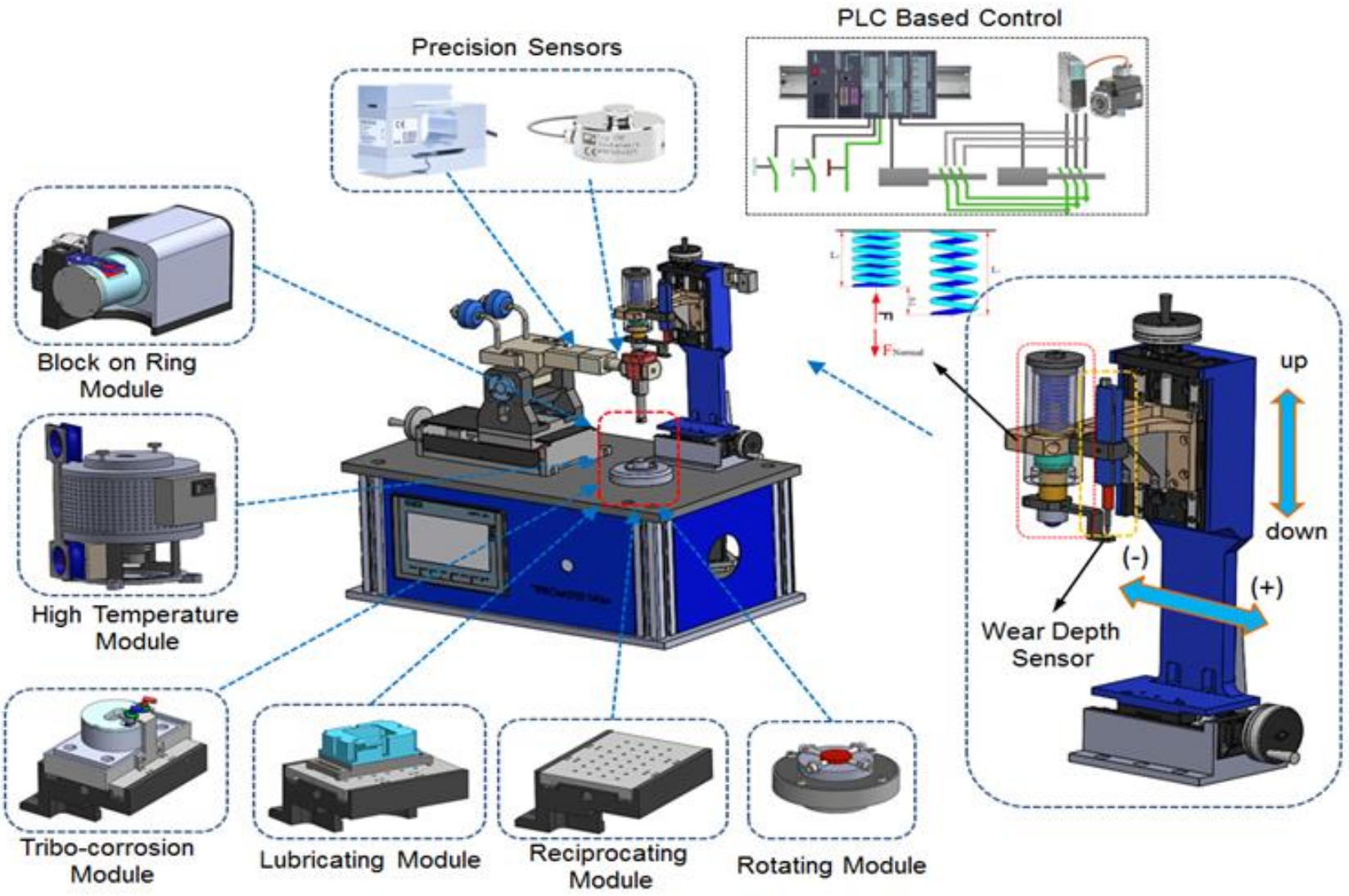
❖ Design concept and system overview

For the multifunctional tribometer developed, the following main features or parameters were selected initially:

- Standard loads up to 100 N. But it can be upgraded or low-graded by selecting high- or low-capacity load-cells.
- Speed control of the rotating disk
- Disc rotational speeds up to 3000 rpm
- Continuous wear depth measurement option between
- Variable test path radius
- Variable stroke and frequency in reciprocating module
- Automatic stop when the coefficient of friction reaches a threshold value or when a specified number of turns is reached
- Measuring the test temperature continuously near or inside the abrading samples
- Measuring the environment temperature and relative humidity continuously
- Capturing the coefficient of friction between the sliding parts or samples.
- Test temperature options from room temperature up to 1000 ⍰C with a sophisticated high temperature module.
- Tribo-corrosion tests option in variety of corrosive liquid with well-designed trbo-corrosion module.
- Test option for conforming surfaces with a specifically designed block-on-ring module.
- A specified test option for piston-ring configurations with piston ring and cylinder liner test module.
- A test option for lubricated system with lubrication or liquid module.
- Test options with dead weights or spring-assisted mechanically loading
- Measuring the applied normal loads by a sensor.
- A new user friendly software to set up experiments, handle, store and analyse the data with real time display of measurement data

Design of a new multifunctional tribometer

❖ Design concept and system overview

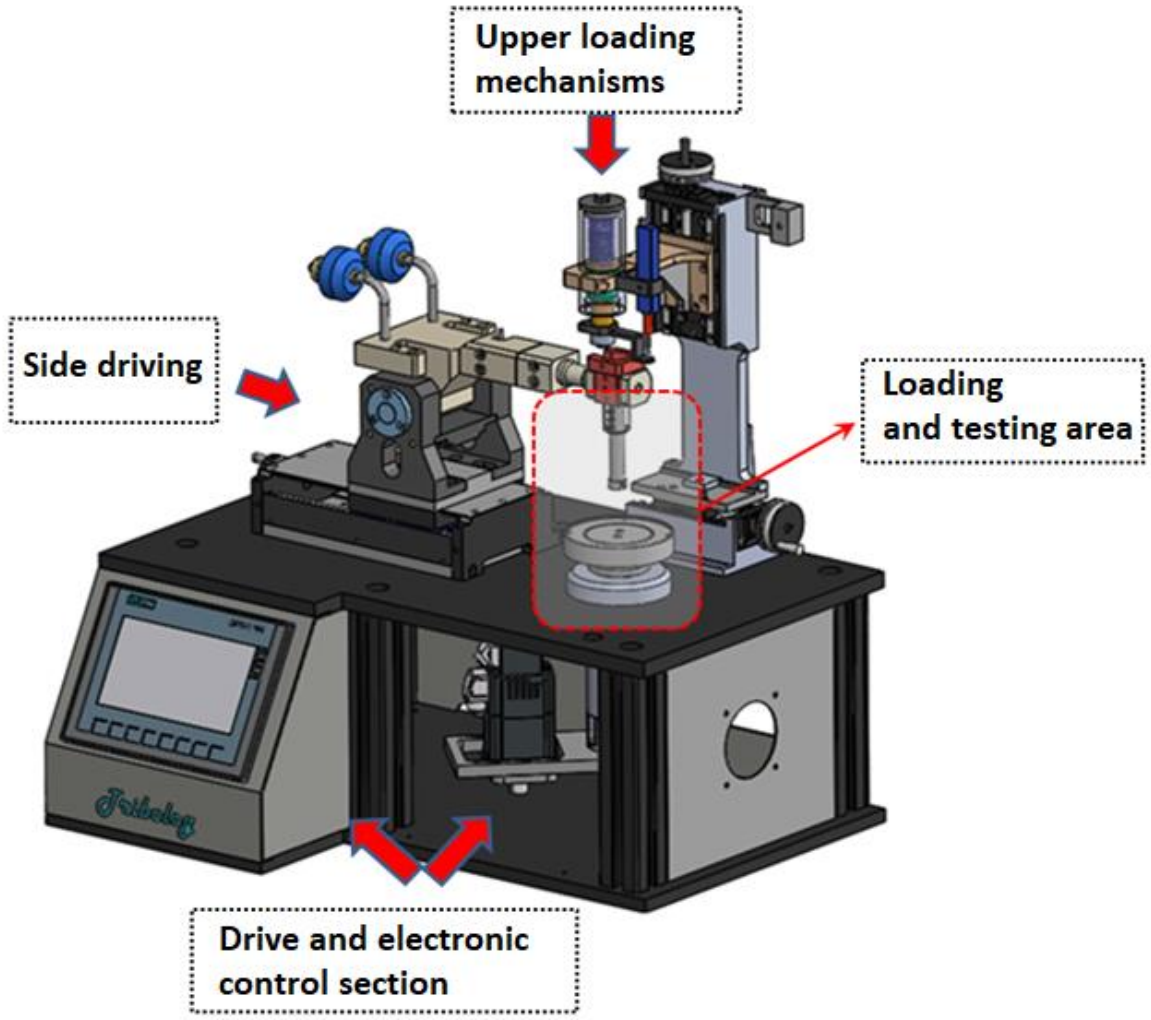


A general 3-D views of multifunctional tribometer with the main moudules.

Design of a new multifunctional tribometer

Design concept and system overview

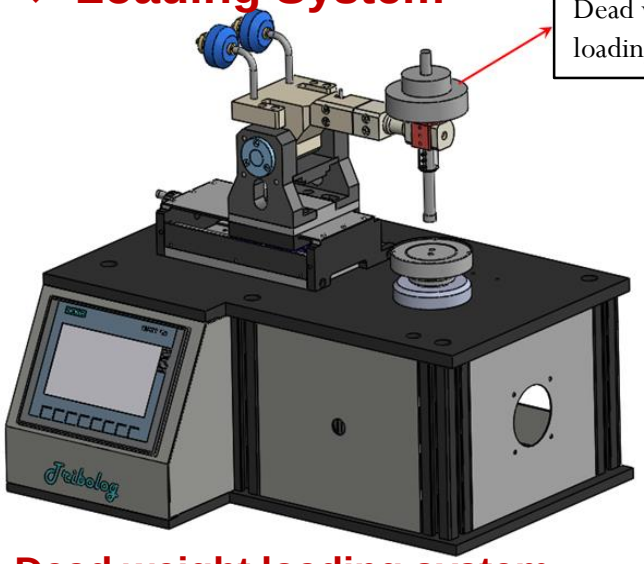
❖ Main Test Platform

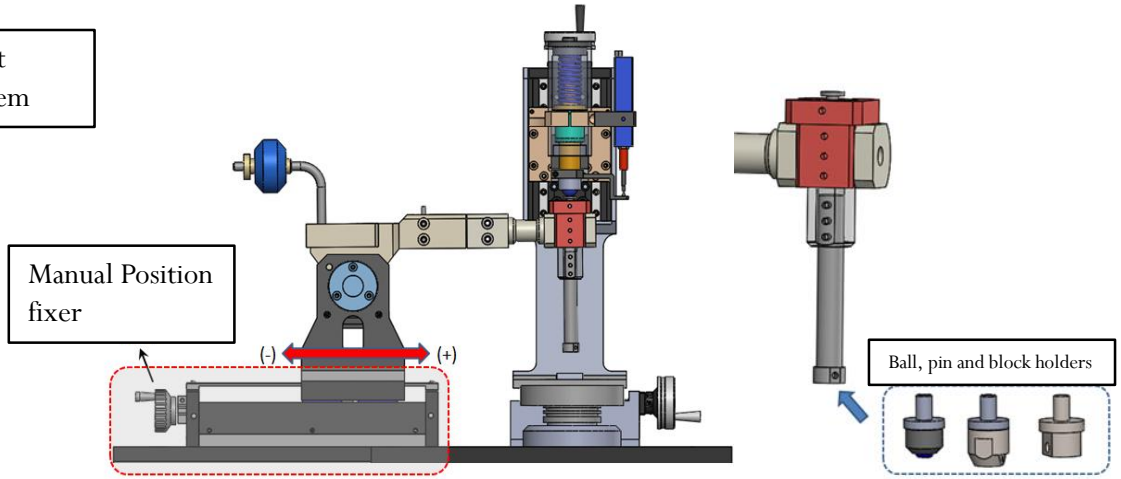


Design of a new multifunctional tribometer

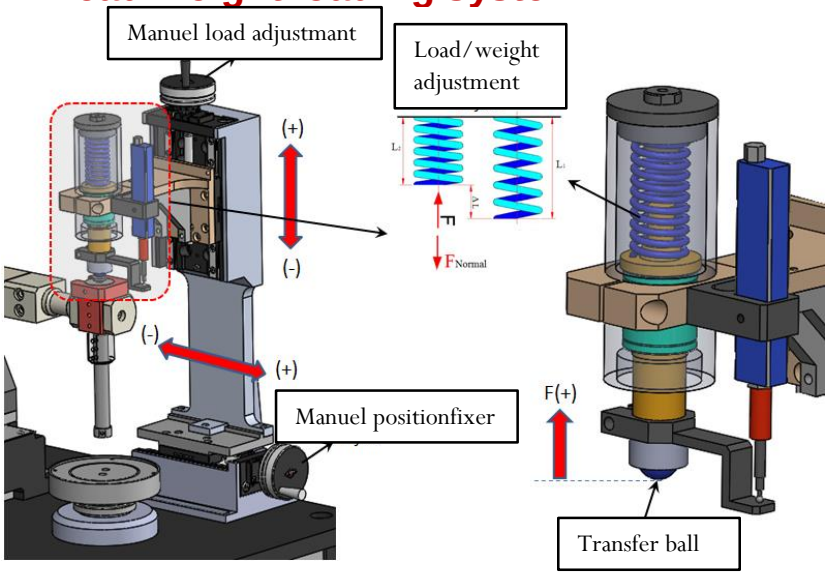
Design concept and system overview

❖ Loading System





Dead weight loading system



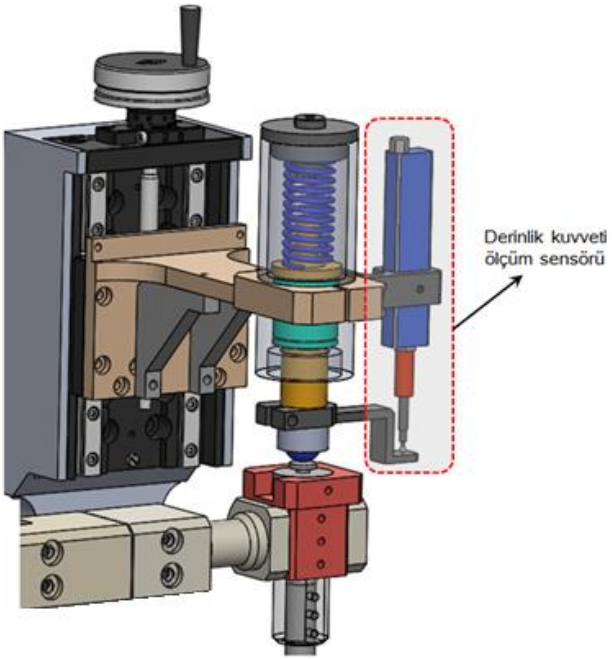
Spring-assisted loading system

Wear depth measuring system

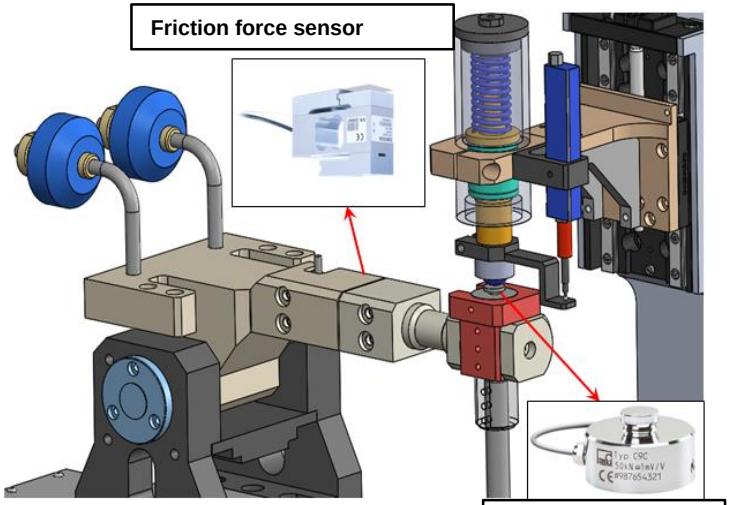
Design of a new multifunctional tribometer

Design concept and system overview

❖ Measuring systems



Wear depth measuring sensor and its position



Friction force sensor

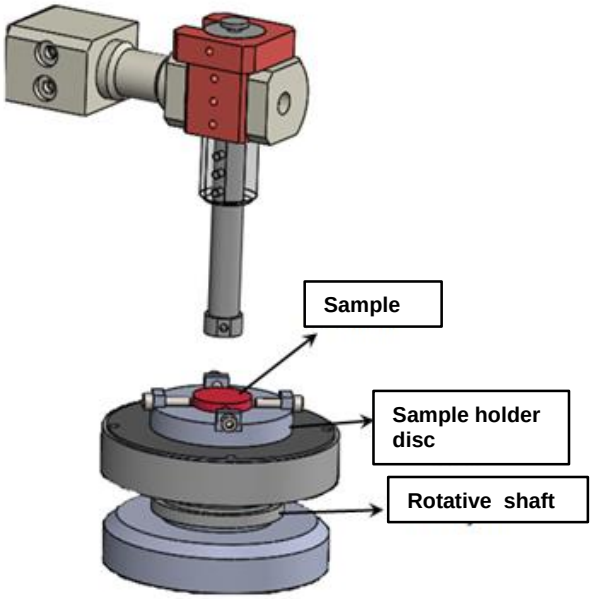
Normal load sensor

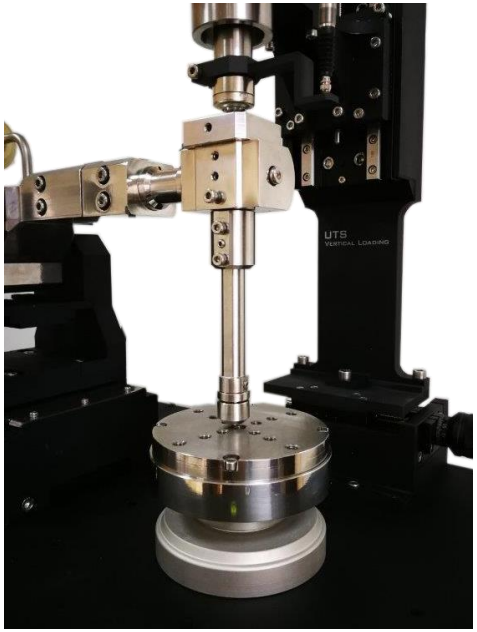
Design of a new multifunctional tribometer

❖ Main mudules

Pin-on-disc module (Rotary Module)

- This module was designed to be able to conduct the rotary tests according to ASTM G-99.
- Friction and wear tests can be performed in different environments and test conditions in accordance with ASTM G99 standard.
- Some specific tests can be conducted in dry, oily, corrosive and hot environments. For this purpose, special containers and environments can be developed.



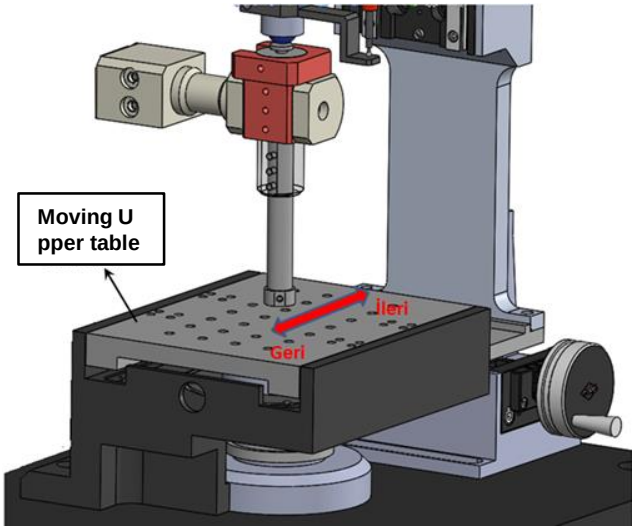


Design of a new multifunctional tribometer

❖ Main mudules

Linear reciprocating module

- The working stroke can be easily changed and fixed.
- This module has a basic motion mode that also serves some other sub-modules.
- With this module, the tribological tests can be performed in accordance with ASTM G33 (Standard Test Method for Linearly-Reciprocating Ball-on-Flat Sliding Wear)
- In this module, the rotating motion system is brought into linearly-Reciprocating motion mode with a special mechanism.
- Special holes and holders are made on the movable table for easy attachment of samples. Therefore, it is possible to work with samples of any geometry and size.
- In this module, the wear depth can also be measured precisely by a wear depth measurement sensor.
- With this module, the friction force is also measured by the sensor on the elastic arm.



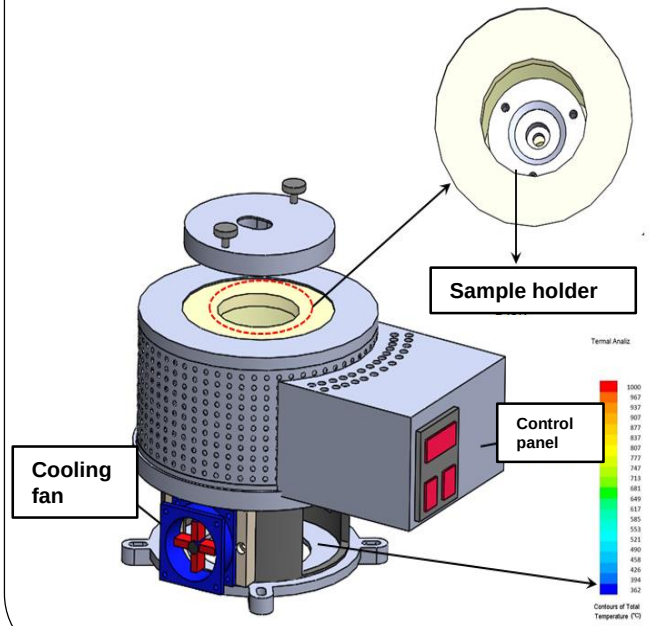
Design of a new multifunctional tribometer

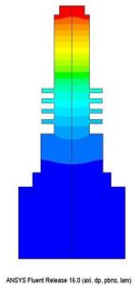
❖ Main mudules

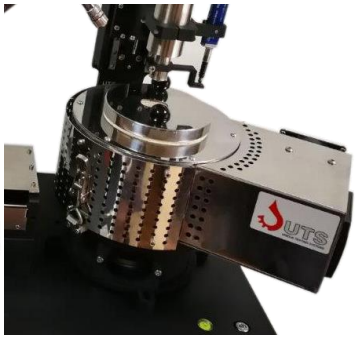
High Temperature module

This module was developed for the tribological characterization of materials to be used in environments where high temperature is operative such as internal combustion engines, steam turbines, jet engines and power plants. This module is designed to be compatible with the rotary pin-on-disk motion of the main test machine.

- An oven type heating system is used with the module The heating rate can be adjusted by a PID controlled system.
- Tribological tests can be performed between room temperature and 800°C with an accuracy of 1 °C. The existing system can optionally provide heating up to 1000 °C.
- Materials with high thermal stability (super alloy) are used in heating oven.
- High temperature stable sensor is used.
- Optionally, a wear depth sensor option is also available.





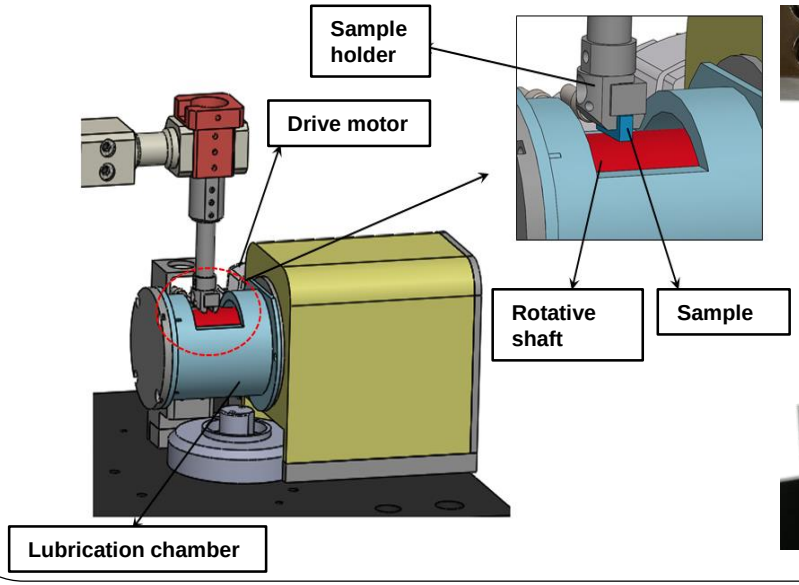


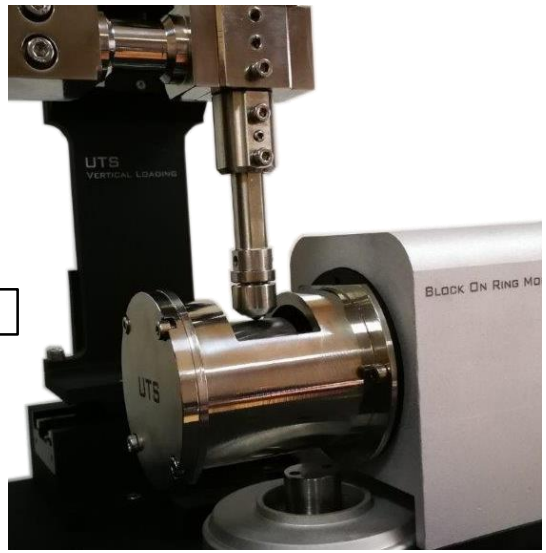
Design of a new multifunctional tribometer

❖ Main mudules

Block-on-ring module

- This module was especially developed for evaluation of tribological behavior of the systems such as plain bearings, gears, cranks, connecting rods and cam mechanisms.
- With this module, precise friction and wear tests in dry, oily (lubricated) and heated environments.
- With the block and ring configuration of this module, it is possible to perform the tests of pairs in point, line and superficial (conformal and non-conformal) contacts.
- Thanks to its specially designed lubrication cell, the system also provides the possibility of observing and measuring the lubricating effect of tribological systems.
- Using this test module many special tribological tests can be performed in accordance with the standards of ASTM D2981, D3704, G77, G176, D2509, 2782.
- A special container with heating feature was also developed for friction and wear tests in oily (lubricated) environment.



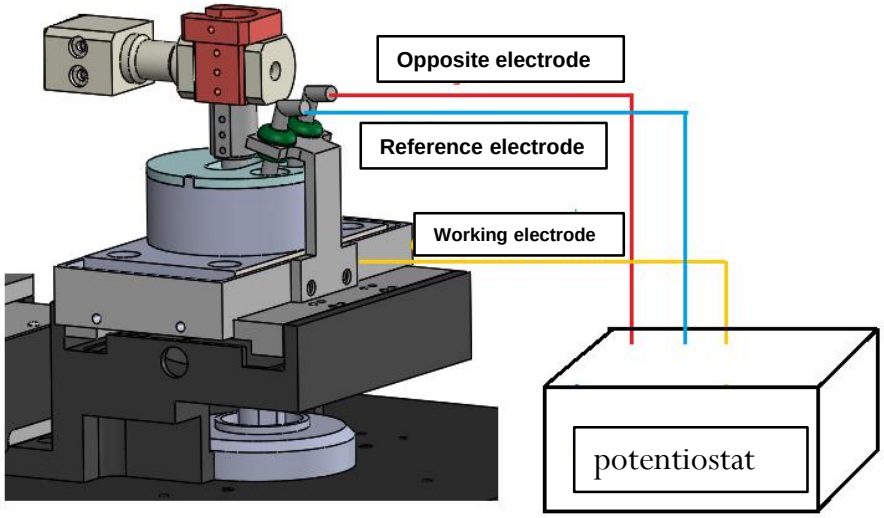


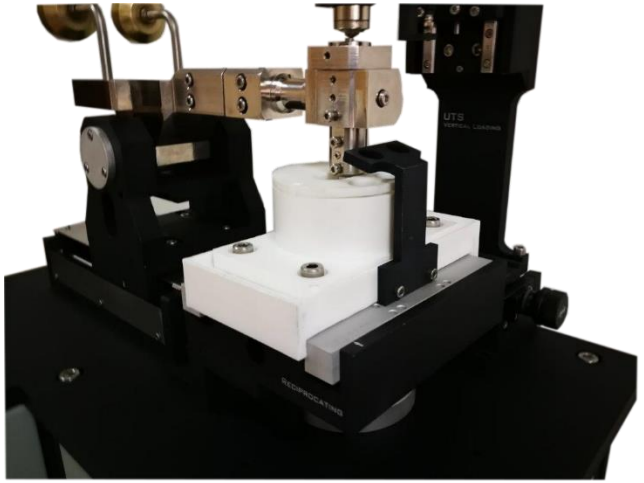
Design of a new multifunctional tribometer

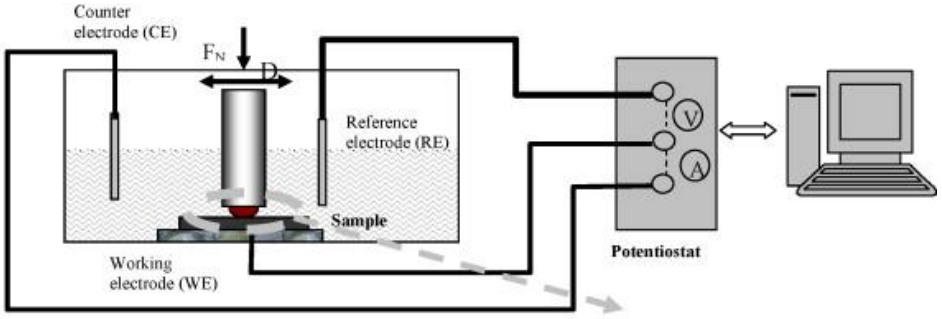
❖ Main mudules

Tribocorrosion module

Tribo-corrosion module is characterized the materials/systems working under the combined effects of mechanical wear and corrosion. It is indispensable for evaluation of systems like pipes, pumps, fuel cells, batteries, biomedical and marine products and any material exposed to wear in a corrosive environment.







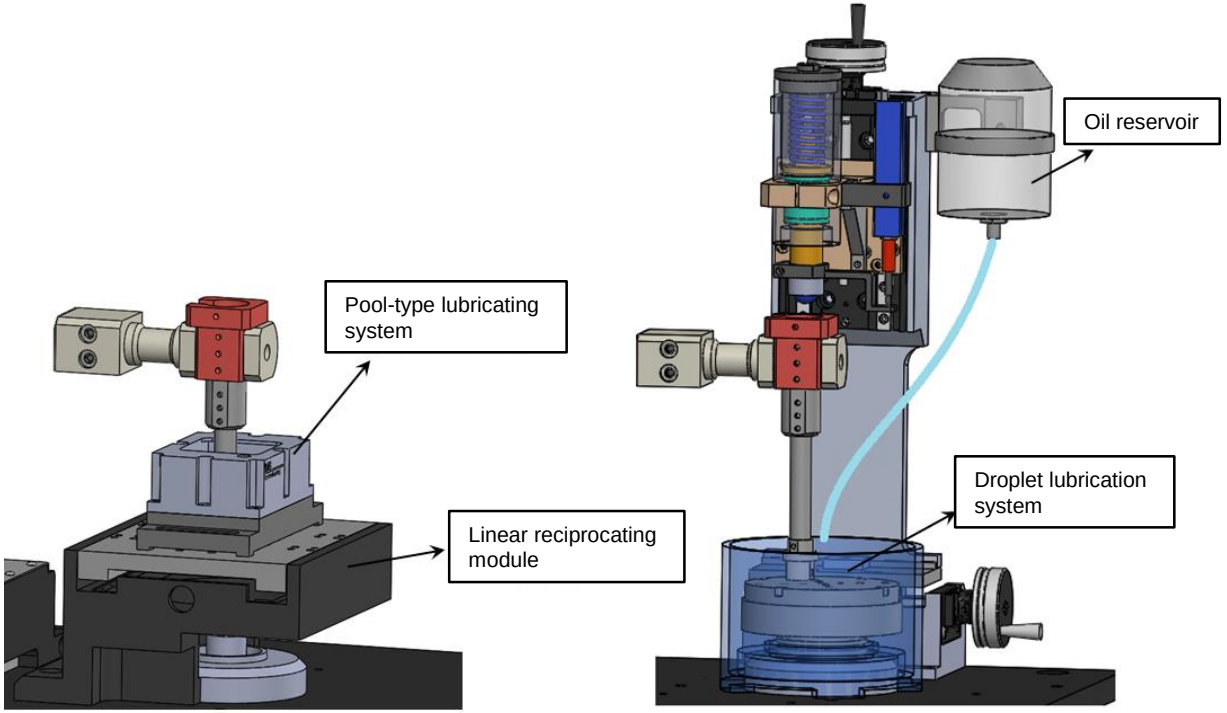
Tribocorrosion system
Contact zone- Tribology: Friction coefficients
Corrosion: Current or potential changes

Design of a new multifunctional tribometer

❖ Main mudule

Lubrication module

- It is well known that for many industrial applications, friction and wear behavior of materials or systems working in liquid or oily environments and their characterization are extremely important.
- This module can work with both rotary and reciprocating main motion modes.
- In the rotational movement type, experiments can be made in both oil pool and droplet feeding
- In the case of drop lubrication, the oil flow can be controlled with a precision valve while oil is being fed from the oil tank to the test medium.
- In the case of linear reciprocating motion, friction-wear tests can only be carried out in the

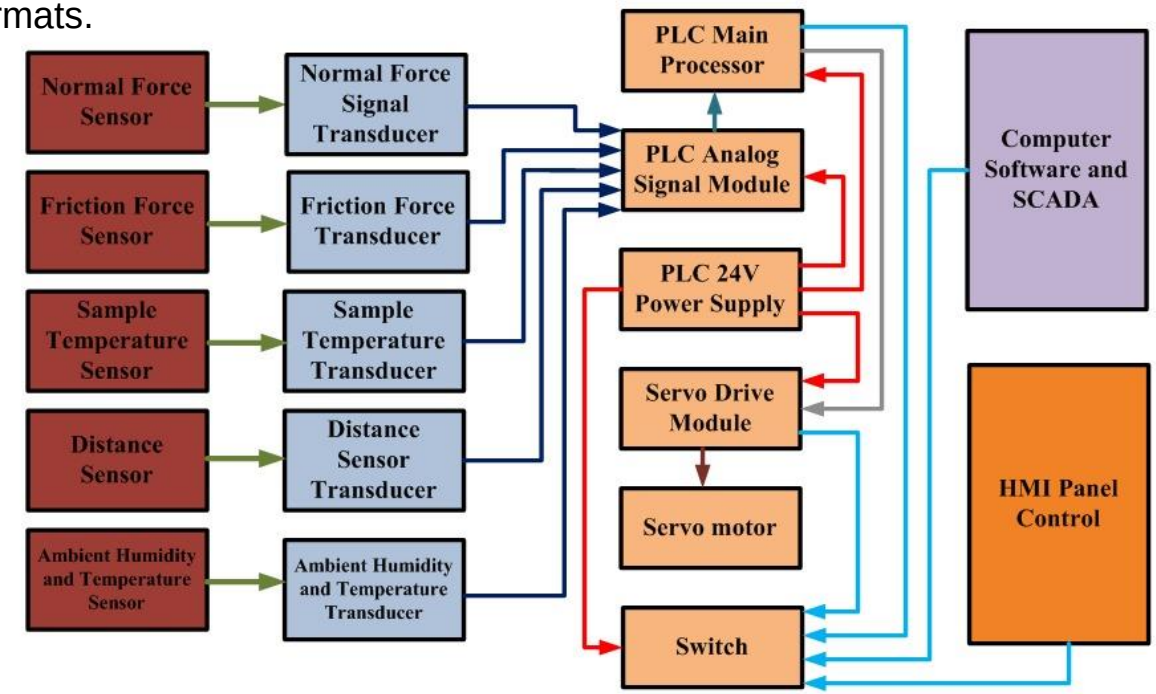


Design of a new multifunctional tribometer

❖ Software and control of the tribometer

A special software was developed for this multifunctional tribometer. This software has four parts: Machine control, data acquisition, analysis and display.

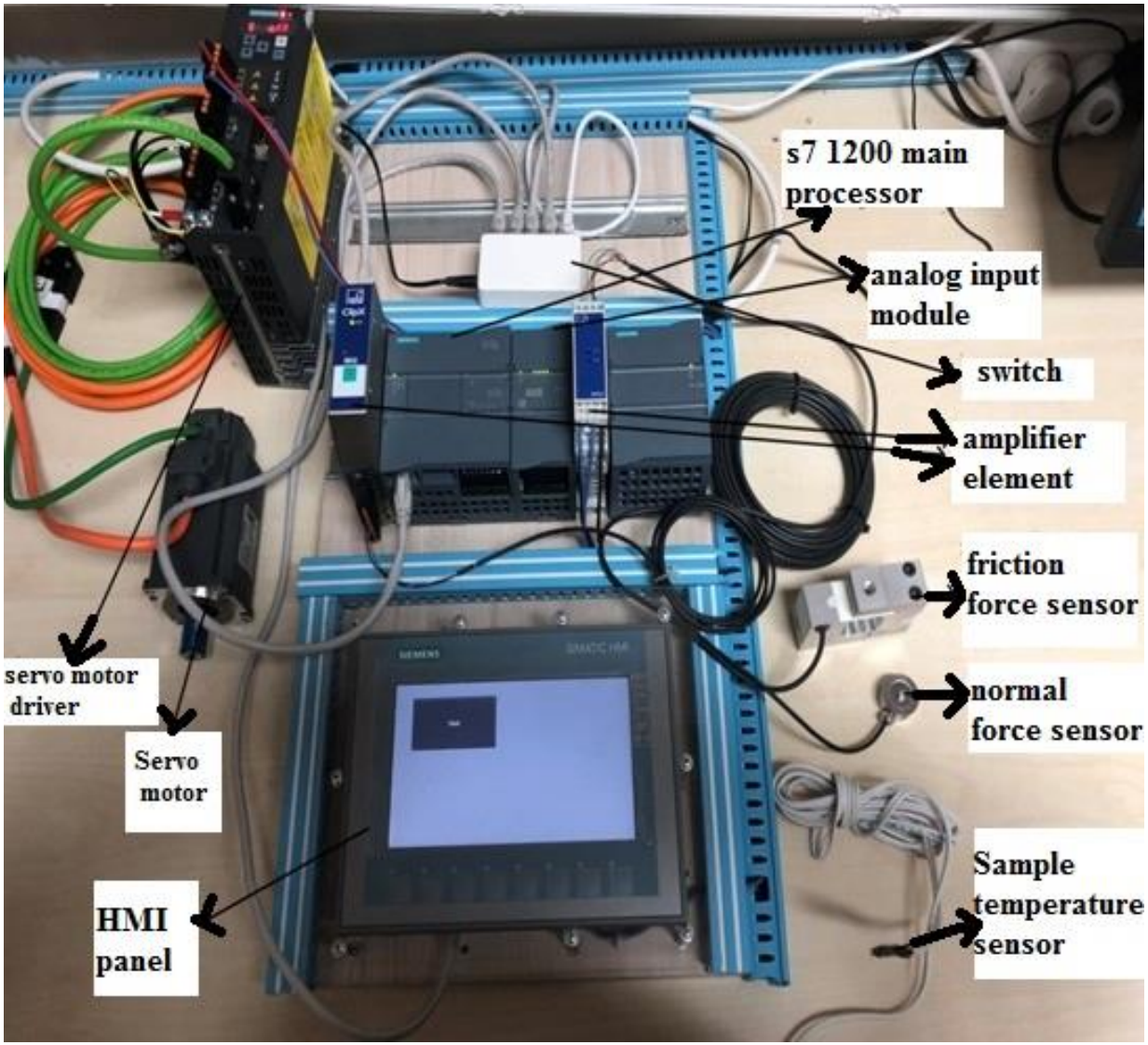
- Real time display of friction coefficient, temperature,
- Easy setup of all the test parameters including rotational speed, frequency, number of laps, threshold coefficient of friction, temperature and time.
- Automatic calculation of mean coefficient of friction, standard deviation and maximum/minimum values from selected parts.
- Two user channels are available for simultaneous display of additional data such as temperature and humidity.
- Data export in other graphical formats.



Design of a new multifunctional tribometer

Software and control of the tribometer

Electronic hardware



Design of a new multifunctional tribometer

Software and control of the tribometer

Electronic hardware

Servo drive motor and controller

CPU

HMI Panel

Power source

Analog input module

Measuring Units

Sürtünme Kuvveti Ölçüm Sensörü

Normal Kuvveti Ölçüm Sensörü

Friction force and normal force loading sensors

Amplifier

Sensitive level measurement sensor

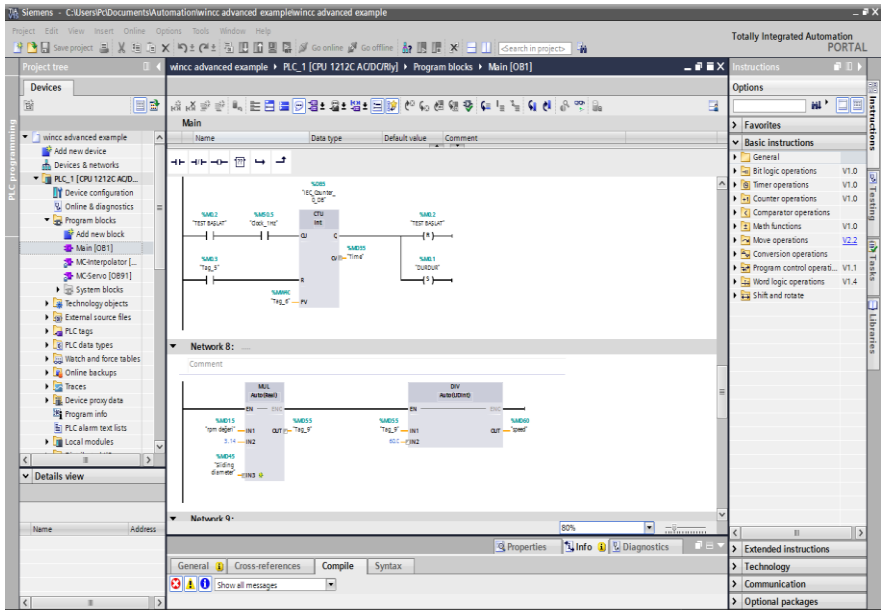
Humidity and temperature sensor

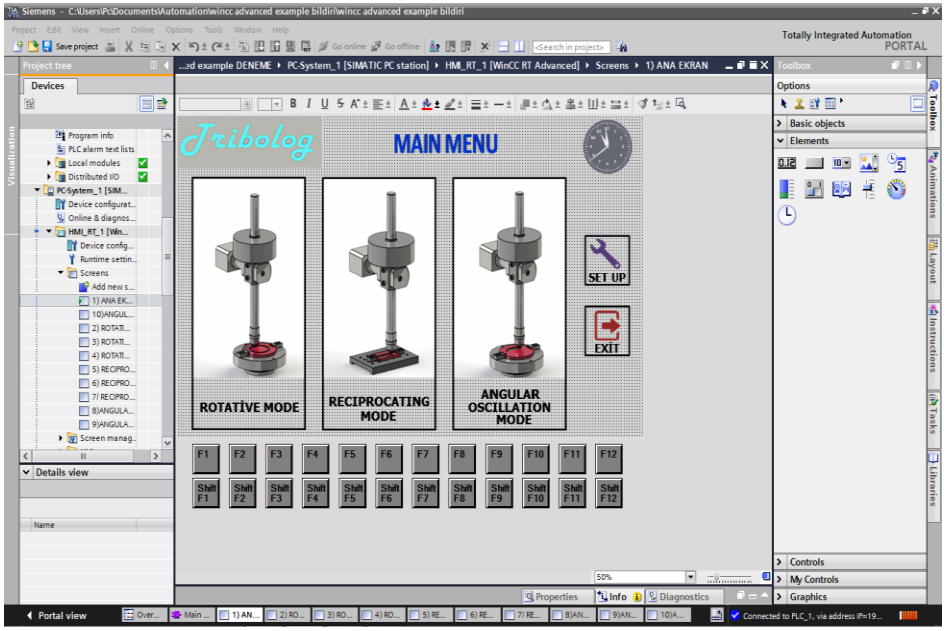
PID sensore

Design of a new multifunctional tribometer

Software and control of the tribometer

Electronic Software



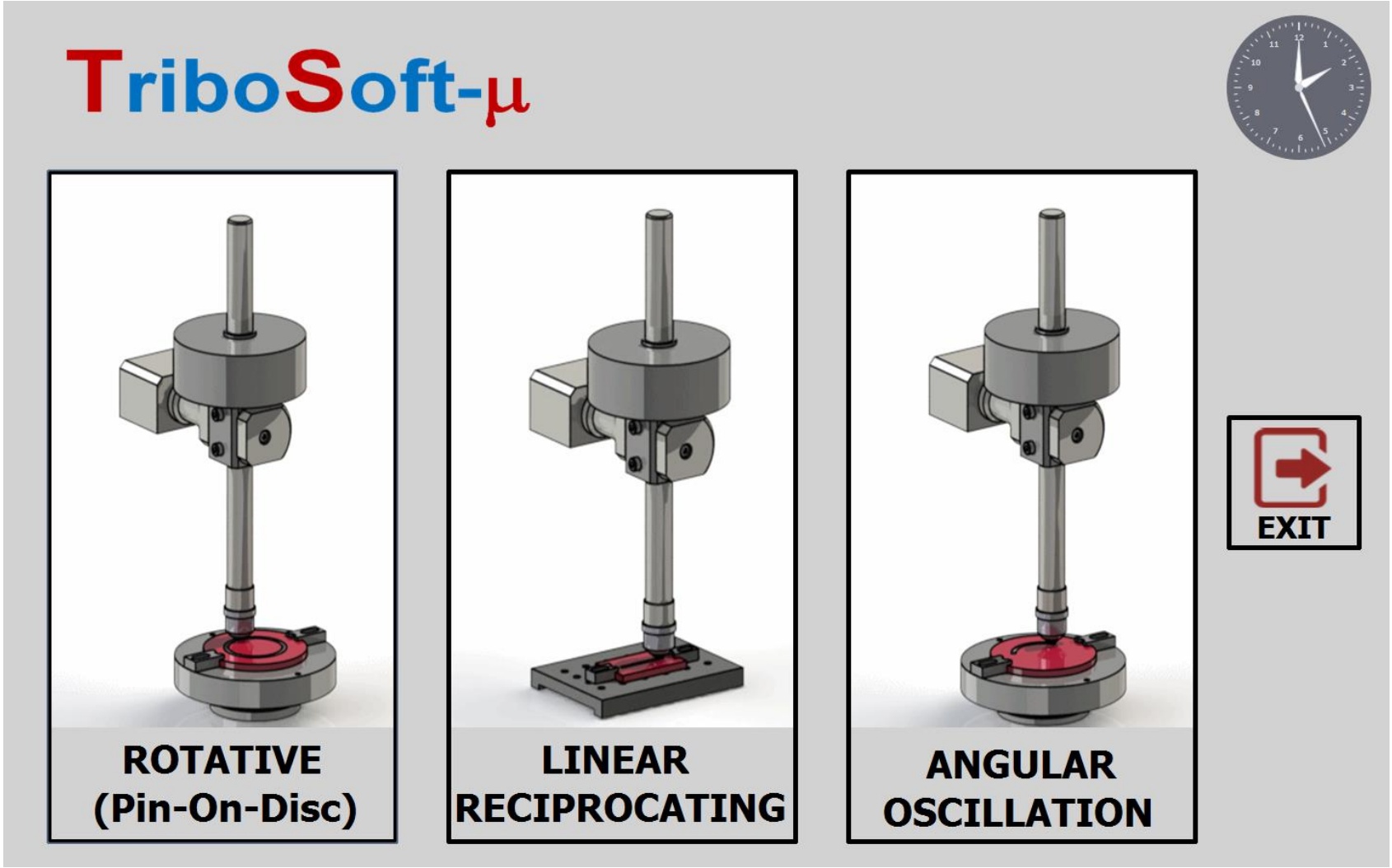


Development of system software

Design of a new multifunctional tribometer

Software and control of the tribometer

Electronic Software

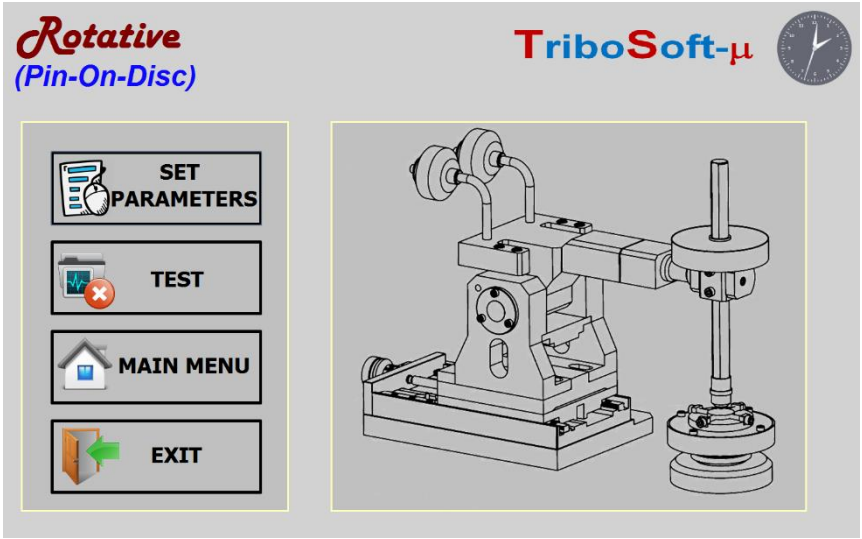


Interface screen main entry window

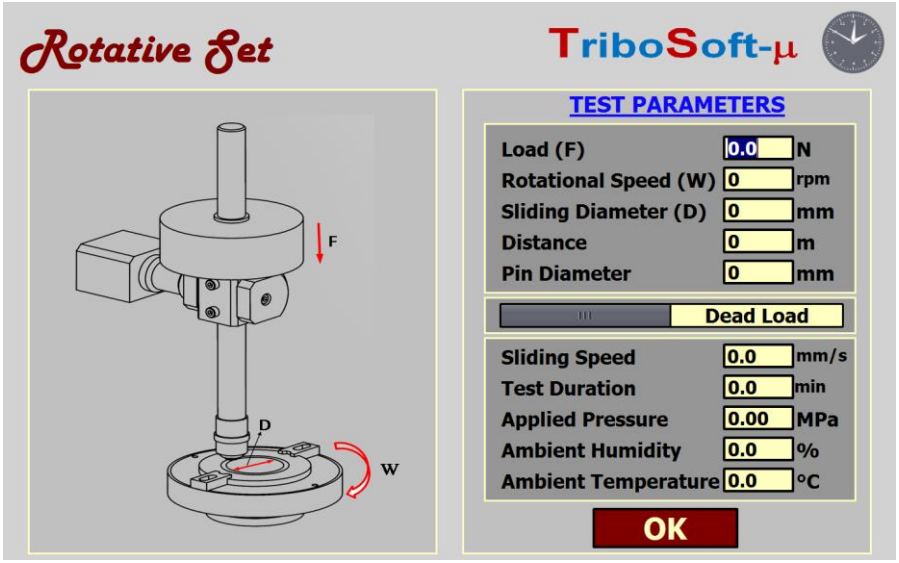
Design of a new multifunctional tribometer

Software and control of the tribometer

Electronic Software



Rotative motion mode input interface

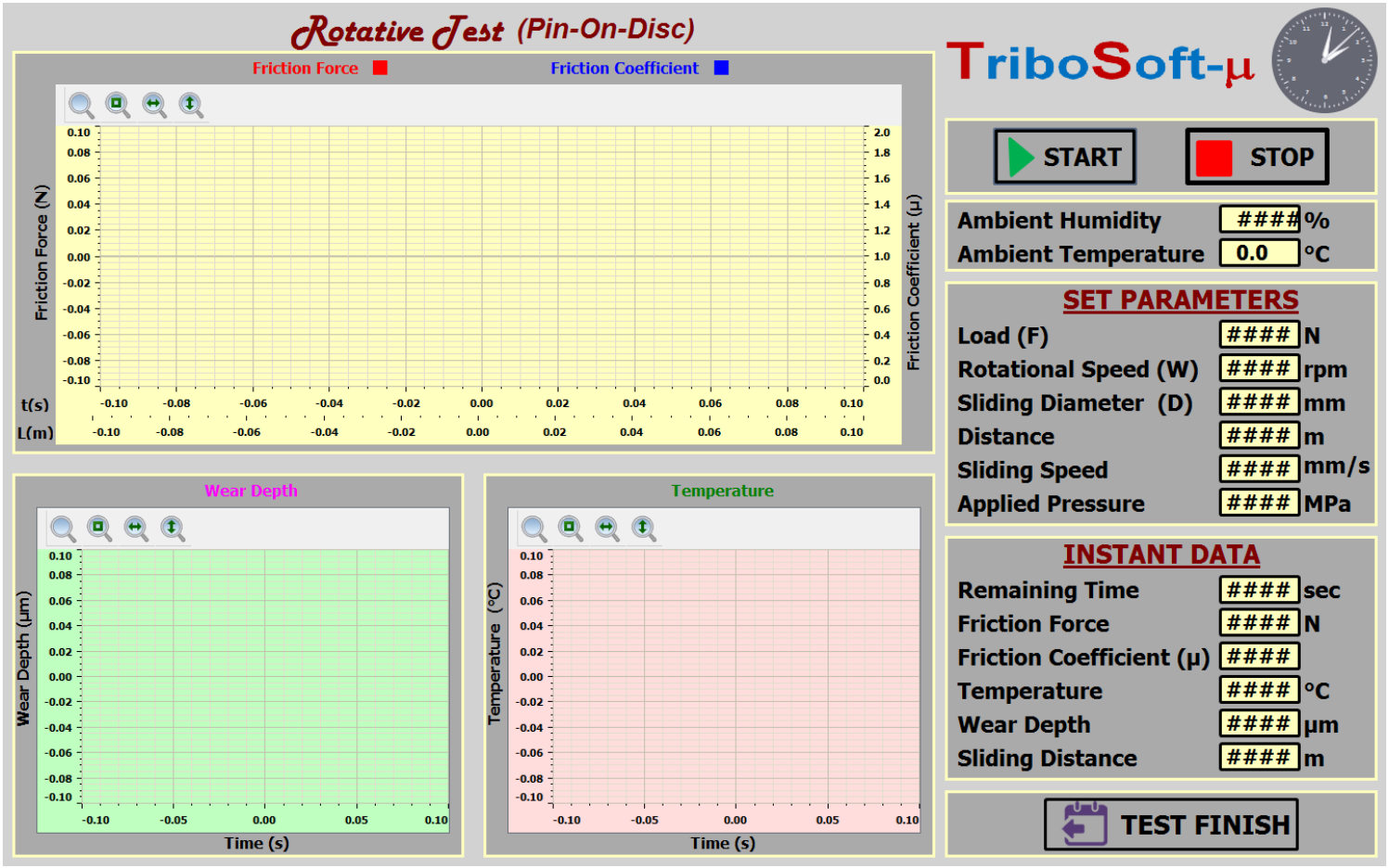


Interface screen to enter the set parameters in rotative motion mode.

Design of a new multifunctional tribometer

Software and control of the tribometer

Electronic Software



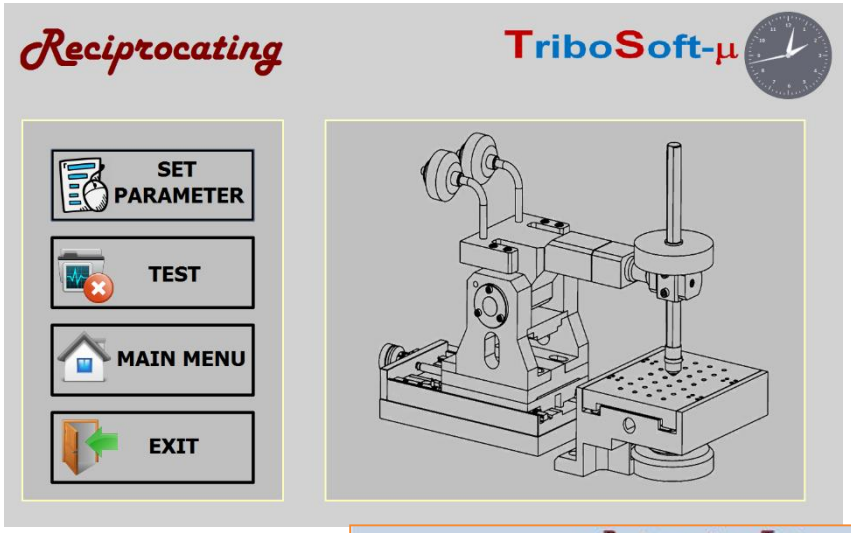
Test Screen

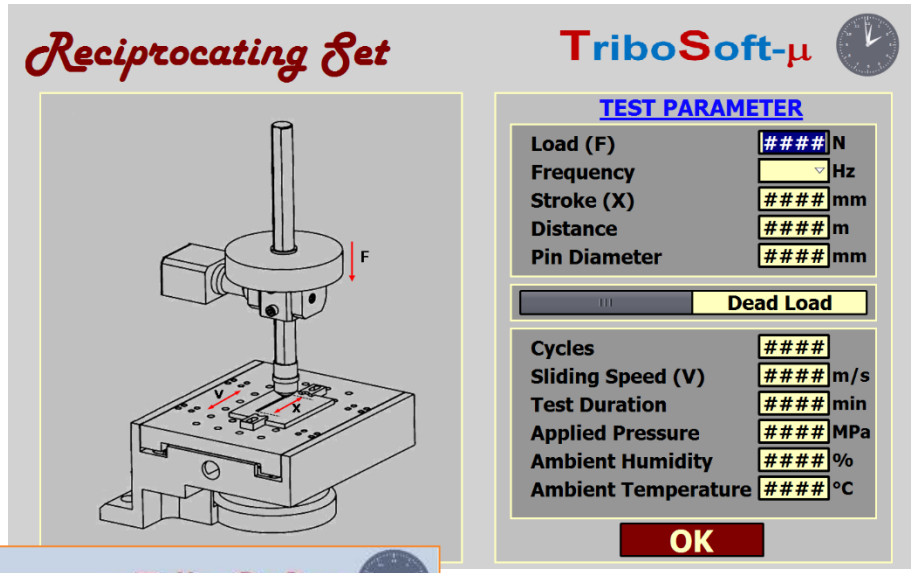
Display of the interface screen created for Rotative motion mode

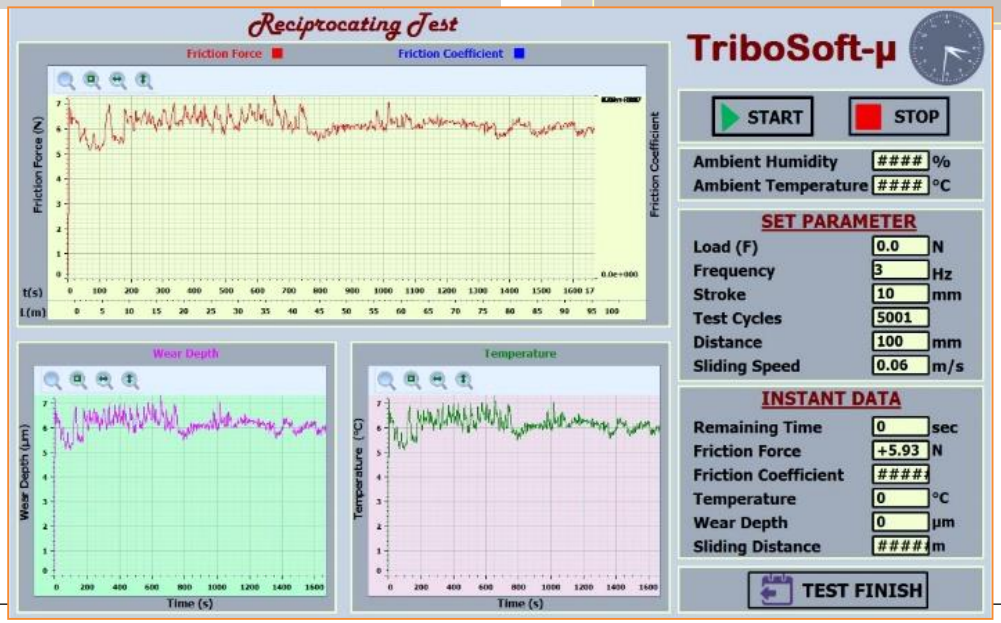
Design of a new multifunctional tribometer

Software and control of the tribometer

Electronic Software – Reciprocating mode



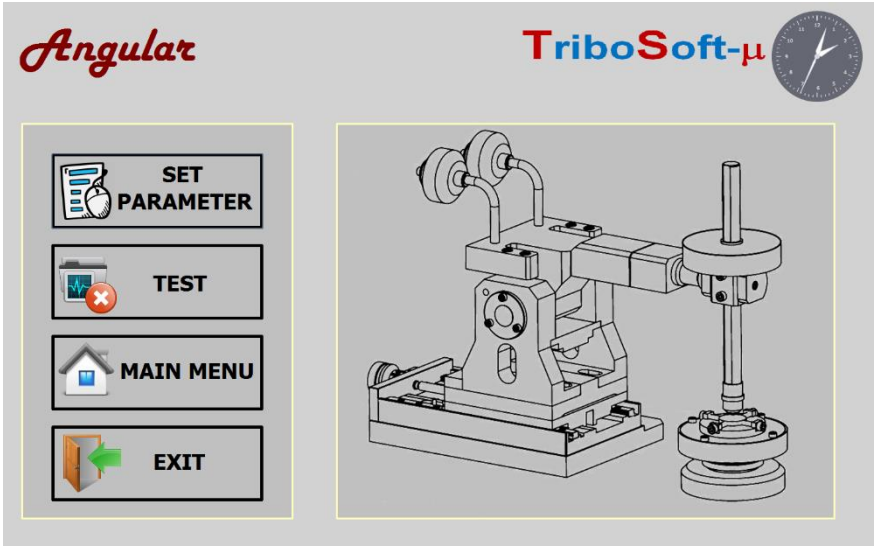


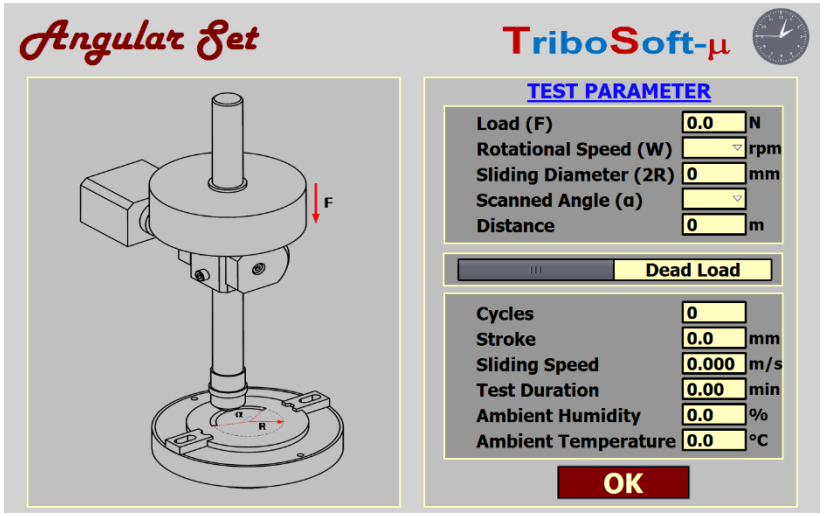


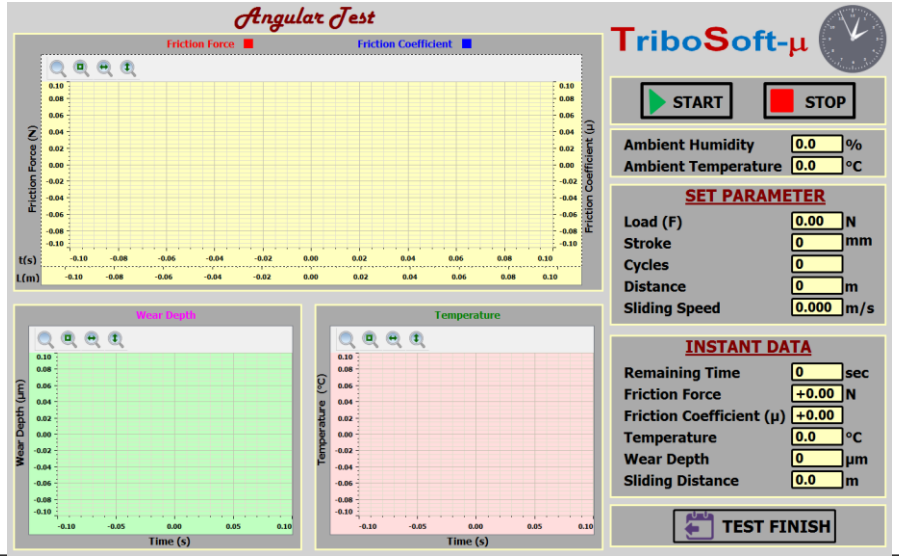
Design of a new multifunctional tribometer

Software and control of the tribometer

Electronic Software – Angular Oscillation Mode







A Case Study

Effect of testing temperature on tribological properties of a Cu-Cr-Zr alloy in different microstructural conditions

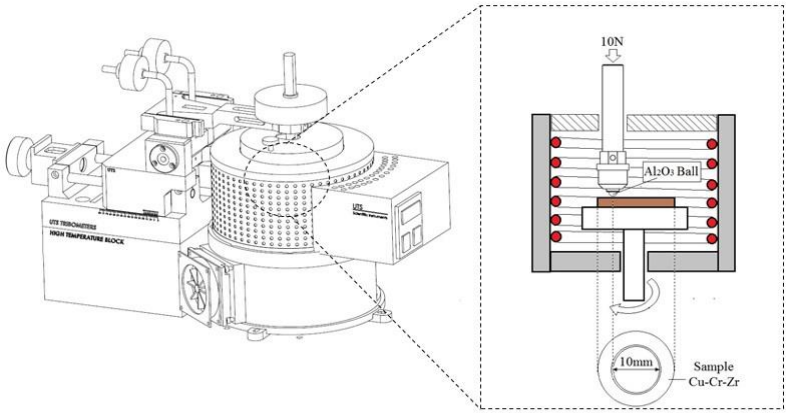
Materials and processing

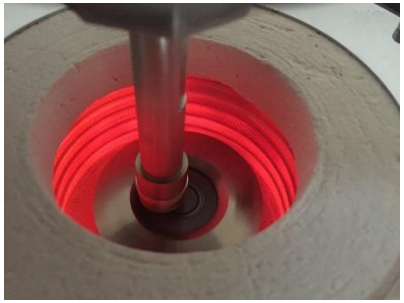
•Cu-0.7%Cr-0.07%Zr alloy was subjected to four different processes:

- ❖*Process 1: Slotution treatment + Quenching*
- ❖*Process 2: Slotution treatment + Quenching + Aging for 1 h at 475 C*
- ❖*Process 3: Slotution treatment + Quenching + HPT*
- ❖*Process 4: Slotution treatment + Quenching + HPT + Aging for 1 h at 450 C*

Friction and Wear behavior

The wear tests were performed on all processed samples at temperatures between 20ºC - 400ºC using the pin-on-disc multifunctional tribometer (UTS TRIBOLOG) with a high temperature module





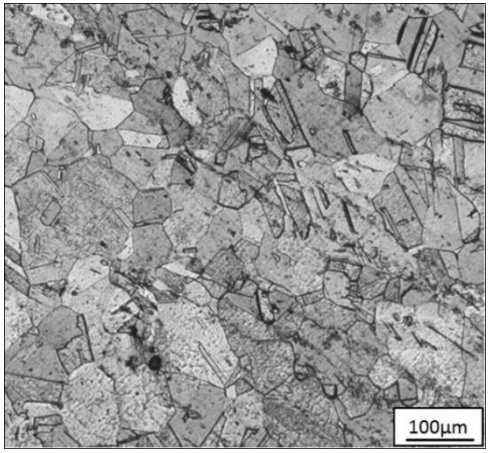
A Case Study

Friction and Wear behavior

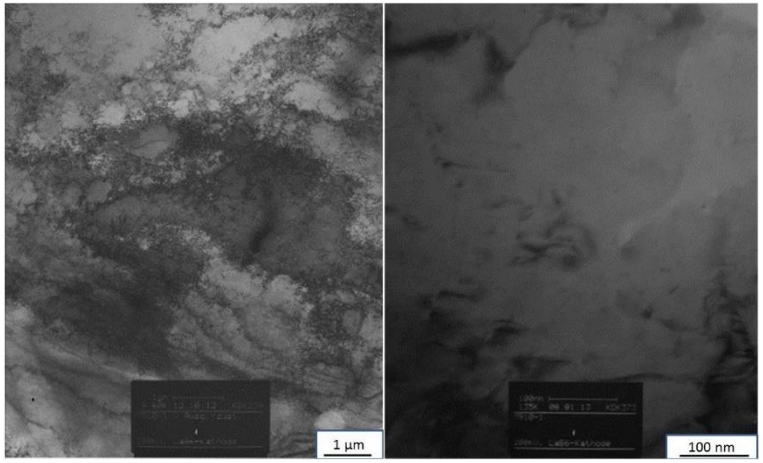
- A 6 mm diameter Al_2O_3 ball with the hardness of 2500 HV was used for the wear experiments.
- The applied load was chosen to be 10 N
- The wear tests were performed with a constant sliding speed of 0.2 $m.s^{-1}$ for a period of 45 min corresponding to a sliding distance of 400 m.
- For the measurements, the samples were cleaned before and after each test with acetone in an ultrasonic bath for 5 min and subsequently dried with hot air.
- The wear mechanisms were identified through the detailed analysis of the worn surfaces by means of scanning electron microscopy (SEM) and laser profilometer.

A Case Study

Microstructure



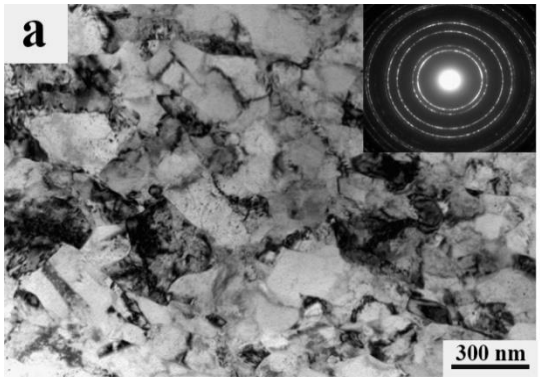
Quenched



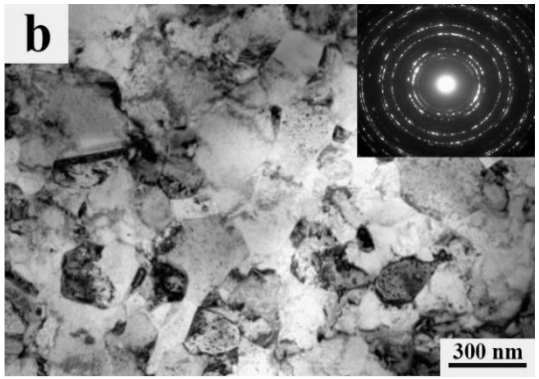
***Quenched** + Aged*

- Coarse grained microstructure,
- Inhomogeneous grain size distribution,
- Grain size ranges between 20 µm and 100 µm,
- Mean grain size is 50 µm.

- Aging didn't couse considerable change in grain size,
- Some precipitaes with 200-500 nm grain size formed.



HPT

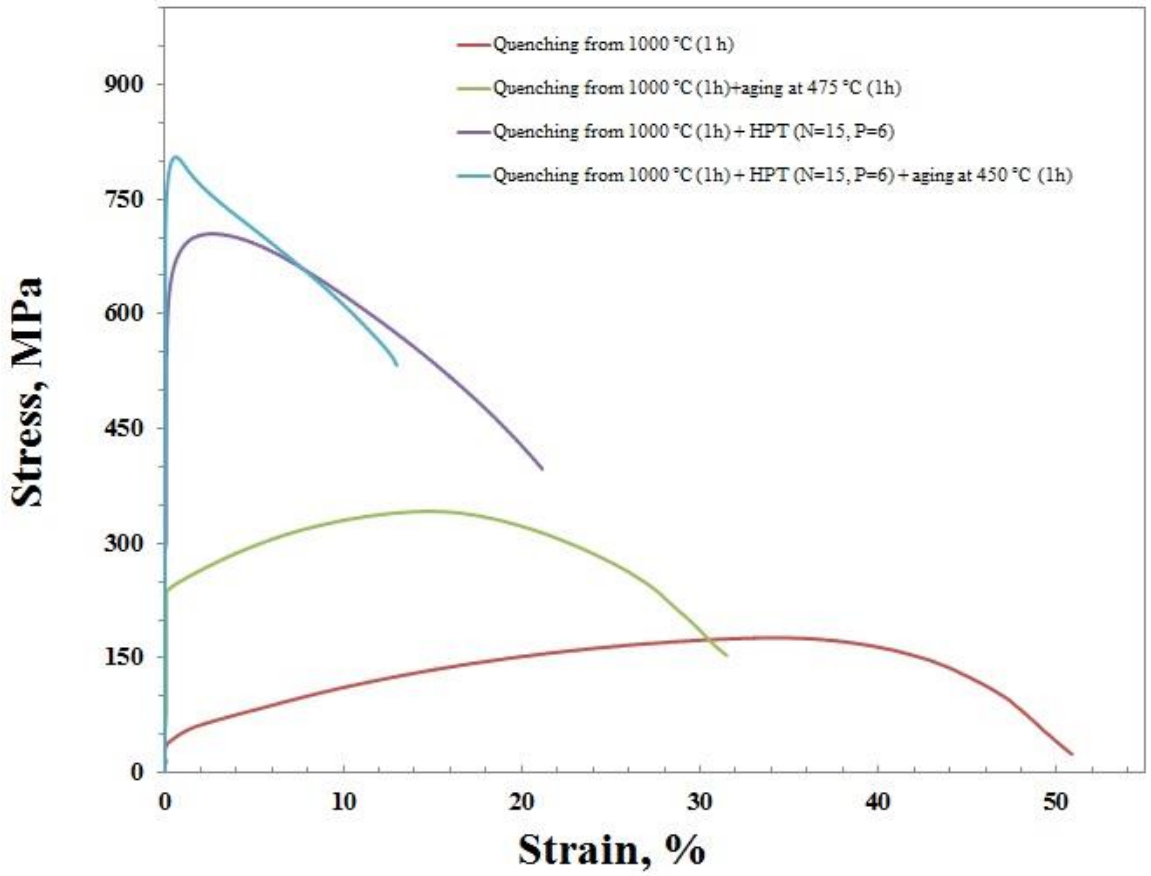


HPT + Aged

- Application of HPT caused UFG structure with an average grain/subgrain size of 155 nm
- Microstructure contains high density of dislocations.
- Some grain interiors are free of dislocations and most of the dislocations are accumulated and tangled with others around the grain boundaries.

- Aging at 450 °C for 1 hour leads to marginal increase in the average grain size up to 183 nm, while separation of bright spots in the SAED patterns indicates increase in the share of grains with high-angle boundaries.
- Also, no recrystallization is evident in the UFG microstructure.

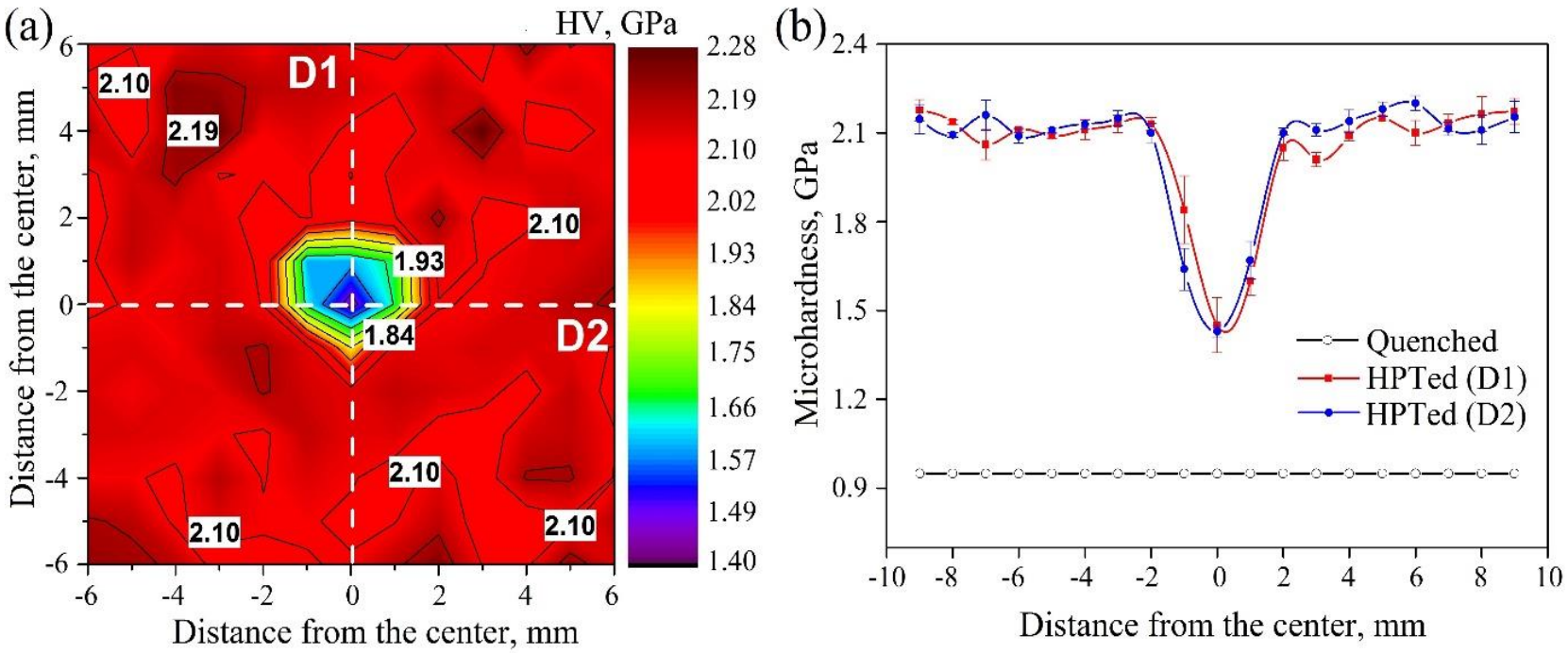
A Case Study



Treatment	YS, MPa	UTS, MPa	EL, %
Quenching from 1000 °C (1 h)	40	177	51,4
Quenching from 1000 °C (1h)+aging at 475 °C (1h)	240	342	31,9
Quenching from 1000 °C (1h) + HPT (N=15, P=6)	620	705	22,4
Quenching from 1000 °C (1h) + HPT (N=15, P=6) + aging at 450 °C (1h)	785	805	13

- The alloy in the initial state has sufficiently low strength properties with a total elongation of 51.4%.
- Aging causes some increase in the flow and tensile stress values of the alloy and decreases the elongation to failure.
- HPT increases strength (YS = 620 MPa and UTS = 705 MPa) with remaining of the total elongation to failure at a rather high level (22.4%).
- Subsequent aging of UFG alloy additionally improves strength values of HPT alloy, and drings about some decrease in elongation to failure.

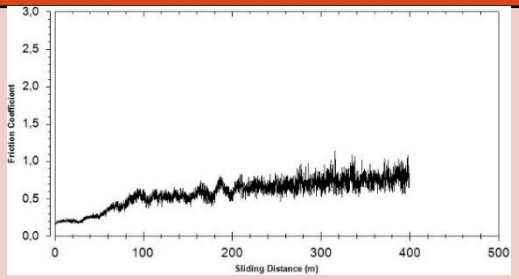
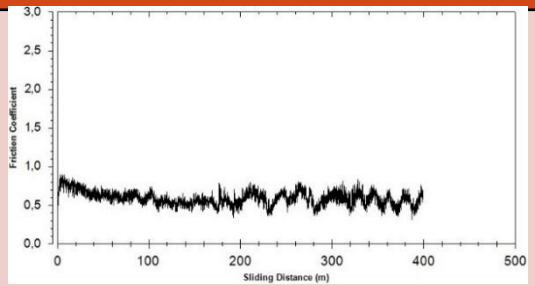
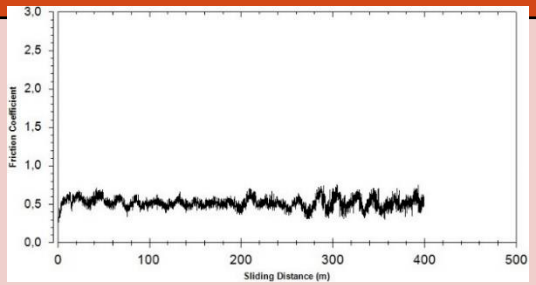
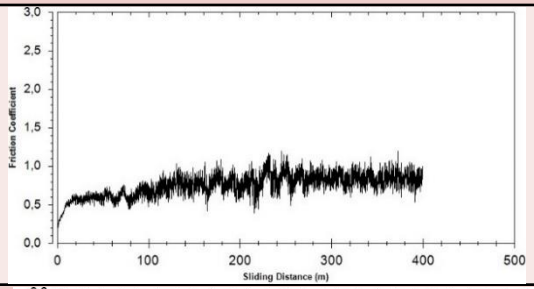
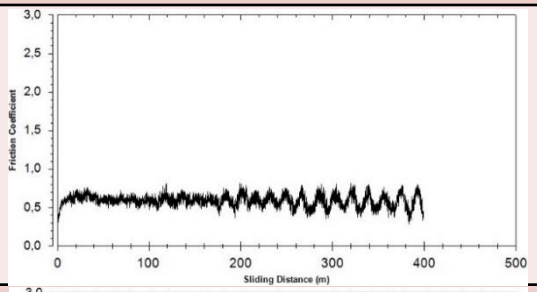
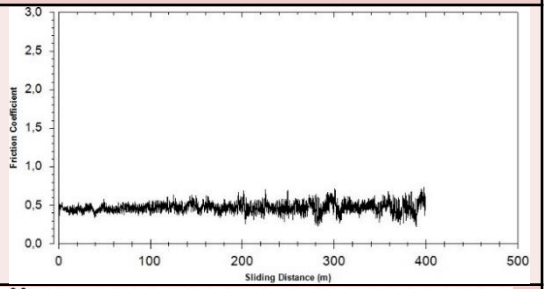
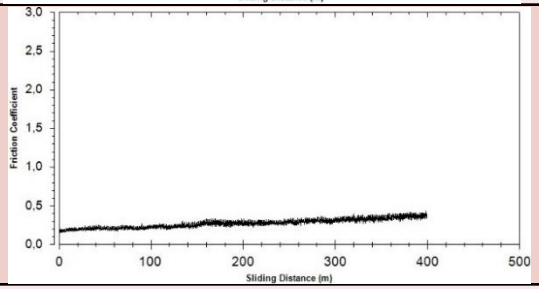
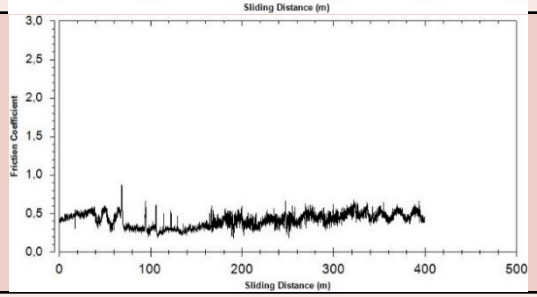
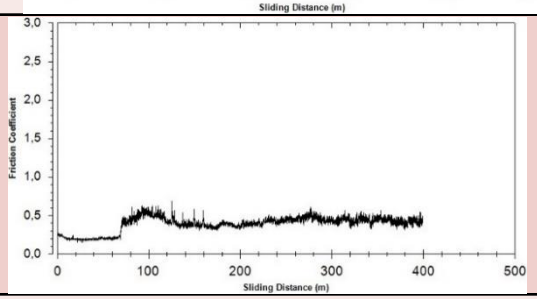
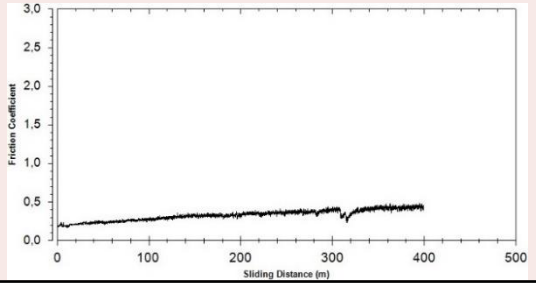
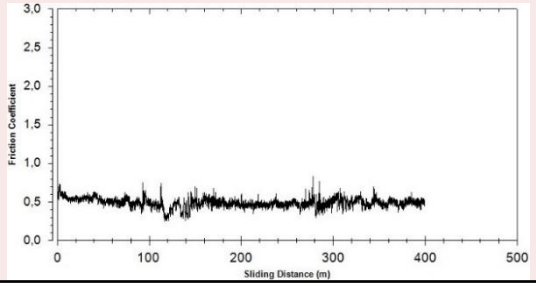
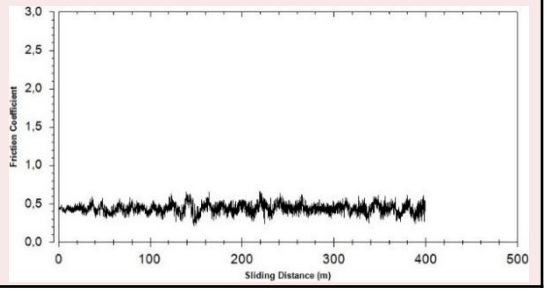
A Case Study



(a) Colour-coded contour map of microhardness value distribution throughout the HPT sample surfaces

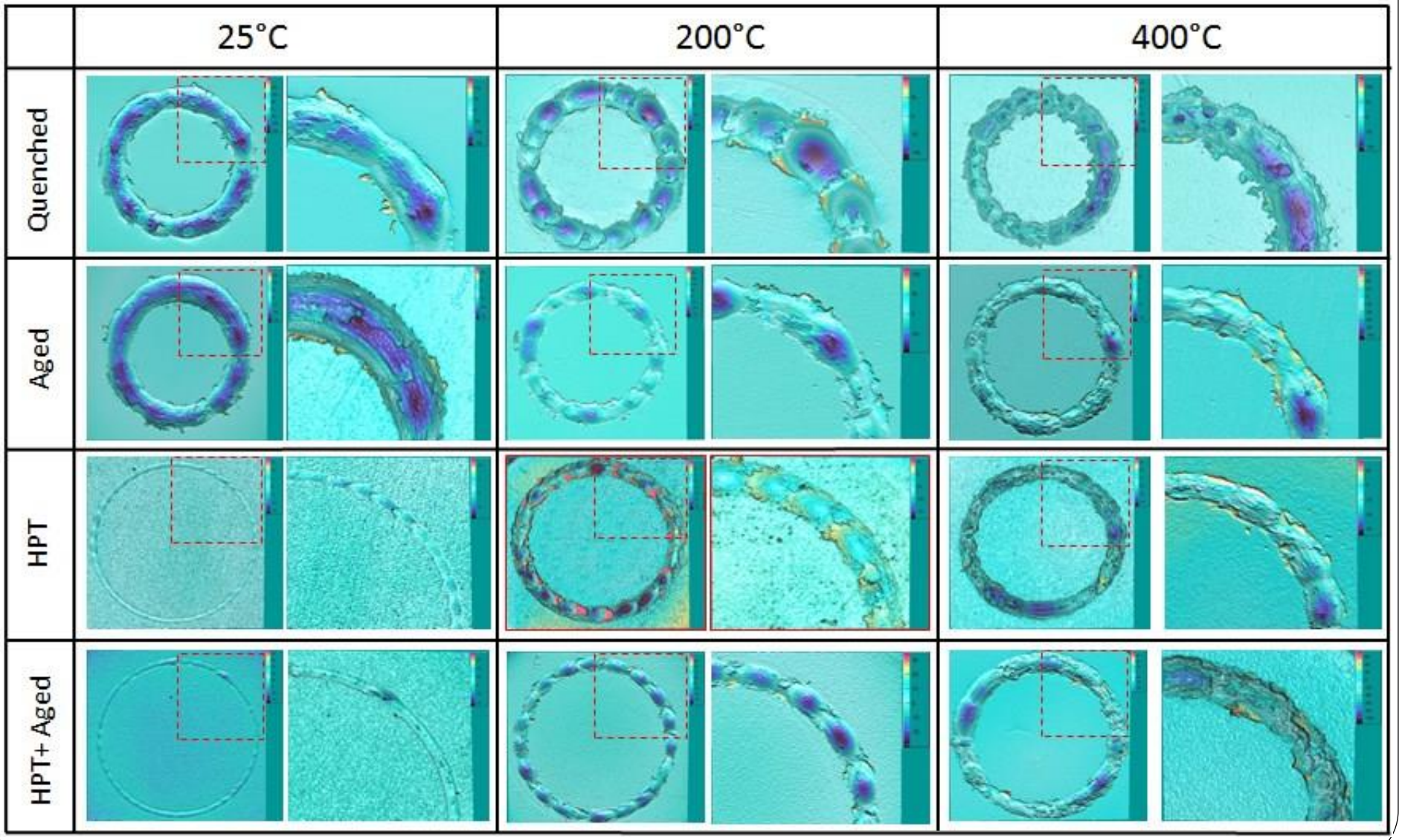
(b) The variation of average microhardness across mutually perpendicular diameters.

A Case Study

	25 °C	200 °C	400 °C
Quenched			
Aged			
HPT			
HPT + Aged			

A Case Study

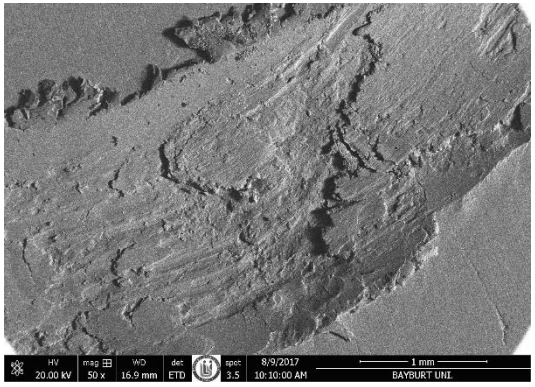
Wear behavior

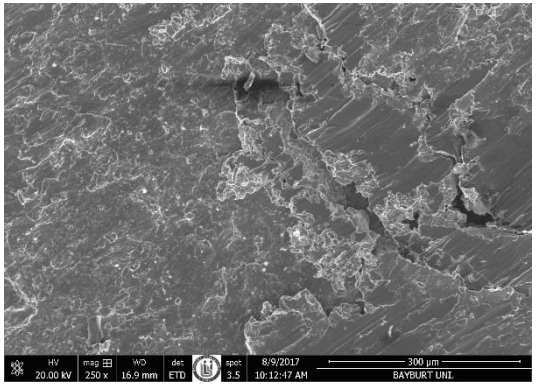


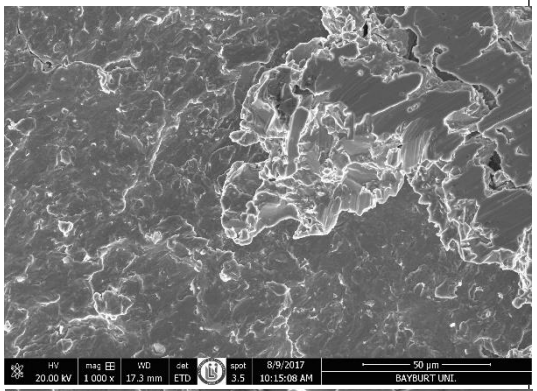
A Case Study

Wear behavior, Quenched

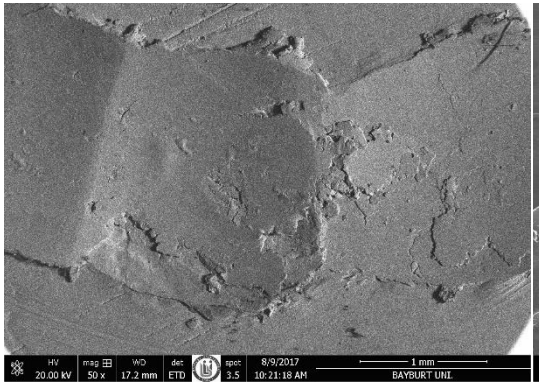
RT

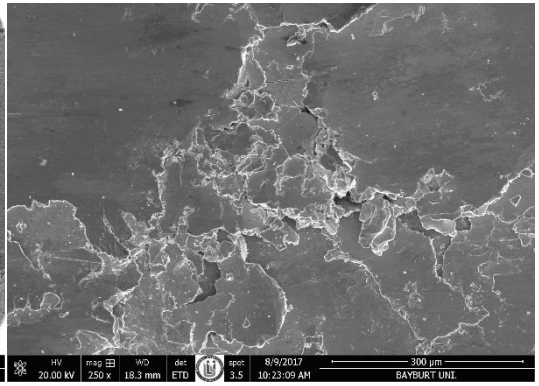


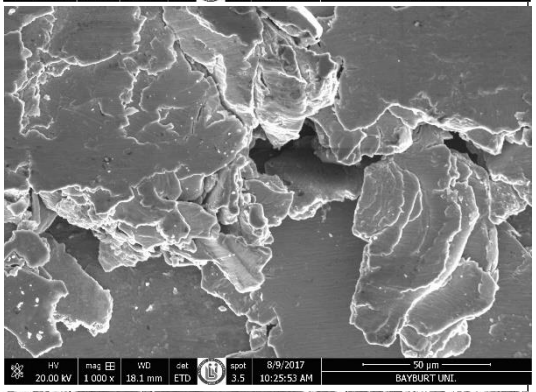




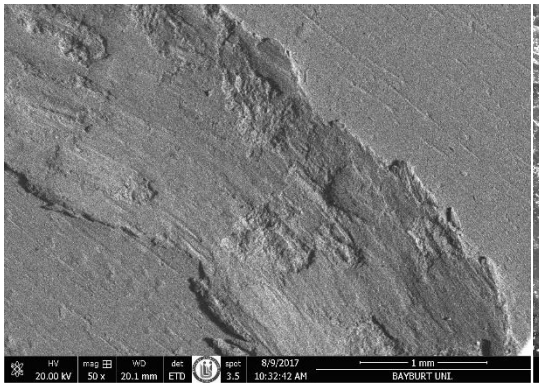
200 ºC

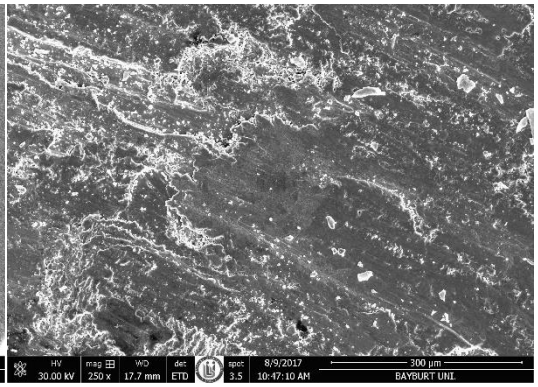


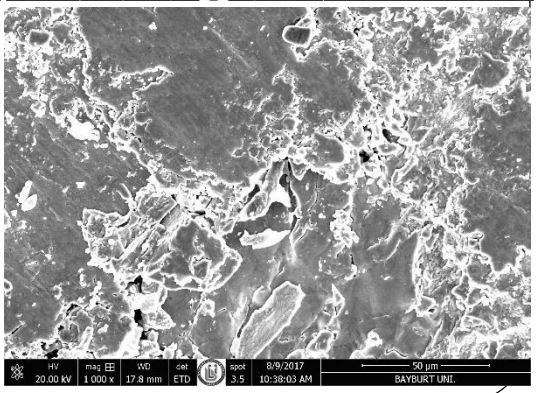




400 ºC



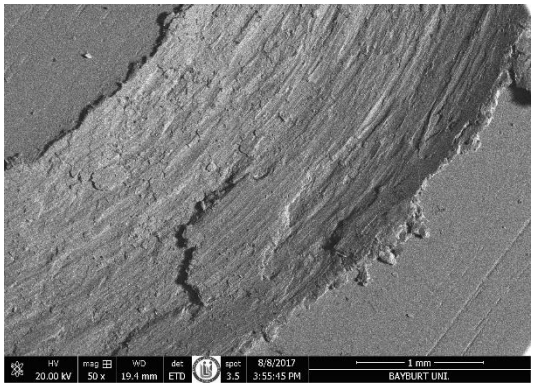


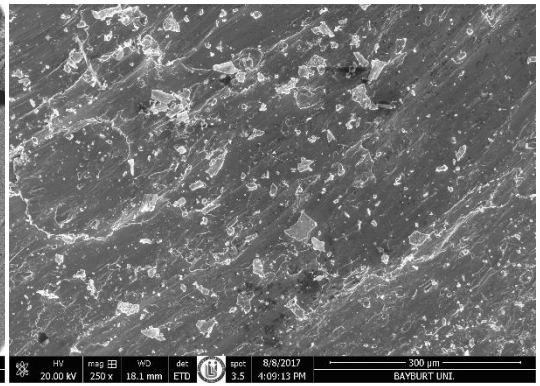


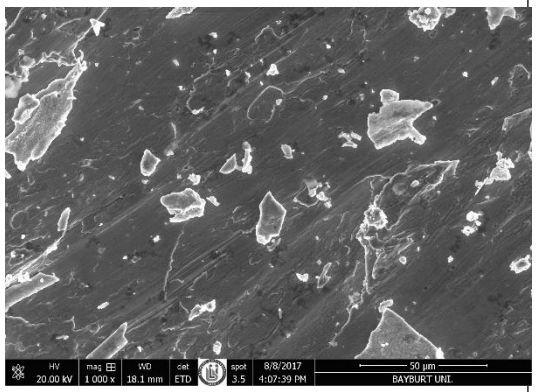
A Case Study

Wear behavior, Aged

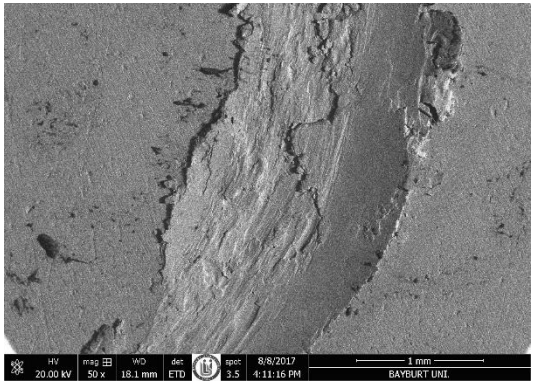
RT

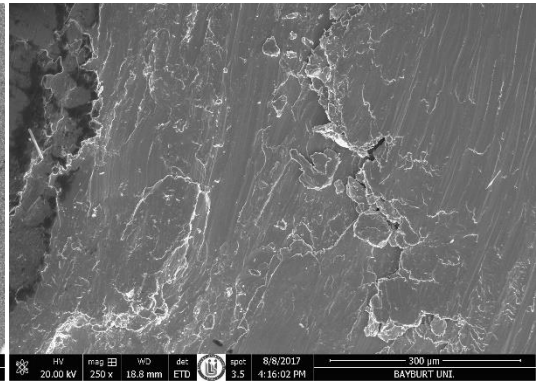


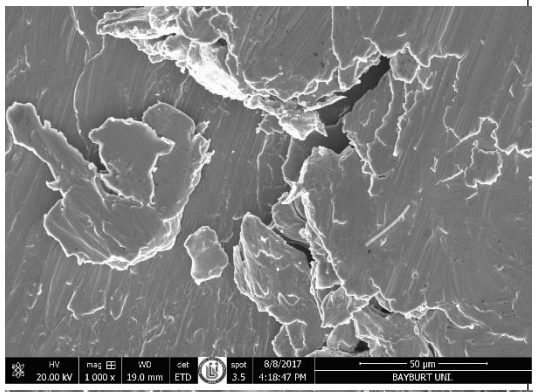




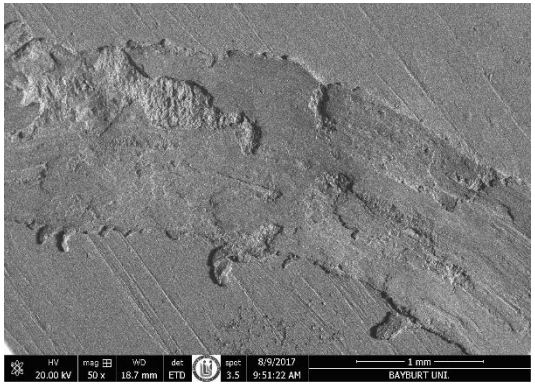
200 ºC

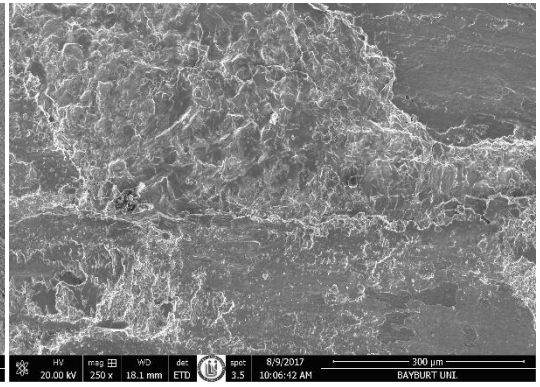


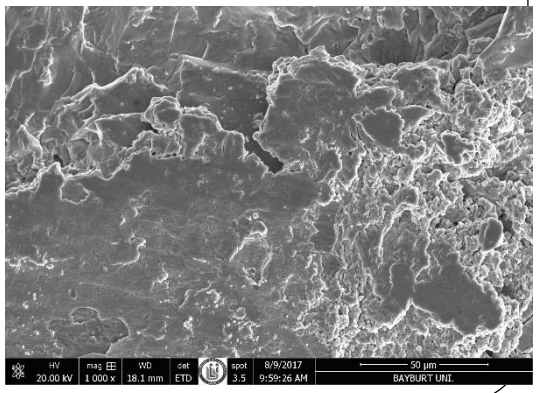




400 ºC



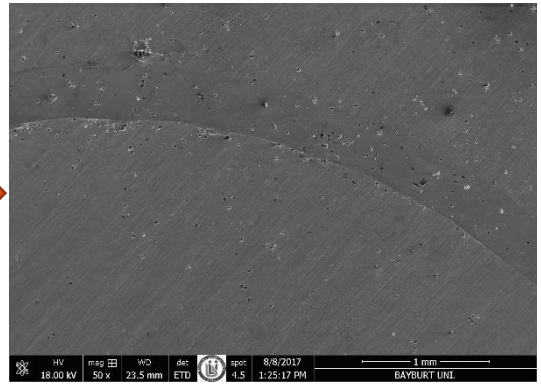


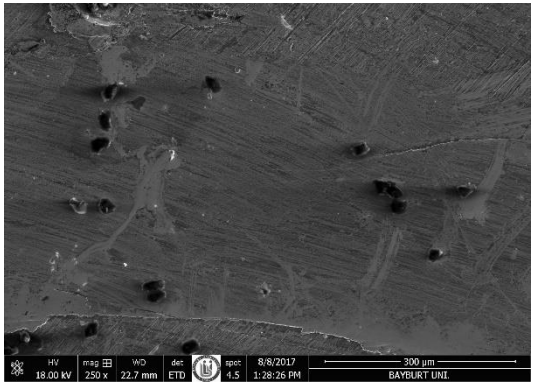


A Case Study

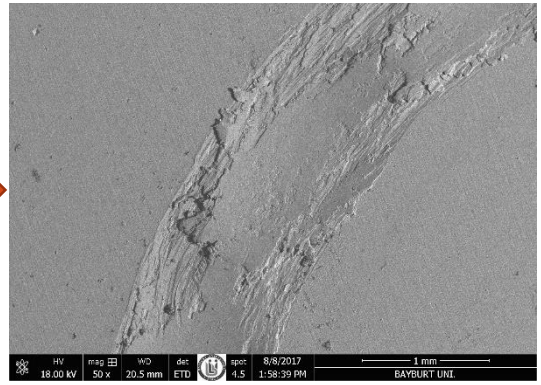
Wear behavior, HPT

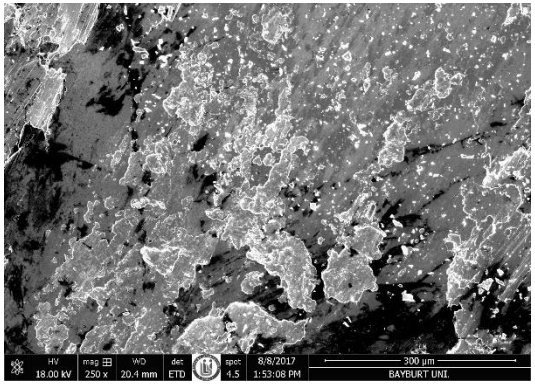
RT

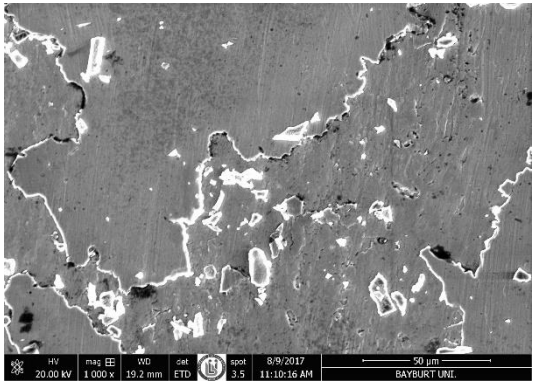




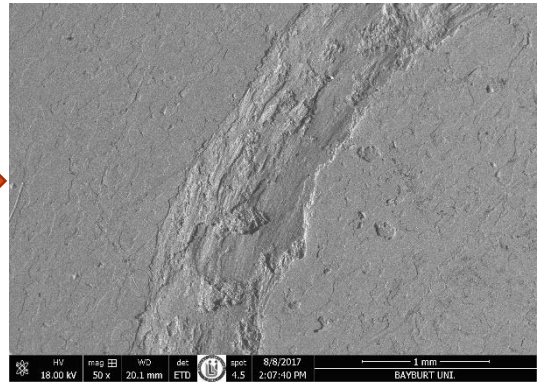
200 °C

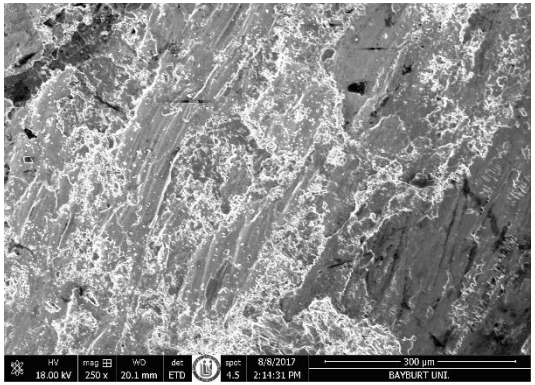


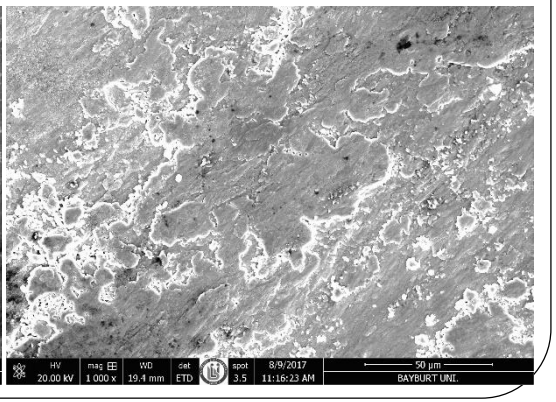




400 °C



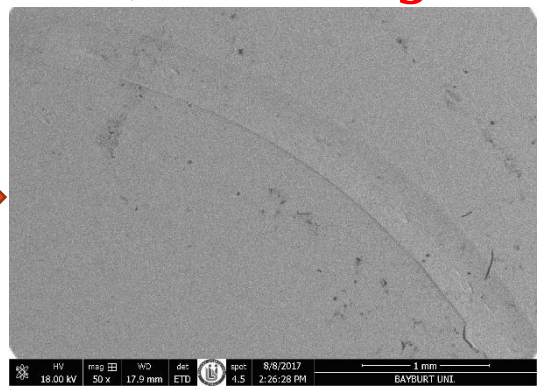


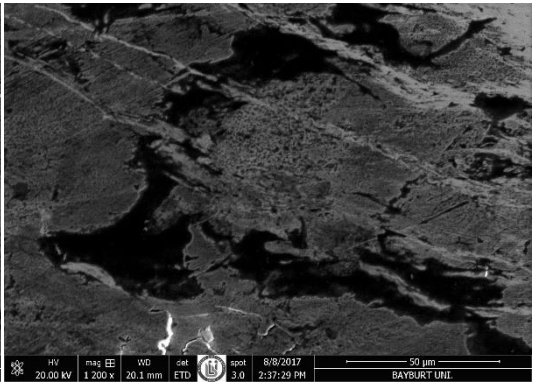


A Case Study

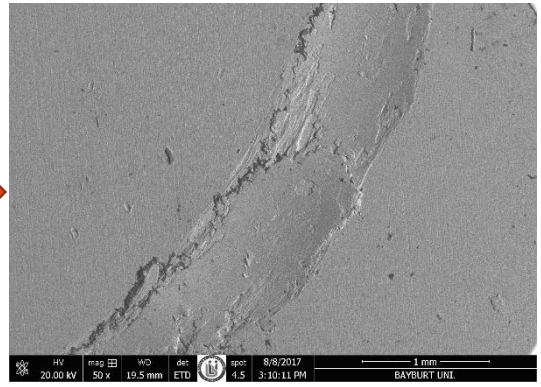
Wear behavior, HPT + Aged

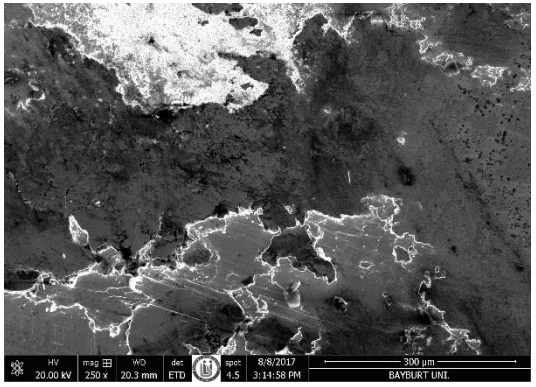
RT

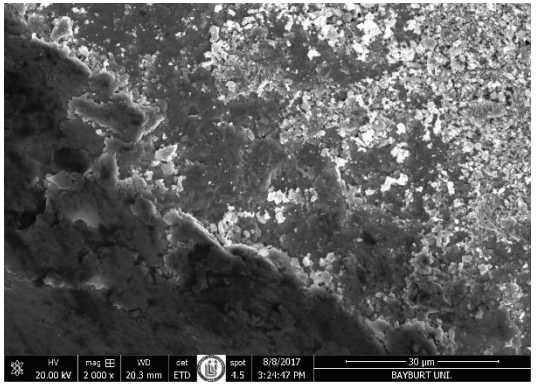




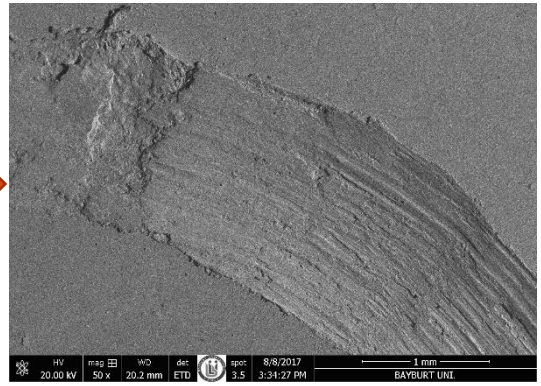
200 ºC

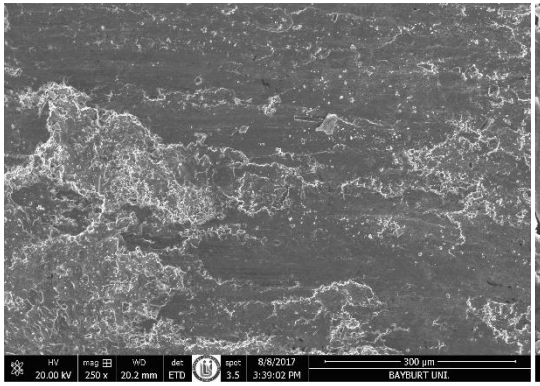


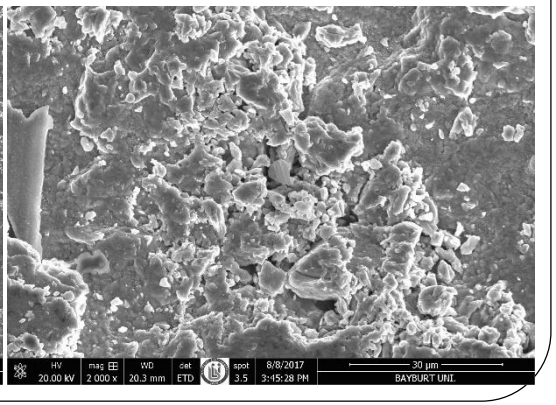




400 ºC







CONCLUSIONS

- Tribometer is a testing device which is used to measure tribological properties of materials or systems like friction force, wear rate and related phenomenon developed between surfaces in a relative motion.
- In this study, a new tribological test platform is presented concerning its design, modular concept, operative system and loading options. This multi-functional tribometer was designed to conduct various tribological tests in the same test platform by chancing the modules.
- Developed tribometer can work together with the modules of “pin-on-disc”, “linear reciprocating”, “block-on-ring”, “high temperature”, “tribo-corrosion”, “lubrication” and “piston ring on cylinder liner”.
- The test platform was also designed to be flexible, and new simulators or modules can be adapted added if they are needed.
- The system has four main motion types of rotary, reciprocating, block on ring and angular rotary.
- The innovative design aspects are suitable to allow for a variety of probes, sample surfaces, and testing conditions.
- A user friendly software was also developed to evaluate, control and digitalize the data coming from the sensors and other electronic parts during testing.
- As a Case study, the effect of temperature on tribological properties of coarse grained (CG) and ultrafine-grained (UFG) Cu-Cr-Zr alloy was investigated.
- At RT friction coefficients are higher in coarse grained samples comparing to UFG ones.
- In the coarse grained samples, friction coefficients decreased with increasing temperature. On the other hand, frition coefficients increase with the temperature in the UFG samples.
- At 400 C friction coefficients of all samples are almost equal to each other.
- In the quenched sample, both abrasive and adhesive wear mechanisms occurs at room tempetaure,while only adhesive wear is active at 200℃.
- In the aged sample, the system behaves like a three body abrasive system at RT. This sample shows both adhesive and abrasive wear mechanism at 200℃.
- At 400℃ oxidative and abrasive wear mechanisms are the main wear mechanisms in both quenched and aged samples.
- Almost any wear didnt occur at room temperature in HPT and HPT + aged samples.
- These samples show both oxidative and abrasive wear mechanisms at 200℃ and 400℃.

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