ABRASION RESISTANCE OF SELECTED COMMERCIALLY AVAILABLE POLYMER MATERIALS

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ABSTRACT

The aim of this investigation was to examine several types of commercially available polymers for potential application in machine elements that are exposed to abrasion. Selected materials were evaluated on a rubber and steel wheel abrasion test rig according to the standard ASTM G65, using as abrasive quartz sand (SiO_2) as abrasive, with a particle grain size in the range of 0.8 – 1.6 mm. Tests were performed under dry conditions and at room temperature. Applied load was 50 N, within testing times of 1½, 3, 4½, and 6 hours respectively. Results of testing revealed influence on wear behavior of polymer hardness as well as influence of abrasive particle embedment.

Keywords: ASTM G 65 abrasive tester, quartz sand, three body abrasion, polymer

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INTRODUCTION

In recent years, due to the trend in designing of machines and machine elements, polymers have taken a significant role as materials for parts like cams and gears, as a substitution for conventional materials [1]. Additionally, polymers are extensively used as materials for manufacturing of parts for mining equipment, conveyor lines, rotary valves, etc. [2]. In all these applications, polymers are exposed to abrasive wear.

Abrasive wear is a wear mechanism generated by the sliding of a hard material over a softer material under load, while surface asperities of the harder material tend to remove the softer material [3]. In general, abrasive wear can be divided into two major groups due to the mechanisms of generation: two body abrasion, and three body abrasion [3]. Two body abrasion occurs in direct contact of two counter surfaces when one is significantly softer than the other one, while three body abrasion occurs when hard particles get trapped between two sliding surfaces. Some estimation say that abrasive wear contributes up to 60% of total costs caused by wear [4].

Since polymers became important technical materials in modern engineering, numerous papers referred to these in the last decades. The first article in history summarizing results of polymer abrasion was published in 1969 [5]. The following years brought a wide variety of experiments related to abrasive wear of polymers [6-13]. Furthermore, a wide variety of experiments has been performed on polymer composites, reinforced polymers and epoxy resins [14-16]. Most of these experiments have been performed on conventional pin-on-disc testing setups with sand paper as counterbody to the polymer pins (two body abrasion), as well as on the ASTM G65 abrasion tester with different testing setups (steel or rubber wheel, Three body abrasion). Attempts to investigate abrasion resistance of polymer materials on micro scale have also been done [17]. Most of these studies can be seen as a summary in several review articles [5; 18].

In this work we investigate polymer materials possibly replacing metals for dosing wheels in rotary feeders, especially for those with smaller geometry, where entire parts have to be made from bulk polymer and where the implementation of reinforcing fibers in the polymer structure is not possible. The selected polymer materials are commercially available.

EXPERIMENTAL

Testing samples

Four different commercially available technical polymers, one polyethylene and three polyurethanes, named Polymer A, B, C and D, have been examined in order to determine their abrasion resistance. The materials were supposed to exhibit beneficial performance under abrasive conditions either by providing pronounced abrasion resistance or by general mechanical properties allowing proper function of the system, e. g. low tendency for wear attack on the counterbody. The size of the specimens used in the ASTM G65 abrasion test rig was 10 mm × 25 mm × 75 mm. The selected testing materials, and their properties can be seen in Table 1.

Table 1. Abbreviations, chemical structures and mechanical properties of selected polymers.

Sample designation	Chemical structure	Shore hardn. (HS)	Elong. %	Density (g/cm³)
Polymer A	polyethylene	60	-	0.96
Polymer B	polyurethane	72	800	1.24
Polymer C	polyurethane	85	410	1.20
Polymer D	polyurethane	92	490	1.11

As reference materials with high abrasion resistance, two steels intended for quenching and tempering have been selected, Table 2.

Table 2. Reference steel materials 34CrNiMo6, and 42CrMo4.

Alloying elements	34CrNiMo6	42CrMo4
C	0.30-0.38	0.38-0.45
Si	Max. 0.40	Max. 0.40
Mn	0.50-0.80	0.60-0.90
Cr	1.30-1.70	0.90-1.20
Ni	1.30-1.70	0.15-0.30
Mo	0.15-0.30	Max. 0.035
	Hardness [HB]	
	248	255
	EN 10083-3	
	Hot rolled	Hot rolled

Abrasive

As abrasive material, quartz sand (SiO_2) with a grain size of 0.8 - 1.6 mm was selected. The choice of this specific abrasive followed the application requirements. For each test a new stock of sand was used, in order to maintain the grain shape conditions and grain size distribution as a constant parameter.

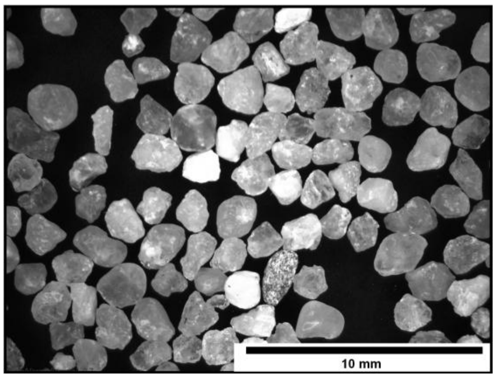

Figure 1. Abrasive particles used in the experiments (Image of abrasive particles before experiment).

Experimental procedure

For the selected specimens, the tests were performed using the ASTM G65 abrasion tester [19]. The decision was based on already available experiences, not only from literature (chapter 1) but as well from our own experimental work. Nevertheless, adjustments of the test system according to the application demands could be done easily to the ASTM G65 apparatus. Adjustment of the system consisted of retrofitting of the test rig with the new nozzle which was capable to maintain the sand flow within the limits defined by application. A schematic of the test rig can be seen in Figure 2. The tested samples were fixed to the sample holder lever, which was positioned in the tangential direction in relation to the rubber or steel wheel. The sample holder lever is connected to the load lever having the same pivot. The load was applied by positioning a calibrated dead weight at the end of the load lever. During testing, the examined samples were exposed to the influence of the abrasive. The abrasive was stored in the sand tank and fed into the contact zone through an appropriate nozzle [19]. After leaving the nozzle the abrasive was entrapped in and moved through the contact zone due to the relative motion of the wheel, which was rotating in direction of the sand flow (clockwise in the schematic).

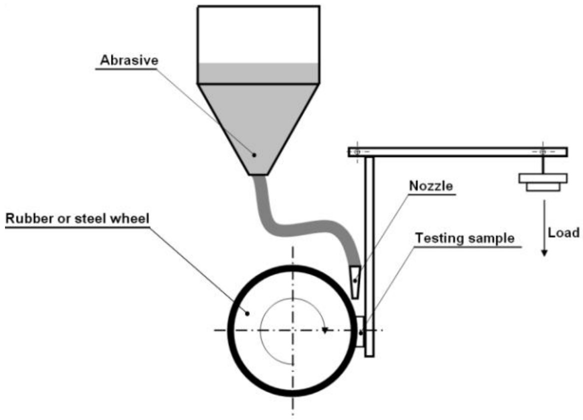

Figure 2. Schematic diagram of the ASTM G65 abrasion test rig.

Tests were carried out at modified conditions with a load of 50 N, a rotational velocity of the wheel of 200 min^{-1}, a sand flow rate of 3 litres/minute and testing times 1.5, 3, 4.5, and 6 hours, respectively. Both test setups – with rubber wheel and with a steel wheel – were used. Before and after testing, each test sample was cleaned in ethanol and dried. Mass loss was determined by weighing the samples before and after the tests with an analytical balance (RADWAG XA 210/X, 0.01 mg to 210 g, RADWAG Balances & Scales, Radom, Poland). Each test was repeated at least two times, and for comparison the volume loss for each selected testing sample was calculated. Wear tracks on the wheel surfaces were measured by a confocal microscope (Leica DCM 3D, Ernst Leitz Wetzlar, GmbH, Germany) for non-contacting assessment of the microscale topography. The size of the scanned area was 0.96 mm × 1.3 mm.

RESULTS

ASTM G65 abrasive test results

The 1.5 hour experiments

Average volume loss (mm^3) as a function of the polymer hardness (HS), for the experiments of 1.5 hour lenght is presented in Figure 3. In general, for both test setups (rubber and steel wheel) the highest volume loss was detected for the Polymer A, which possess the lowest hardness. Nevertheless, it should be noticed that for the steel wheel test setup, the polymer A exhibits lower wear volume (by 65 %) when compared to the rubber wheel setup.

A similar trend was detected for Polymer B, with approximately 22 % volume loss obtained in the tests with the steel wheel setup as compared to those with rubber wheel one. However, it can be noticed that this trend changed after an increase in hardness on Shore scale over 85 HS. Polymer C exhibited 48% lower, and Polymer D 35% lower volume losses in the tests with the rubber wheel setup in comparison to the tests with the steel one. Moreover, the lowest wear volume in the tests with two setups was obtained with Polymer C.

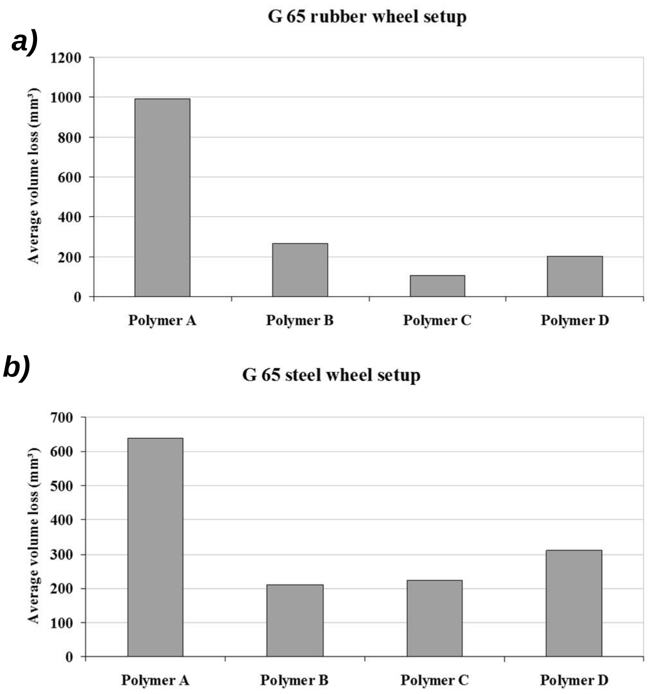

Figure 3. Average volume loss for the selected polymer materials in the 1.5 hr experiments: a) ASTM G65 rubber wheel setup; b) ASTM G65 steel wheel setup

Figure 4 presents the comparison charts between Polymer C and D, which were the best performing polymers, and the reference steels. It can be clearly seen there was no difference in wear resistance between Polymer C and the reference steels in the tests with the ASTM G65 rubber wheel setup (Figure 4 a). Only Polymer D exhibited a worse performance than the reference steels, when tested in the rubber wheel setup. Furthermore, the difference between the four materials when tested in the ASTM G65 steel wheel setup was even more pronounced; 35% less wear was detected for Polymer C, and 20% less wear for Polymer D.

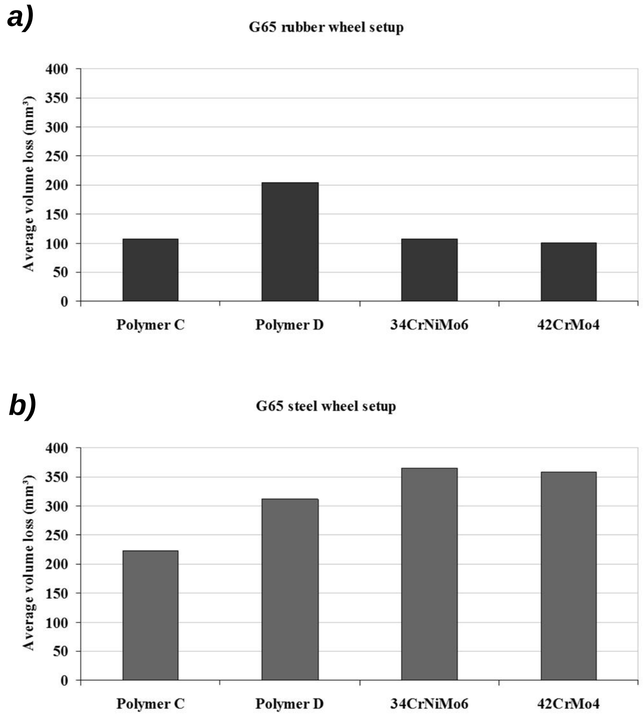

Figure 4: Average volume loss of best performing polymers and selected steel materials.

3 – 6 hour experiments

The two best performing polymers, Polymer C and Polymer D were selected for the longer term experiments. The average volume loss (in mm³) as a function of time is presented at Figure 5. It can be seen that, by increasing the testing time, the difference between Polymer C and Polymer D became obvious. In the rubber wheel test setup (Figure 5 a), Polymer C exhibited a mild increase in wear comparing to the 1.5 hour test results, reaching a wear loss volume of about 750 mm³ at the volume loss at the end of the test. On the other hand, Polymer D was completely worn off after 4.5 hours of testing. This difference was even more pronounced in the tests with the steel wheel test setup, see Figure 5 b, in which Polymer D was completely worn off after 2 hours of testing. A negatiive trend in the wear behavior was detected for Polymer C in the time sequence between 4.5 and 6 hours; for all tested samples, the detected mass loss was lower after 6 hours of testing than after 4.5 hours.

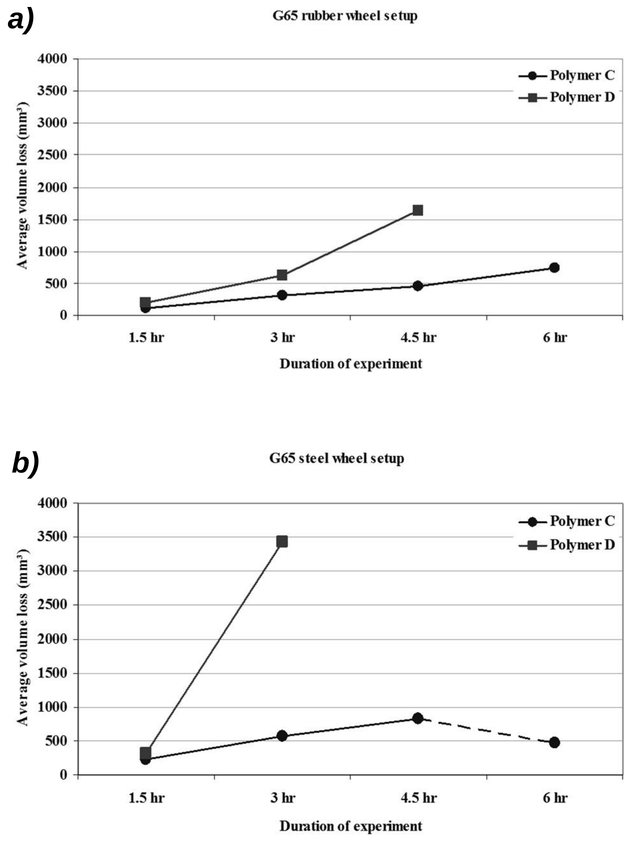

Figure 5. Average volume loss for selected polymer materials after the 6 hr experiments: a) ASTM G65 rubber wheel setup; b) ASTM G65 steel wheel setup.

Surface analysis

Images of 3D surface topography results from the measurements inside the wear scars are presented in the Figures 6 and 7. The scanned areas were 0.96 mm × 1.3 mm in size. As it can be seen for all selected polymers in the Figures 6 and 7, the abrasion grooves were parallel to the main direction of motion of the wheel of the test setup and the abrasive sand. The only exception was Polymer A, for which no grooves were detected.

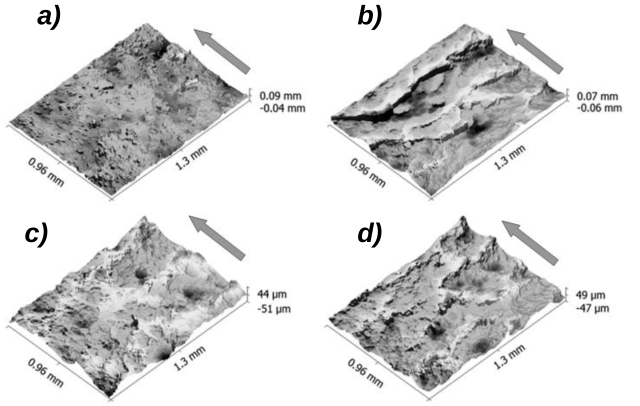

Figure 6. 3D surface topography within the wear scar generated during the tests with the rubber wheel for: a) Polymer A; b) Polymer B; c) Polymer C; d) Polymer D
Note: Arrows indicates sliding directions!

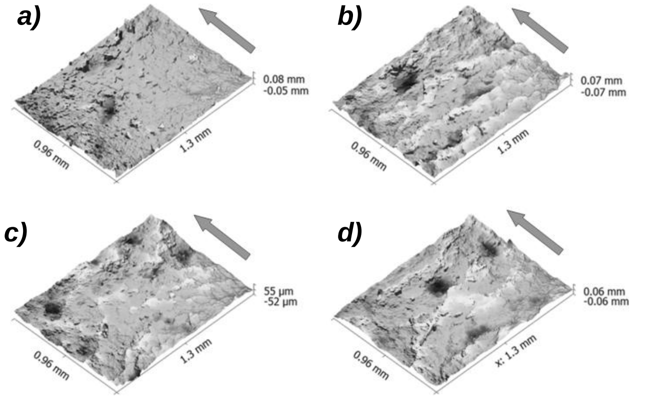

Figure 7. 3D surface topography within the wear scar generated during the tests with the steel wheel for:
a) Polymer A; b) Polymer B; c) Polymer C; d) Polymer D
Note: Arrows indicates sliding directions!

DISCUSSION

As known from the literature, hardness plays a significant role in abrasive resistance [20]. It is a common rule that harder materials possess higher anti abrasion resistance [21]. It should be taken into account that throughout the entire experiment, different contact conditions were present. For instance, depending on the surface material of the testing wheel of the ASTM G65 equipment, the conditions in contact could be either a soft-soft or soft-hard combination, and this affects the abrasive behaviour dramatically. As it can be noticed from Figure 3, for both testing setups, Polymers A, B and C behaves similar to the steels and ceramics in the terms of the abrasive resistance (lower wear loss volume for materials with higher hardness). For Polymer D which possesses the highest hardness, abrasive behaviour changes comparing to Polymer A, B, and C. Additionally, it should be mentioned that the hardness is not the only parameter that affects the present tribosystems. For instance, for all polyurethanes (Polymer B, C, and D), the elongation is the lowest for the Polymer C, which exhibits the best performance. Among the polyurethanes, Polymer C is the stiffest one, which from a design standpoint can play a significant role considering the necessity for maintaining the geometry of the designed machine component within prescribed tolerances during the operation. Apparently, Polymer C with the lowest elongation-to-hardness ratio exhibits the highest resistance against abrasive wear. Relatively low wear in comparison with that of the reference steels (Figure 4) can be attributed to the elasticity of Polymer C, which is high enough to allow deformation of the surface of the test sample, in order to allow the passage of sharp sand particles without significant damage of the surface, and still not high enough to allow extensive wear of the surface. In the last testing sequence of Polymer D in steel wheel setup (Figure 5 b), a diverging trend was observed; while for the rubber wheel setup, the amount of wear was progressive with continuous increase in the wear volume with time, the progress of wear was rather unlinear in the steel wheel test setup. The reason for a decrease in the volumetric wear rate after 4.5 hours of testing was sand particles that had become embedded in the sliding surface of Polymer C, protecting the surface from wear and adding to the mass of the test sample. Figure 8 presents the wear scar topography generated on Polymer C after 6 hours of experiments. In this case the entrapment of the particles occurs on the inlet side, when sand particles enter into the contact zone, and get embedded to the high contact pressure. Due to the elasticity, which is not high enough to allow displacement of particles out of the bulk polymer material, the sand particles remained in the contact area.

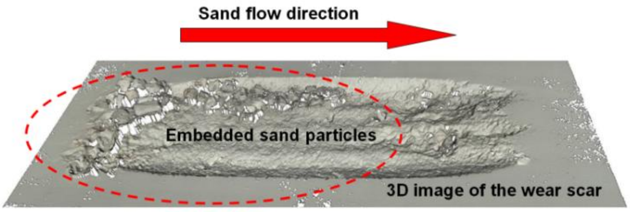

Figure 8. 3D surface topography of Polymer C wear scar from a 6 hours experiment (The arrow shows the direction of motion of the wheel surface, and the main direction of the abrasive sand).

Additionally, it is noteworthy that the surface topographies of the other selected specimens tested under steel and rubber wheel setup (Figure 6 and 7) revealed a similar behavior of polymer samples as reported previously in the literature [5]. All selected polyurethane had topography with grooves parallel to the sliding direction. The groove formation is the consequence of delaminating of surface polymer layers due to the abrasion.

CONCLUSIONS

Several conclusions can be derived:

- Among the present materials studied, the polyethylene-based samples exhibited the lowest resistance against abrasion.
- For the polyurethane-based samples, the abrasion resistance depended on both hardness and elongation before break
- At high contact pressures, the entrapment of sand particles, and hence, lower wear are possible.

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