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Understanding Wear Performance: New Mechanical Engineering Laboratory Design

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Understanding Abrasion Wear Performance: New Mechanical Engineering Laboratory Design

Mechanical Engineering Department is promoting development of new laboratory experiments that are introducing engineering concepts and testing procedures advancing real life problems to replace gradually older labs and equipment. The objective of this lab is to recognize the effects of harsh environmental conditions on different materials' surface, to select and recommend a material for an outdoor application. Students are investigating different forms of wear by using testing procedures able to simulate environmental conditions in accelerated modes. The corresponding wear tests are performed using an oscillating sand abrasion tester (ASTM F735) and a reciprocating abrasion tester (ISO 1518). Different sand qualities (silica or alumina) and tips (abrasion grades) are used for evaluating the abrasion wear performance. This paper is reporting the work in progress of the new lab development. The lab conception involves establishing the equipment testing conditions and specifications of: applied load, testing time, and number of cycles for lab setting conditions. The change in roughness profile of samples under investigation and the wear results is assessed by profilometry (KLA, Tencor) and electronic balance. Optical microscopy images are generated to evaluate the wear tracks. Current laboratory purpose is to offer guidance for materials selection, optimization and to advance students "ability to develop and conduct appropriate experimentation, analyze, interpret data and use engineering judgement to draw conclusions" (ABET, Outcome 6).

Introduction

Abrasion wear is the most common type of wear caused by hard surface materials sliding across a softer surface and resulting in a progressive loss of material. Car tires in contact with rough road surfaces or abrasive particles moving on materials' surface during working conditions (gas pumping equipment, extrusion dies for bricks and tiles, punching and pressing tools, cutter blades) or the action of sand particles during harsh outdoor exposure are all examples of abrasive wear conditions. The resistance to abrasion is recently under study due to its important economic loss prevention and is correlated to the intrinsic materials' mechanical properties [1-4]. Engineering polymers and polymer composites have suitable tribological properties, are lightweight, offer high design flexibility, cost efficiency and could be an alternative to metals for diverse applications where resistance to abrasive wear is required [5-10].

This laboratory is an experimental approach and offers support in understanding different concepts covered in other related classes: structure and properties of materials, engineering materials, materials lab, senior design, and mechanics of solids. The objective of the new lab is to analyze, select and recommend the best material for an application requiring exposure to outdoor severe environmental conditions. Students receive similar size specimens for materials under consideration consisting off different common types of polymers, and metals. Their initial task is to investigate the physical and mechanical properties of the specimens by consulting pertinent literature and perform hardness measurements to evaluate material's resistance to an applied load. Subsequently, accelerated wear/ abrasion processes are performed by operating the corresponding testing equipment. The outdoor environmental conditions are recreated during the testing as more severe conditions for shorter periods of time. Students are using the testing equipment to perform and evaluate abrasion wear, collect data and analyze the results in order to offer material recommendations for the required applications.

Materials and Equipment Description

Materials considered for experimentation throughout this laboratory are a few common polymer types purchased from local companies: high density polyethylene (HDPE), polyvinyl chloride (PVC), polycarbonate (PC), high impact polystyrene (HIPS) and polypropylene (PP), and metals: aluminum alloys (e.g. 6160) and steel (e.g. 4140) that are cut to appropriate dimensions. The samples' hardness is tested using Rockwell hardness equipment (LECO) according to standard ASTM D785-03 for polymers and ASTM E 18-07 for metals. At least three measurements are performed on each sample; the average and standard deviation values are recorded and compared to values found in the literature.

Two types of wear testing equipment (Taber instruments) are used in order to simulate the exposure to environmental conditions that are abrading materials' surfaces. The equipment is testing materials in accelerated abrasion modes; it also provides the possibility of evaluating the surface condition changes for the selected polymers and metals. Figure 1 is representing the equipment used for the proposed laboratory experiment: (a) oscillating abrasion tester (Taber, Model 6160) [11] and (b) linear reciprocating abrasion tester (Taber, Model 5900) [12].

(a) (b)

Figure 1. Testing Equipment: (a) Oscillating abrasion tester - Model 6160 [11] and (b) Reciprocating linear abrasion tester – Model 5900 [12]

The first type of tester (Figure 1. a) used for current evaluation is testing materials' surface in conformity with ASTM F735 by using sand (quartz silica sand graded 6/9, alumina or silicon carbide) that oscillates and abrades the samples' surface. The size and shape of the abrading material is the same for each material under investigation. Samples (coupons) are cut to appropriate dimensions and placed in a fix position in a tray (multiple samples can be simultaneously loaded). The quartz silica sand is covering samples' surface to a depth in agreement with company's recommendations. During the testing procedure, the assembly of samples and sand has a continuous reciprocating movement and the sand is scratching the samples' surface simulating the harsh abrasion exposure. In order to establish the appropriate testing conditions, a group of students working under an independent study class was assigned the task to observe the impact of the stroke length, speed of oscillation and testing length on the samples, the corresponding significant changes and potential differences. After exploring different testing conditions and their impact on the samples' surface, the following settings are selected: 3 in (76.2 mm) stroke length, 200 cycles per minute and a set of 30,000 cycles. The testing parameters are selected based upon equipment limitations, laboratory time constraints; they offer discernible wear results on samples' surface for further comparison. The testing speed is limited in order to avoid spill of the abrading material (sand) during the reciprocating move. The number of cycles is selected in order to observe a significant weight loss of the specimens for the selected time for testing. Roughness parameters (e.g. average roughness Ra, root mean square roughness Rq, maximum height of profile Rz, maximum profile peak height Rp, maximum profile valley depth Rv, total height of profile Rt) are evaluated before and after performing the oscillation abrasion test by using the Alpha-Step D-500 stylus profilometer (KLA, Tencor) and results are recorded.

The second type of tester used is the linear reciprocating abrasion tester (Figure 1. b), that is working in conformity to ISO 1518. The apparatus has an extended arm that holds a tip attached at the arms' end. The tip is pressed against the samples' surface in a linear reciprocated movement under a selected load (multiple loads are available). The specimen under consideration is fixed on the tester support/ platform. Different settings may be adjusted for operating under different working conditions: abrasive tip type, load, speed, and stroke length. The group of students involved in the independent study class worked to establish the best setting conditions for this procedure. The goal is to ensure similar testing conditions for all tested samples with the prospect of assessing abrasion effects on all samples. The tip used for testing all materials is a non-resilient tip capable of producing extreme abrading environment (H22 vitrified wearaser). Other tips are also used for the ongoing investigation (e.g. H18, H38). The established testing conditions are: 0.4 in (10 mm) stroke length, 15 N load, 75 cycles/minute, ensuring a total of 15 minutes testing time. In order to evaluate the abrasion testing results the weight/ mass loss is measured using an analytical balance. The volume of the material removed by abrasion is investigated by assessing the samples' profile after performing the reciprocated abrasion test. The Alpha-Step D-500 stylus pofilometer is used with appropriate settings for the stylus movement speed and load. The optical microscope with incorporated PAX-it software is used to investigate the surface abrasion using different magnifications. All data are recorded, stored and available for subsequent analysis and evaluations by students.

Results and Discussions

This laboratory experiment offers students the possibility of "hands-on" activities by experimenting different materials' properties and testing with the focus on understanding the wear behavior. Students are initially collecting available information about physical and mechanical materials' properties (e.g. density, hardness, and Young's modulus) by consulting reliable publications and web resources (e.g. the companies' database). They are performing appropriate hardness measurements on all samples: HRR (Hardness Rockwell R) for polymers and HRB or HRC for metallic samples. Typical hardness values for a few evaluated samples indicate an HRR average of: 94 for HIPS, 118 for PVC, 124 for PC, and 63 HRB for 6061 Aluminum, 23 HRC for 4140 Steel. The measured hardness values are compared to hardness values found in the literature [13].

Before and after performing the wear testing all samples are cleaned with isopropyl alcohol and compressed air is used to blow all possible surface debris. Samples are initially exposed to the oscillating abrasion testing. The same type of materials, different coupons are later subjected to the reciprocated linear abrasion equipment. The established testing conditions are captured in the lab procedures. Roughness parameters are evaluated with profilometry, using similar conditions for all tested samples. At least three measurements are performed on each sample's surface. Students are assessing a few of the most important roughness values before and after performing the abrasion testing. They are determining the average values, standard deviations and make comments on the materials response to abrasion according to parameters' evolution. Figure 2 offers a typical comparison of roughness profiles after performing abrasion testing using quartz silica sand, where HDPE surface is compared to PC (a) and PVC (b). The Figure 3 offers a typical comparison of roughness profiles after abrasion testing, where the HIPS surface is compared to PC (a) and PVC (b). The travel length of the stylus tip is established at 2 mm nanometers (horizontal axis). Students observe that for example HDPE has similar roughness profiles with PVC, but rougher compared to PC, while HIPS has rougher surface compared to both PVC and PC. All roughness values are selected and recorded for later evaluations. Table 1 is a typical example of a table built for two materials (e.g. M1 and M2). Students are using this type of table to present the collected roughness data for different polymers and metals. Data are collected after performing profilometry investigation before and after the exposure to quartz silica sand abrasion testing under the established testing conditions.

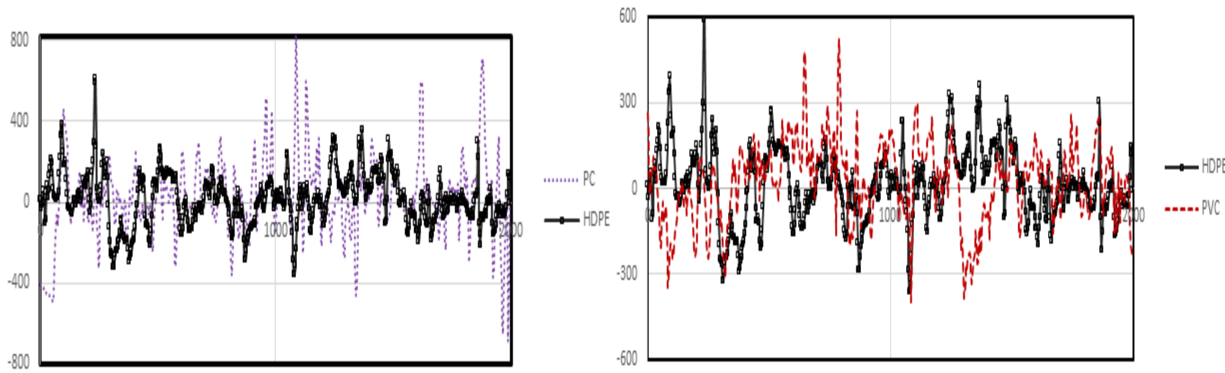


Figure 2. Roughness profiles after abrasion testing using quartz silica sand: high-density polyethylene (HDPE) compared to (a) polycarbonate (PC) and (b) polyvinyl chloride (PVC)

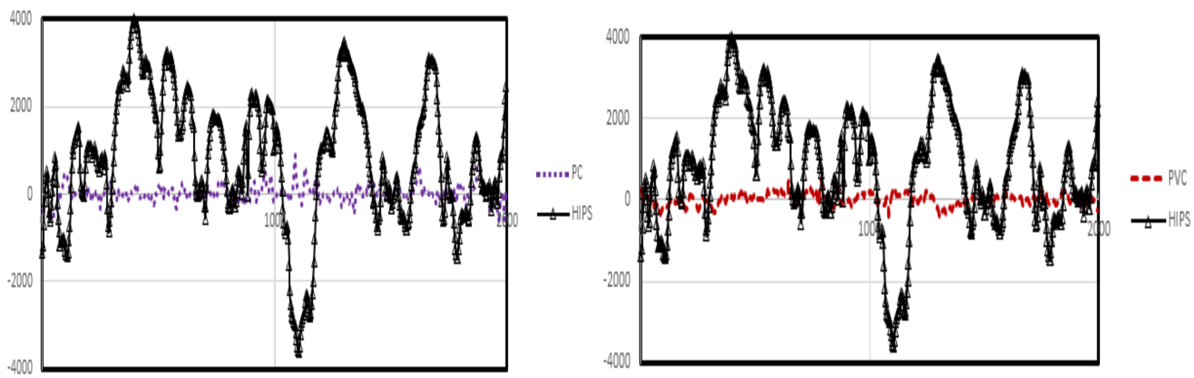


Figure 3. Roughness profiles after abrasion testing using quartz silica sand: high impact polystyrene (HIPS) compared to (a) polycarbonate (PC) and (b) polyvinyl chloride (PVC)

A higher increase in the surface roughness values is indicating more deterioration of the materials' surface condition during the accelerated abrasion testing.

The same type of materials are later exposed to linear reciprocating abrasion testing, using the H22 abrader tip. Samples are cleaned before and after performing the test in conformity with established cleaning procedures.

Table 1. Typical roughness data recordings for materials (M1 and M2), before and after performing the sand abrasion testing

	Before Sand Abrasion Testing [nm]					After Sand Abrasion Testing [nm]			
		Ra (filt.) (nm)	Rq (filt.) (nm)	Rp (filt.) (nm)			Ra (filt.) (nm)	Rq (filt.) (nm)	Rp (filt.) (nm)
M1	**Avg.**				**M1**	**Avg.**			
	St. dev.					St. dev.			
M2	**Avg.**				**M2**	**Avg.**			
	St. dev.					St. dev.			

The samples' evaluation consists of weight loss measurements and volume loss calculations. The weight loss measurements are performed using the analytical balance in order to find the mass that was removed by abrasion. The weight loss (WL) is the difference of the weight of the specimen before abrasion (A) and the weight of the specimen after abrasion (B).
For example, typical weight loss measurements after performing the linear reciprocating testing using the H22 tip for few selected samples in milligrams are: 0.8 for HDPE, 0.3 for HIPS, 0.3 for PP, and 9.6 for PC.
Figure 4 offers an example of a profile scanning result, graphing the testing of a polymer (e.g. M3) surface after performing the reciprocating linear abrasion testing, using the H22 tip with a stroke length of 10 mm. The graph is obtained by using the profilometer equipment (KLA) and it is showing the depth and the width of the abrasion track. Subsequently, the weight and volume loss are correlated with hardness results and roughness evaluations.

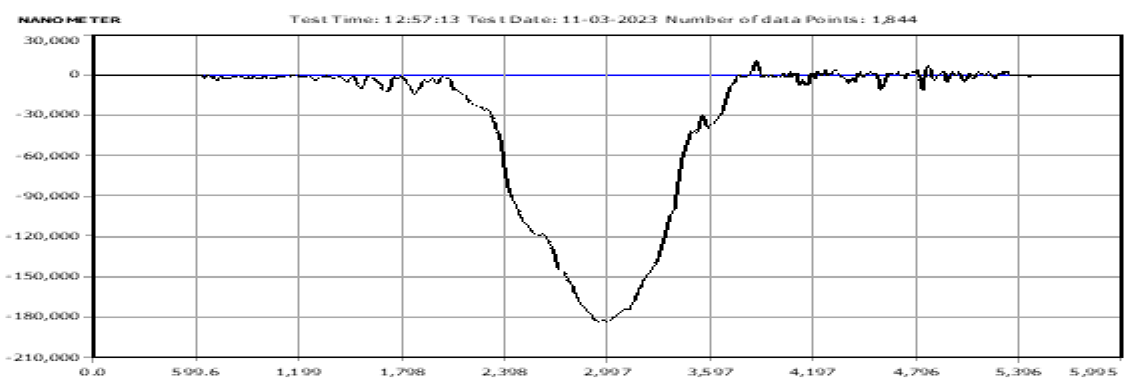
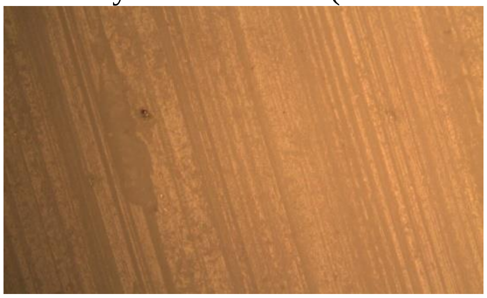


Figure 4. Typical profilometry measurement after testing a polymer (M3) using the reciprocating linear abrasion tester using the H22 tip
The optical microscopy investigation offers further understanding of the linear reciprocating abrasion behavior at micro-scale level. It is used to observe the appearances of the abrasion tracks in order to select the best materials for an outdoor application. Figures 5 and 6 are showing typical optical microscopy pictures of two selected samples: for example the high impact polystyrene and polycarbonate (HIPS and PC), after performing reciprocating linear abrasion testing with H22 tip. The represented images are using 100 X magnification (a) and 500 X magnification (b). Students observe that the images indicate a smooth appearance of the wear/ abrasion track for HIPS and a rough appearance for PC with apparent material delamination for PC (observed at 500 X magnification).
Students are actively involved during the new designed laboratory in performing testing, conducting measurements, collecting and analyzing results. In the same time, they are gathering

more skills by becoming familiar with different abrasion testing equipment, analytical balance, profilometer and optical microscope. They are planning and conducting experiments in a team formed by 3 to 6 students (ABET Outcome 5).


(a)

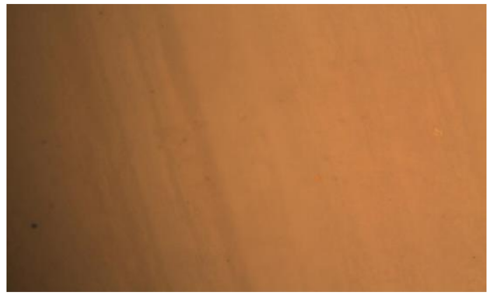

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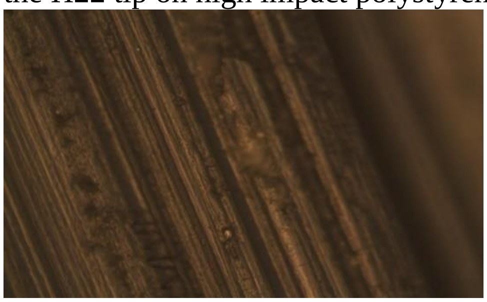
Figure 5. Optical microscopy image after performing linear reciprocating abrasion testing using the H22 tip on high impact polystyrene (HIP): (a) 100 X and (b) 500 X magnification


(a)

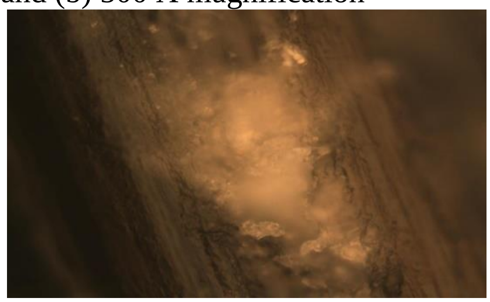

(b)

Figure 6. Optical microscopy image after performing linear reciprocating abrasion testing using the H22 tip on polycarbonate (PC): (a) 100 X and (b) 500 X magnification

For the final laboratory assessment, students are expected to build tables, graphs, and offer appropriate observations about weight loss, wear and roughness evolution. They offer recommendations on the potential use of materials for an outdoor industrial application (ABET Outcome 6). They are instructed to collect data and present it in a poster format simulating an engineering presentation to a company management (ABET Outcome 3). The lab assessment takes into consideration the poster quality of visuals, data collection, presentation, analysis and the final recommendation results.

Conclusions

A new laboratory experiment is created with the focus on materials' response and appropriate material selection for harsh abrasive conditions. The laboratory involves standardized testing procedures of common types of polymers and metals in order to make recommendations for an outdoor application. Students have the possibility of solving a real-life problem by using multiple testing equipment, conduct the experiments, collect data and perform data analysis. They learn to present the results in a professional manner by building a poster containing the information gathered throughout experiments in a concise form. They are using engineering judgement to draw conclusions and make recommendations in regard to materials' selection. The laboratory design is envisioning addressing multiple ABET outcomes: Outcome 3, to communicate effectively with various audiences through the creation and presentation of a poster; Outcome 5 and 6, by working on a team while conducting experiments and analyzing the collected data and Outcome 7, as this particular lab will involve exposing students to various new testing equipment.

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