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Prototyping Low-Cost Tribometer with Block on Ring Configuration for the Optimization of Metal-Forming Applications

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"Prototyping a Low-cost Block-On-Ring Tribometer for Evaluating Metal-Working Materials"

Introduction:

Manufacturing processes for metal-mechanical applications are commonly subjected to diverse characteristics such as material deformation, tool wear and damage, lubricant usage, among others. These activities are reviewed periodically to counterattack those effects that consume time, money and reduce quality. These processes require tribological evaluations based on hypotheses and research questions. A research question was formulated based on developing an experimental setup that will enable testing with various metals and components that could be performed under controlled conditions, including the ability to apply testing with a fluid or lubricant media or in dry conditions. The evaluations should be conducted to measure friction and wear rate between materials. Also, these evaluations should consider temperature, humidity, and other critical conditions that could affect the results. The data collected should be analyzed to determine the effects of various metals and components on friction and wear. Finally, the results should be compared to theoretical predictions.

The engineering technology curriculum envisioned this project as part of experiential learning. The project team should discuss the results and draw conclusions based on the data. They should then present their findings and make recommendations to the appropriate stakeholders. Finally, they should demonstrate teamwork, proper scheduling and organization that ensures the success of the project. Teamwork, proper scheduling, and organization are crucial elements in ensuring the success of any project. By working together effectively, adhering to a well-planned schedule, and maintaining proper organization, the project team can streamline their efforts, minimize errors, and maximize efficiency, ultimately leading to the achievement of their goals and the delivery of high-quality results to the stakeholders. Also, document the process, results, and conclusions in a comprehensive report. Documenting the process, results, and conclusions in a comprehensive report is essential for several reasons. Firstly, it provides a record of the project's journey, allowing future teams to learn from successes and failures. Secondly, it serves as a reference document for stakeholders, ensuring transparency and accountability. Finally, it enables the project team to reflect on their work, identify areas for improvement, and apply lessons learned to future projects.

Research Background:

Tribology is the science and engineering of interacting surfaces in relative motion. Tribometer or tribotester is a generic name for a device which is used to simulate friction and wear at the interface between contact surfaces in relative motion under controlled conditions. The earliest reference provided by the dictionary is to the 1774 writings of Goldsmith, who used the word tribometer to mean a "measurer of friction."

The purpose of tribometers is to simulate real world frictional and wear applications without sacrificing material. Some others are:

- Simulate the tri-contact situation on a particular machine.
- Evaluate candidate bearing materials for a friction-critical application.
- Evaluate fluids and lubricants for a particular application.
- Qualify lubricants for use based on established criteria.
- Monitor surface contamination on a product.
- Investigate the fundamental nature of friction between solids or lubricated solids.

Alternative lubrication additives have become some of the industry's top sources to crack the code for longer lasting and more durable metal-forming applications. The prototype built in this project is more user-friendly and interactive for stakeholders and will be able to run tribological research experiments on various metals with the ability to run cycles with or without lubricants.

What is a tribometer?

Tribometers, also known as devices, that measure friction and wear, are mostly used in industry for investigations and research on materials (base or working material and fluids or lubricants as well). Experimentation with various metals could be tested under controlled conditions including the ability to apply lubrication or non-lubricative additives. Consistent contact between surfaces causes friction and wear resulting in the loss of structural integrity of the material over time. Therefore, lubrication and design play an intricate role in improving the life of metals operating under various load conditions.

In this experiment, a Block-On-Ring prototype was tested on aluminum rings and steel specimens. Ultimately further validating that our prototype satisfies the necessary operating protocols under ASTM standards (ASTM D2714, ASTM G77).

Project Objective:

The College of Engineering and Computer Science (CECS) at The University of Texas Rio Grande Valley promotes cutting-edge research with international impact as a path to a better life, built on compassion, community, and technology, and foresee every performed activity as a promoter for economic prosperity and commitment to the global community. With an extensive selection of undergraduate programs in the engineering field, the Department of Informatics and Engineering provides a setting for technology development and applied research in the Engineering Technology (ENGT) program. According to the program description, engineering technology education emphasizes primarily on the applied aspects of science and product improvement, industrial practices, and engineering operational functions. A capstone two-semester senior project course is a part of the engineering technology curriculum. This course provides the students with an opportunity to address and experience the critical problems faced in the day-to-day life of an engineer in an advanced manufacturing industry. One such problem is to measure friction and wear rate between materials to improve the performance of mechanical machinery used in industrial applications.

The aim of this senior design project is to design and fabricate a working prototype for a block-on-ring tribometer at low cost. This tribology testing configuration is a widely used technique that evaluates the sliding wear behaviors of materials in different simulated conditions, allowing reliable ranking of material couples for specific tribological applications. The tribometer will be used to measure the friction and wear properties of materials' surfaces. The prototype should be simple to construct, reliable, and cost-effective. The ring tribometer should be able to measure a wide range of surface parameters. The project team should research the literature on similar projects, design the machine, fabricate, test, and then present the results to stakeholders. They should also document the process, results, and conclusions in detail to provide a complete picture of the project. Present and future stakeholders will have the ability to analyze material properties in friction, wear, and displacement while saving the university the costs of an industrial tribometer.

Design specifications:

The integrity of the machine must adhere to ASTM G-77 guidelines and be able to withstand a load force up to 76.5 N. The accuracy of the results must be within 10%. The machine should also be capable of measuring displacement. Operation must be able to perform under the specified load function while maintaining 72 rpm or more, depending on the setup arrangement proposed by the evaluation. The machine must also be capable of performing a test cycle in 30 seconds. The machine must also be capable of measuring displacement accurately. The operation must be reliable and repeatable. The machine will be housed in the Engineering Technology lab for easy accessibility and will also be on a cart for mobility options to different locations. The machine must be easy to maintain and troubleshoot. It must also be capable of adjusting to ensure optimal performance. The machine should also be able to operate safely. This block-on-ring configuration allows the evaluation of flat blocks or conformal mode contact pair. The evaluation consists of a stationary block subjected to a constant load of 150 N mounted on a ring. A constant angular speed of 250 rpm for 900 seconds was employed.

Project Description:

A senior design project was conceived with the idea to design and fabricate a low cost tribometer that will serve as an experimental platform for industry and in-house research on materials that require validation of tribological characteristics. The proposed budget to build and fabricate a working tribometer machine is around $3500. Present and future key stakeholders will have the ability to analyze properties in friction, wear, and displacement while saving the university over 500% in costs of an industrial tribometer. The integrity of the machine must adhere to ASTM guidelines for a Block-On-Ring configuration and be able to withstand a load force up to 76.5 N. Operation must be able to perform under the specified load function while maintaining 250 rpms. The machine will be housed in an engineering technology lab for easy accessibility and will also be on a cart for mobility options to different locations.

Design of experiments:

Consistent contact between surfaces causes friction and wear resulting in the loss of structural integrity of the material over time. Therefore, lubrication and design play an intricate role in improving the life of metals operating under various load conditions. To explore friction and wear under various conditions (metals, lubricity, etc.), a prototype tribometer was built that was low-cost, user-friendly, and interactive. In this study, specimens taken from steel and aluminum-based metal samples were tested in a block-on-ring prototype for wear performance over various parameters including number of revolutions and time. Specimens also underwent tests with lubrication additives to further validate the life extent of metals under certain forces.

Experiments were conducted with block-on-ring prototypes on aluminum rings and steel specimens. The tribometer prototype was validated and satisfied the necessary operating protocols under ASTM standards (ASTM D2714, ASTM G77). This project was successfully completed by students from the Engineering Technology program at (XXX).

Prototype of a low-cost tribometer:

The prototype was designed with a power rating of 1.5 HP DC motor and can output RPMs as listed in the ASTM standard to withstand loads of up to 68kg.

The following research data can be obtained from the machine:

- Coefficient of friction
- Displacement

The test capabilities of the machine are listed as follows:

- Regulate RPMs.
- Tune applied load via PWM Controller.
- Distinguish the load amount.
- Run tests by counter.
- Ability to run tests by number of cycles.

Design Methodology:

The prototype of a tribometer was designed within ASTM Standards (ASTM D2714-94, ASTM E122-17). The machine could utilize both lubricant and non-lubricant substances for testing block-on-ring configuration.

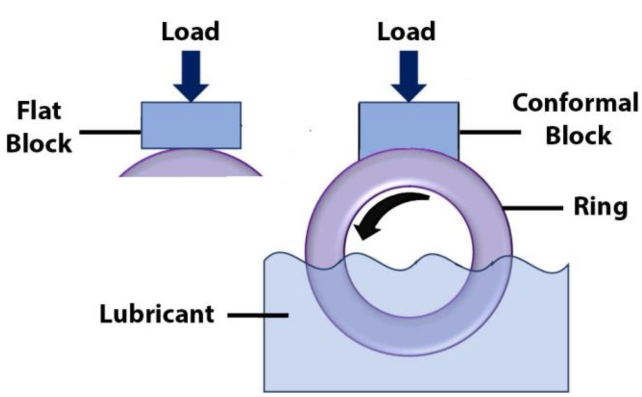


Figure 1. A Block-on-ring testing arrangement

The prototype is operated using a steel test ring rotating against a steel block (Figure 1). (immersed/not in lubricant) Velocity of test ring is 7.9 m/min = spindle speed of 250 rpm. Specimens were subjected to 68 kg normal load applied to 6.8 kg of dead weight on a 10:1 ratio lever system. Test duration is 5000 cycles.

Testing parameters:

- The friction force after a certain number of revolutions
- The average width of the wear scar on the stationary block at the end of the test
- The weight loss of the stationary block at the end of the test.

Experiments:

Three block-on-ring tests were carried out and data was collected. Each of the test cycles was run at 250 RPMs while recording samples at 300, 600, 1200, and 5000 revolutions.

The following parameters were revised to ensure safe operating condition of the machine before conducting experiments.

1. Check the accuracy and integrity of the machine.

2. Verify that all sensors are working and implemented.

3. Make sure the machine is operable in safe working conditions including the operator's personal safety.

Experimental conditions:

I. Specimen tests may or may not undergo a lubrication application.

II. Indoor operation with controlled temperature and humidity.

Test Formulation Model:

Block-on-ring tribotesters, operate under a specified load under which a flat or conformal block specimen is applied to a ring (Figure 1). The user can calculate volume loss and frictional force (Figure 2).

Coefficient of friction is calculated from friction force values as follows:

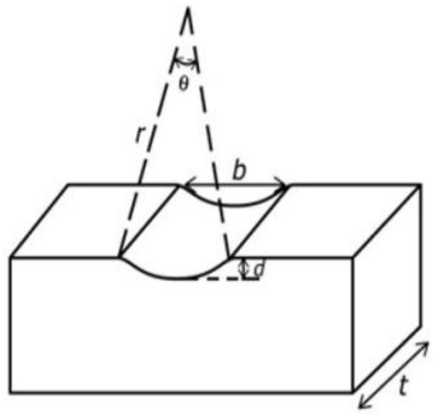
$$f = F / W \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where:

f = coefficient of friction

F = measured friction force, kgf, and
W = normal force, kgf.

With aid of Figure 2, we can calculate the block wear scar volume by using the shown formula. Once obtained the scar volume, we go to ASTM G77 and look for the worn volume on the displayed tables in this standard.



t	= block width, mm	Scar Width	$= b = D \sin\frac{\theta}{2}$
r	= radius of ring, mm	Scar volume	$= \frac{D^2 t}{8}(\theta - \sin\theta)$
D	$= 2r =$ diameter of ring, mm		
b	= average scar width, mm	where θ	$= 2\sin.^{-1}\frac{b}{D}$
θ	= sector angle in radians		
d	= scar depth, mm	∴ Scar Volume	$= \frac{D^2 t}{8}\left[2\sin^{-1}\frac{b}{D} - \sin\left(2\sin^{-1}\frac{b}{D}\right)\right]$

Fig. 2: Wear scar on a block used in an experimental evaluation.

Results & Discussions:

Diverse tests were performed to ensure the repeatability of experiments under different boundary conditions. At an initial stage, an aluminum ring was tested against a steel block. As the machine was running at 72 rpms, the aluminum ring failed the test when a load was applied causing the aluminum to overheat and deform, which was part of the evaluation and observations with this machine. Another evaluation performed was with a steel ring to steel block contact and held better structural properties. The ring and the block were D2 tool steel, which was quenched, having a hardness of ~58-62 HRC. An attachment was fabricated in nylon for the user to apply lubrication during the test process. Nonetheless, the sensors are fully responsive and programable that can output test results via Arduino to a serial monitor.

Fig.3 Low cost tribometer with block on ring configuration

Lessons Learned

The senior design students have proved their ability for continuous self-learning, by understanding how to address professional responsibilities. As a result of the different personalities coming together to work on a demanding assignment, friction between students was not a problem, and did not cause any disturbance in team collaboration; by the end of the project, cohesion became evident and individual performance showed improvement.

Students' commitment and self-confidence in their work, from the beginning of the project, was vital for the successful completion of the project. Stressful situations and technical difficulties tend to drop the students' interest in the project, but true commitment and enthusiasm of participate in an innovative, groundbreaking project kept the students on track; for this assignment, students remained aware of the challenges resulting from participating in a cutting-edge engineering project and the high level of commitment involved.

At the end of the project, the students learned the importance of organization, scheduling and made the best use of the meeting sessions to achieve specific tasks according to schedule; wise used technology to improve the project outcome is essential for student success. The project success was validated by the design and prototyping of a low-cost block-on-ring tribometer for evaluating metal-working materials.

Communication between faculty advisors was vital to create and promote a learning-friendly environment, determine project definition, and identify benchmarks to ensure outcomes. Weekly team meetings are recommended to confirm completed benchmarks and analyze results.

Faculty must foresee challenges and have a possible solution in advance, to avoid delays affecting the project outcomes. It is vital for the faculty advisors to formulate multidisciplinary teams with critical thinking skills from the beginning of the project, linking different learning backgrounds to achieve improvement in the overall team performance.

Conclusions & Future Work:

The prototype of a tribometer was successfully fabricated and tested (Figure 3). Present and future stakeholders will have the ability to analyze material properties in friction, wear, and displacement while saving the university over 500% in costs of an industrial tribometer. There are many aspects that can be improved with further iterations of design and testing by the next batch of engineering technology students. Some future work would be to implement a closed-loop circuit for the motor using a PID controller and automate the load leveling arm, incorporate an all-in-one touch display for the control panel, and to further test/collect data on lubricated and non-lubricated applications.

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