ABRASION TESTING WITH RUBBER WHEELS [1]

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Abstract

The ASTM G 65 dry-sand rubber wheel test is a popular low-stress abrasion test in the USA. It uses coarse silica sand as the abradant and this abradant is thought to simulate the kind of abrasion that occurs in mining and agriculture. The sand is forced against the test specimen with a chlorobutyl rubber wheel. The wheel wears and requires periodic replacement. However, in 2008 the only USA supplier of these wheels stopped making them, A search was launched to find a new supplier, but concurrent with this search this study was conducted to identify a lower-cost and more available rubber to replace the chlorobutyl rubber. This paper describes tests of four candidate replacement rubbers. Wheels were made from these rubbers and the ASTM G 65 test was performed on a reference material with these rubbers. The candidate rubbers did not perform the same as the chlorobutyl rubber and tests were performed to explain these results.

Keywords: Abrasion; Wear testing; Chlorobutyl rubber.

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INTRODUCTION

The use of rubber is used as a triboelement in abrasion testing dates back at least 40 years.[1-3] In most instances the rubber is used to force an abrasive against a test specimen. It is the source of the normal force acting on the abrasive and in some cases it is also the source of the abrasive motion. Figure 1 presents a schematic of common 2-body and 3-body abrasion tests. Those that use rubber are noted. One of the most popular abrasion tests in the USA, ASTM 65,[4] uses a wheel with a rubber tire to make line contact with a flat test specimen as abrasive is fed into the interface. Another ASTM test (G 76) uses a horizontal flat rubber pad as a counterface for a test materials rider in an abrasive slurry.[5] Another slurry test (ASTM G 105) employs rubber wheel like the ASTM G65, but the procedure calls for three different rubber wheels –each with a different hardness.[6] This was done to respond to findings that the abrasion results in three-body (rubber, abrasive, specimen) test depends on the rubber hardness or Durometer.[3]

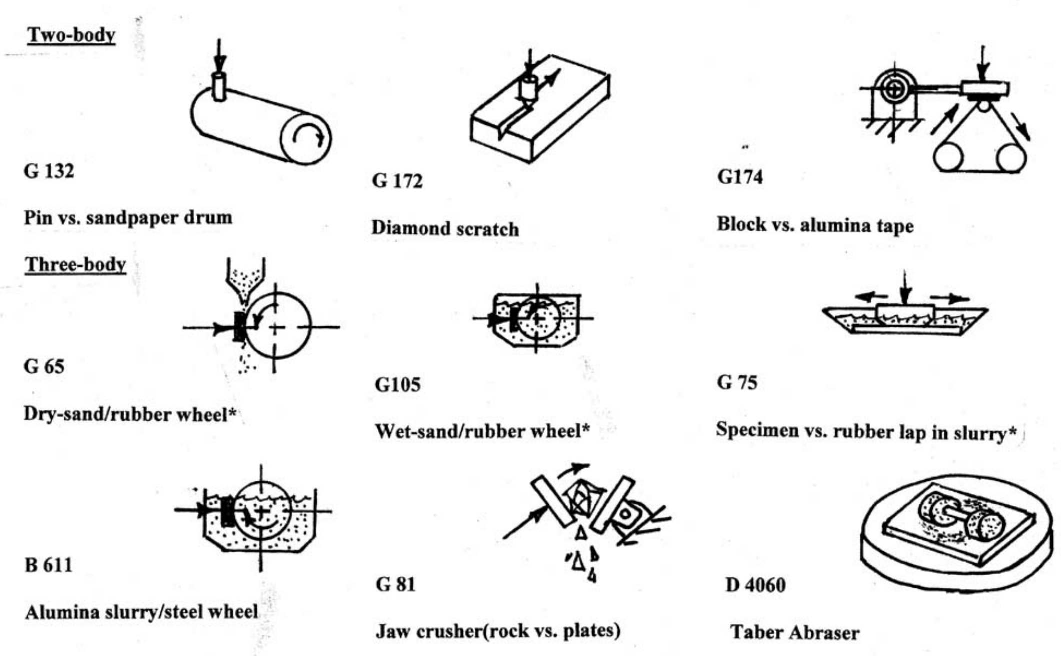

Figure 1. Schematics of some ASTM abrasion tests. The ones with the asterisks use rubber to produce the normal force on the abrasive.

In 2008 a problem arose in the use of chlorobutyl rubber (CBR) for abrasion testing using the ASTM G 65 dry sand rubber wheel test. The test, which is illustrated in Figure 2, uses a rubber tired steel wheel to produce the force and sliding of the abrasive against the test specimen. The rubber specified for the ASTM standard test became unavailable in the USA because the only supplier ceased production for business reasons. Concurrent with the lack of wheels, hardfacing companies started to add macroscopic carbide phases in fused metal matrices. Abrasion testing these heterogeneous hardfacings can produce serious grooving of the rubber making the wheel life only a few tests. In addition, the wheels are very expensive. These two incidents prompted this study to investigate the use of alternate rubbers for the ASTM

G 65 test and possible for other tests. The project objective is a wheel that is lower cost, more available, and produces the same results as the CBR wheels.

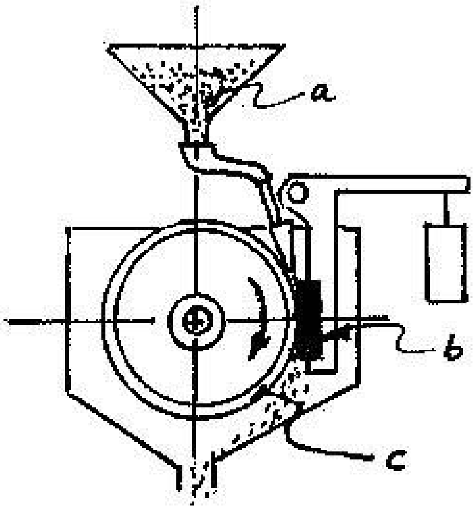

Figure 2. Schematic of the ASTM G 65 dry/sand rubber wheel abrasion test; a = sand hopper, b = test specimen, c = rubber wheel

Specifically this paper discusses the evaluation of three types of Neoprene rubbers and an SBR rubber as replacements for CBR. ASTM G 65 tests were performed on type D2 tool steel with the four candidate rubbers and the wear volumes were compared with results with CBR wheel. Mechanical property and other tribological tests were performed on the candidate rubbers to explain the abrasion result differences. It was determined that none of the candidate rubbers performed the same as the CBR in the ASTM G 65 test and that CBR wheel had friction and resilience differences that could explain why it “works” better than the other rubbers.

INVESTIGATION

The definitive test for a rubber to replace CBR in the ASTM G 65 test is to make a wheel for the test rig from candidate rubbers and to measure the wear volume on a standard material and compare the results with the candidate rubbers. This was done for the four candidate rubbers in this study:

1. 60A Neoprene (NEO)
2. 70A Neoprene
3. Neoprene/ethylene propylene diene mer (EPDM) blend
4. Styrene butadiene rubber (SBR)

This test was performed on each of the test rubbers with type D2 tool steel (1%C, 12% Cr, Fe bal) hardened to 60 HRC as the reference test material. Two to six replicates were run on each rubber. The test wheels conformed to the ASTM G 65 specifications in dimensions and all other use factors such as surface finish. The rationale for the ASTM G 65 tests was that the rubber wheel supplies the force with which the abrasive acts on the wear surface and the how well the abrasive embeds in the wheel determines the velocity with which the abrasive particles rub on the wearing surface. If the rubbers produce different forces and velocities they will likely produce different wear results.

Physical and mechanical property tests were conducted on the candidate rubbers and CBR rubber to try to correlate the properties with the wear volumes measured in the ASTM G 65 tests. Durometer and spring constant should be a measure of the force that the rubber produces on an abrasive. Abrasive-to-rubber friction should determine how well the abrasive embeds in the rubber. Essentially we tested the rubber properties that we felt could affect abrasion results. The rubber tests included the following.

Durometer – The Shore A Durometer of each rubber wheel was measured in accordance to the ASTM D 2240 test method on the wheel periphery in at least three places.

Spring constant –The spring constant of each rubber was measured by axial loading of a 1-mm diameter steel pin against the side of each wheel with forces of 50, 500, 1000gf and the steady-state indentation depth of the penetrator was measured (see Figure 3). The spring constant for the rubber was calculated as the slope of the force/deflection curve for each rubber.

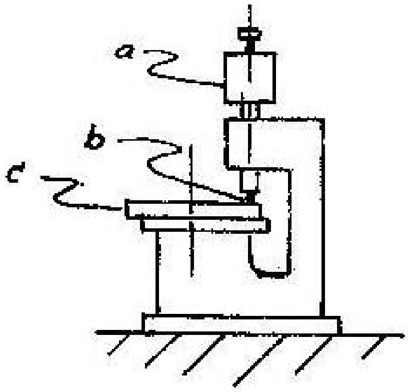

Figure 3. Spring constant test rig; a = loading mass, b = penetrator, c = rubber wheel from abrasion test rig.

Friction of abrasive versus rubber – The static coefficient of friction of a single abrasive grain was measured against the control CBR and each candidate rubber by sliding the rubber in contact with a stylus made from a single crystal of emerald (see Figure 4) against the test rubbers in a sled-type friction-measuring device. The breakaway and kinetic friction forces were measured over a short stroke length of about 3 cm with a speed of about 10 centimeters per second. The normal force was supplied by a 100 g mass. Three tests were conducted on each rubber. The same mineral stylus was used on each test.

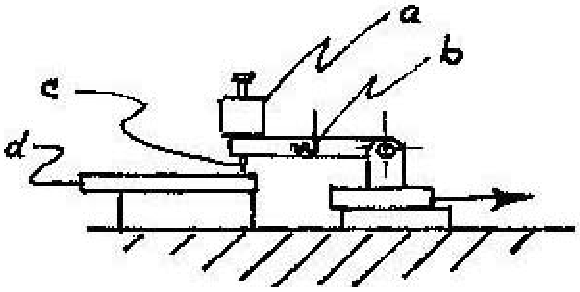

Figure 4. Test rig to measure the static coefficient of friction of an abrasive grain (emerald) sliding on a test rubber; a = loading mass, b = force sensor, c = abrasive grain on stylus, d = test rubber.

Rolling friction – The CBR wheel was attached to a pivot arm and dead-weight loaded against a flat and horizontal 1020 steel test specimen covered with a single grit thickness layer of 50 to 70 mesh silica sand (the type used in the ASTM G 65 test). The slide was pulled with a force transducer and the rolling coefficient of friction of the three-body (rubber/sand/steel) tribosystem was measured. The normal force was 130N, the same as the force used in the ASTM G 65 test. This test was repeated three times on CBR and SBR rubbers.

ASTM G 65 tests with candidate rubbers – Nine-inch (228.6 mm) -diameter rubber wheels with an eight-inch (203.2 mm) carbon steel core were made from the four candidate rubbers. Three replicate ASTM G 65 tests were conducted on type D2 tool steel at 60 HRC using procedure A: 2000 wheel revolutions, 130N normal force, 50 to 70 mesh test sand with a flow rate between 300 and 400 g/minute, with a peripheral speed of 0.8 meters per second. The test metric was the mass loss on each specimen converted to a wear volume using the density of the D2 tool steel.

Rubber abrasion tests – It was thought that the way that a rubber wears during the ASTM G 65 test might have an effect on the performance of a rubber when used in abrasion testing. The test used to compare the abrasion resistance of the candidate and control rubber was the ASTM G 174 loop abrasion test [9]. The test rubbers were machined to the standard shape specified in ASTM G 174 (3 x 8 x 28 mm). The flat face of the test specimens were line-contact loaded against the 132 cm – long test loop made from 30μm aluminum oxide finishing tape (Figure 5). Each rubber was abraded with the standard test of 100 loop passes, 200-gram mass for normal force, and 0.25 m/s loop speed. The wear volume of each rubber in the test was calculated from the scar size. Three tests were conducted on each rubber.

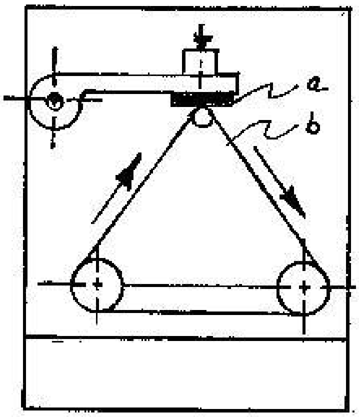

Figure 5. ASTM G 174 Loop abrasion test rig; a = test specimen, b = abrasive finishing tape.

Tribotester abrasion tests – In an effort to confirm the different test performance of the candidate rubbers, four engineering materials were ranked for abrasion resistance by dry sand test using a different test configuration and different rubbers than the ASTM G 65's CBR rubber. The device was called Tribotester and it is shown schematically in Figure 6. The test is very similar in concept to the dry sand rubber wheel, only the rubber wheel is a different size and the test specimen is horizontal. Four test materials were ranked in abrasion test with two different rubber wheels: SBR and 60A Neoprene. Test specimens were made from 6061-T6 aluminum, PMMA plastic, 1018 carbon steel, and 1045 carbon steel at 50 HRC. The rubber wheel had a width of 10 mm and a diameter of 109 mm. The wheel force on the test specimen was 55 N, the test speed was 30 rpm, and the test duration was 450 revolutions. The test abrasive was 50 µm aluminum oxide. The abrasive self feeds because of the hopper design and the test was conducted with 200 g of abrasive. The test metric is the wear volume measured in the 450-revolution test and the wear volume is calculated from mass loss measurements on the test specimen.

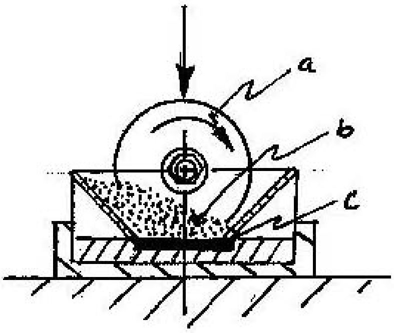

Figure 6. Schematic of Tribotester setup for a dry abrasion test; a = rubber wheel, b = test abrasive, c = test specimen.

TEST RESULTS

Comparison of candidate rubbers vs. CBR in ASTM G 65 – Figure 7 shows that the CBR wheel produced more volume loss on D2 tool steel than all of the rubber wheels made from candidate rubbers when tested in the standard test using procedure A. SBR was the closest match and the EPDM/ Neoprene blend produced the lowest wear volume. None of the candidate rubbers matched CBR's ability to abrade with 50/70-mesh silica abrasive.

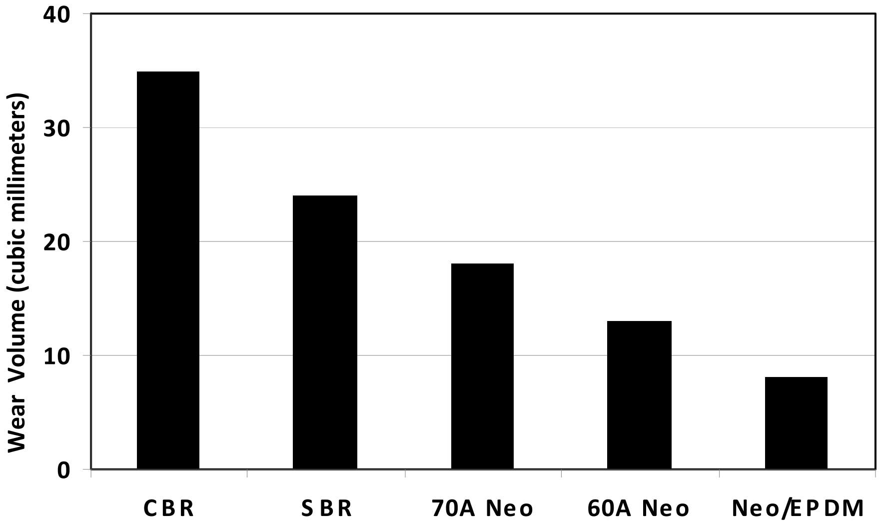

Figure 7. Wear volumes on type D2 tool steel in the ASTM G 65 abrasion test (Procedure A) conducted with wheels made from candidate rubbers to replace CBR.

Property tests on candidate rubbers – The comparative hardnesses of the candidate rubbers are shown in Figure 8. The 60A Neoprene wheel had a hardness that was statistically the same as the CBR wheel (61 vs 59 A), but did not produce the same D2 abrasion results. All of the test rubbers with the exception of the 70A Neoprene were purchased from suppliers to the ASTM G 65 hardness specification of 60 +/- 2 Shore A hardness but the measured hardnesses varied from the purchase specification

The spring rates of the candidate rubbers are compared with the spring rate of CBR in Figure 9. The slopes of the load/deflection curves (the spring rate) were the similar for the candidate rubbers, but the maximum penetration depth at a given force varied significantly. At 1kg force (10N), the penetration of a flat-faced 1 mm diameter steel penetrator in CBR was almost twice the penetration measured in three candidate rubbers: SBR, 60Neoprene, and 70 A Neoprene. A 90A reference polyurethane rubber (PUR) had almost negligible penetration and the EPDM/Neoprene blend had the most penetration.

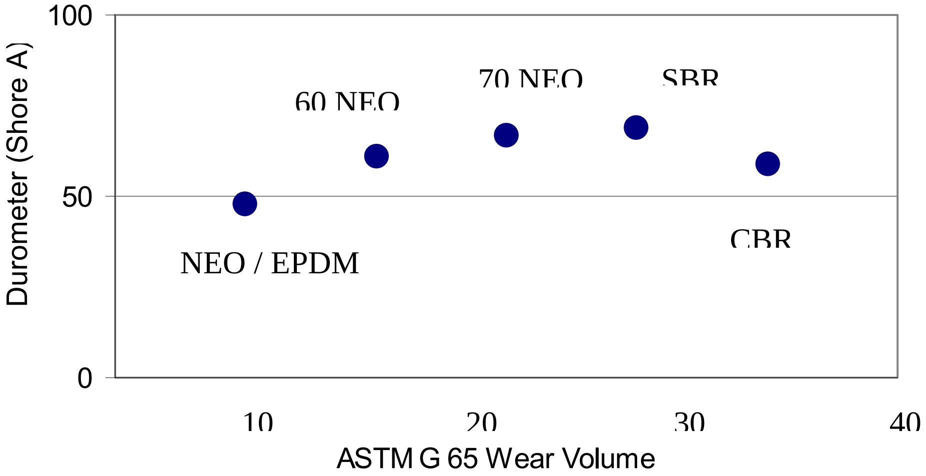

Figure 8. Effect of rubber hardness on type D2 tool steel abrasion in the ASTM G 65 abrasion test.

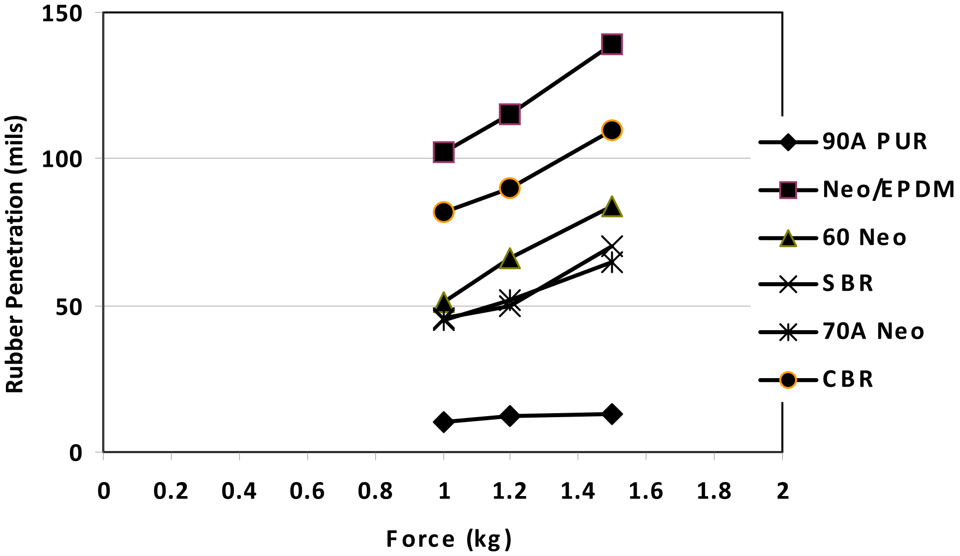

Figure 9. Force/deflection curves for the test rubbers and some selected reference rubbers.

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Static friction comparisons – The static coefficient of friction of the candidate rubbers sliding in contact with a single abrasive grain are compared to CBR in Figure 10. CBR had the highest static coefficient of friction and the EPDM/ Neoprene blend had the lowest.

Rolling friction coefficients – The rolling coefficient of friction of the CBR/silica/steel tribosystem with a 130N normal force was 0.4. The rolling friction coefficient of the SBR/silica/1020 steel tribosystem under the same conditions was 0.5.

ASTM G 174 abrasion tests - The two-body abrasion resistance of the CBR rubber is compared with the candidate rubbers in Figure 11. The CBR rubber had the highest wear volume, making it the rubber with the worst abrasion resistance. The SBR rubber had the best two-body abrasion resistance.

Wear ranking of materials with different rubber wheels – Figure 12 compares the abrasion resistance of four materials (PMMA, 1018 steel, 1045 steel, and 6061-T6 aluminum) ranked with a rubber wheel here body abrasion test with a neoprene wheel and with an SBR wheel. The material rankings were the same, but there was a difference in the wear ratios within the two groups. For example, hard steel is the most abrasion resistant material as determine by both types of rubber wheels, but with SBR, the wear volume ratio of hard steel to soft steel was 2; with the neoprene wheel the hard steel to soft steel wear ratio was 1.2.

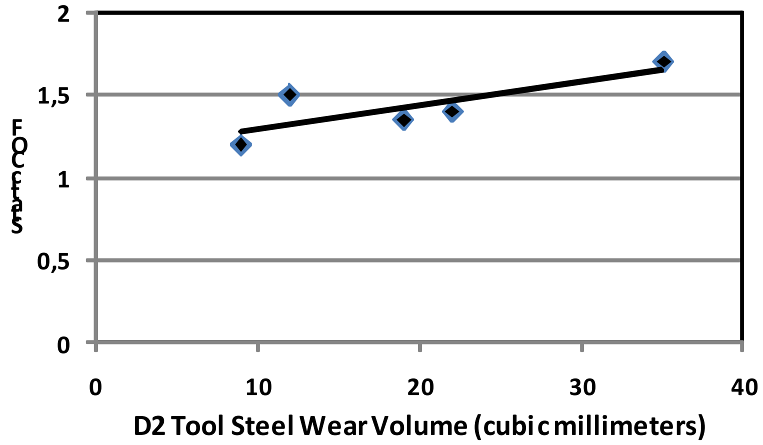

Figure 10. Effect of coefficient of static friction on ASTM G 65 abrasion results on type D2 tool steel.

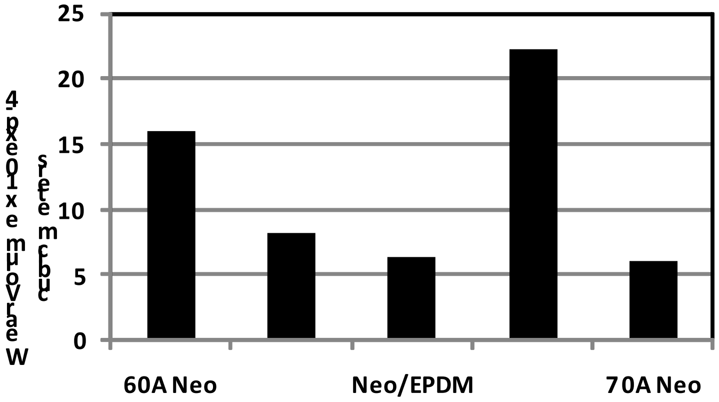

Figure 11. Abrasion resistance of test rubbers as determined by two-body abrasion in the ASTM G 174 loop abrasion test (the lower the wear volume, the better the abrasion resistance).

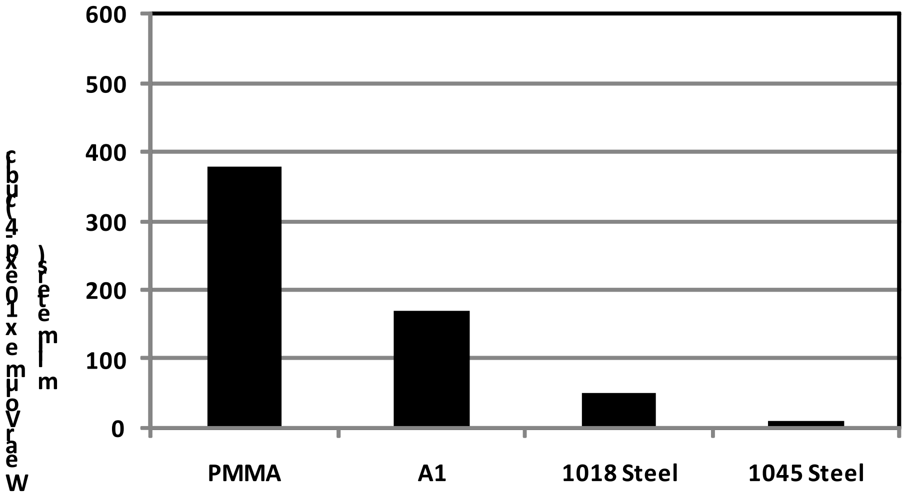

Figure 12 A

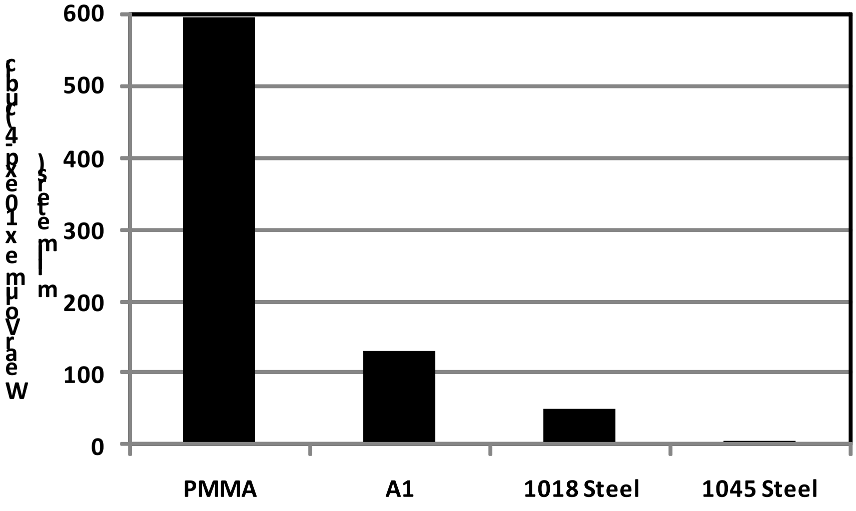

Figure 12 B

Figure 12. Tribotester abrasion wear volumes on PMMA, 6061-T6 aluminum (Al), 1018 steel and 1045 steel at 50 HRC ranked with a Neoprene wheel (a) and with an SBR wheel (b).

DISCUSSION

Why CBR rubber works better – This study suggests that CBR has the following attributes that make it more effective in the ASTM G65 test that some other rubber:

1. It had the highest static friction coefficient versus abrasive of the rubbers tested.
2. It indents easier than three of the four candidate rubbers
3. It abrades easier than the candidate rubbers
4. It recovers from indentation faster than the other rubbers (resilience).
5. It produces more effective abrasion in the ASTM G 65 test than the candidate rubbers.

Items 1 to 3 explain item 5. The fact that CBR is “sticky” compared to the other rubbers (higher friction) makes abrasive grains temporarily become fixed to the wheel and allow rubbing on the test counterface. The role of its ability to easily indent helps to hold abrasive grains “fixed” to the rotating wheel (Figure 13 b).

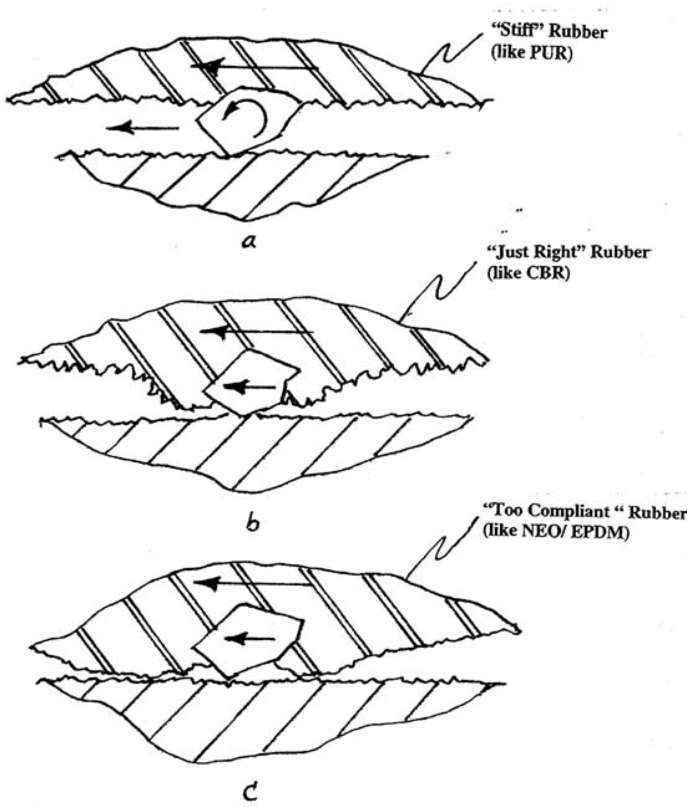

Figure 13. The perceived way that rubber wheels can interact with and “fix” abrasives to produce abrasion.

The CBR rubber grasps an abrasive particle better than a hard-to-indent rubber like polyurethane or Neoprene and a ‘too soft” rubber like EPDM/ Neoprene. This latter rubber also indents too easily thus limiting the force that is available to push the abrasive against the test counterface. The rubber wheel probably touches the test specimen (Figure 13c). Observation number three: CBR’s low abrasion resistance, suggests that the abrasive grains readily remove wheel materials, roughening it and making it easier for abrasive grains to become fixed to the rotating wheel. A confirming observation in this study was that the SBR and Neoprene wheels had an almost polished surface finish after the ASTM G 65 tests while the CBR wheel was always rough and dull after testing (Figure 14). It was also noted in optical microscope studies of the test rubbers after rubbing with a dozen or so individual grains of 50/70 silica that CBR had less residual deformation left after grains of sand were forced into the rubber. It had better resilience that the other rubbers. The sand grains left “dents” that took time to recover.

Overall this study verified that chlorobutyl rubber is effective in producing 3-body abrasion in laboratory test rigs that use rubber as the source of the force and motion of the abrasive on the test substrate. The ranking tests on the Tribotester with SBR and Neoprene wheels suggest that other rubbers can effectively rank materials in three body abrasion tests, but the relative wear volumes may be different for different rubbers and wear volumes may be lower than if CBR rubber was used in the test rig.

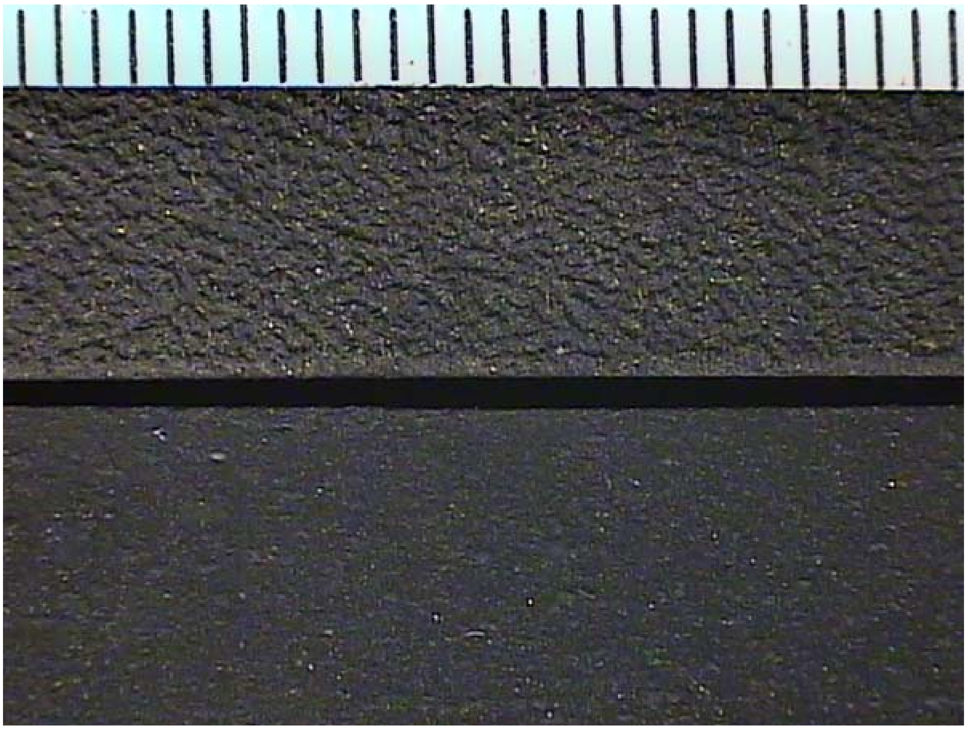

Figure 14. Surface texture of CBR wheel (upper) compared with Neoprene (70A) after many uses in the ASTM G65 abrasion test. Each division equals 1 mm.

One reviewer of this study suggested that if wear ratios are used (for example the wear volume of the test material be expressed as a wear ratio with a reference material) other rubbers could be used as test wheels in the G 65 test. To check this hypothesis we abraded type 304 stainless steel and type D2 tool steel with 50/70 silica using the ASTM G 65 procedure A with a SBR wheel and we compared the 304 /D2 wear ratio calculated from data in the appendix of the ASTM G 65 test standard. The data from the test standard produced a wear ratio of 5.1; the wear ratio for this same material pair was 7.2 in our study. This limited testing suggests that the use of wear ratios needs additional study before it an be used as a test metric in ASTM G 65.may not be the way to use other rubbers in the ASTM test. This study has shown that CBR is more effective than other rubbers in producing three-body abrasion so it should remain the preferred rubber for ASTM G 65.

CONCLUSIONS

1. Chlorobutyl rubber is more effective than other rubbers in producing 3-body abrasion that Neoprene and SBR in laboratory abrasion testing.
2. Chlorobutyl rubber wears more than other rubbers in abrasion testing
3. Chlorobutyl rubbers effectiveness in abrasion testing is the result to its tackiness, ability to easily indent and recover, and to surface roughening that occurs under abrasion conditions.
4. Chlorobutyl rubber needs to be replaced with a more durable and easier to obtain rubber because its poor abrasion resistance makes grooving possible with heterogeneous test specimens.
5. Additional study is needed to find a replacement for the chlorobutyl rubber used in the ASTM G 65 abrasion test.

Chlorobutyl rubber may be the best performing rubber for the wheel in the ASTM G 65 test from the abrasion standpoint, but it still needs to be replaced because of its high cost and poor availability. SBR was identified as the best candidate of the rubbers tested in this study with the best potential for replacing CBR in the ASTM G 65 abrasion test.

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