The effect of test parameters on large particle slurry erosion testing

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Abstract: Understanding the effect of testing parameters is important for getting the test environment as close as possible to real applications and for understanding the processes that are involved in the testing itself. A pin mill type slurry-pot wear tester was developed for heavy-duty testing with high speed and large abrasive size [1]. This study focuses on the effect of different testing parameters on large particle slurry testing. Parameters such as rotation speed of the samples, particle size and slurry concentration were varied.
Round steel samples and slurry with water and granite gravel were used for testing. The test parameter variations were 4 to 10 mm for granite particle size, up to 23 wt% for slurry concentration and up to 20 m/s for sample tip speed. The relationship between the particle size, slurry concentration, and the amount of particles are discussed. Also the role of the kinetic energy of the abrasive particles is considered for large particle sizes.

Key words: Slurry erosion, high speed slurry-pot, pin mill, particle size

1. INTRODUCTION

In the mining industry, erosion is the major wear mode in slurry pumping. In real applications the particle size can be as high as several centimeters. With larger particles, the wear mechanisms in the slurry systems shift from plain erosion to high stress abrasion and impact wear.

A new high speed slurry-pot erosion wear tester was developed at the Tampere Wear Center. The tester is based on the pin mill sample configuration that differentiates it from most of the other slurry-pot testers in use. [1] In the published slurry-pot tests, [2-4] small abrasive particles have been used, mostly smaller than one millimeter in average size. Moreover, sample speeds have been normally lower than 10 m/s. Therefore also published studies about particle size effect on slurry erosion have been mainly done with particle sizes around one millimeter, such as by Clark et al. [4]. Only a few studies have been conducted using larger particles, such as the pin mill studies by Jankovic [5] who used particles up to 5 millimeter in size.

In the present work, various testing parameters, such as sample speed, particle size and slurry concentration, were studied in large particle slurry erosion testing with the new slurry-pot tester. The aim was to understand the testing conditions better and have more knowledge about large particle testing for further development of the method.

2. MATERIALS AND METHODS

A pin mill type high speed slurry-pot [1] was used to cover various testing conditions in slurry erosion wear with round stainless steel samples. Fig. 1 illustrates the construction of the equipment. The samples are rotated horizontally in pin mill configuration on four levels. The levels are varied according to the sample rotation test method [1] during test. The test duration was 4x5 minutes as presented in Table 1.

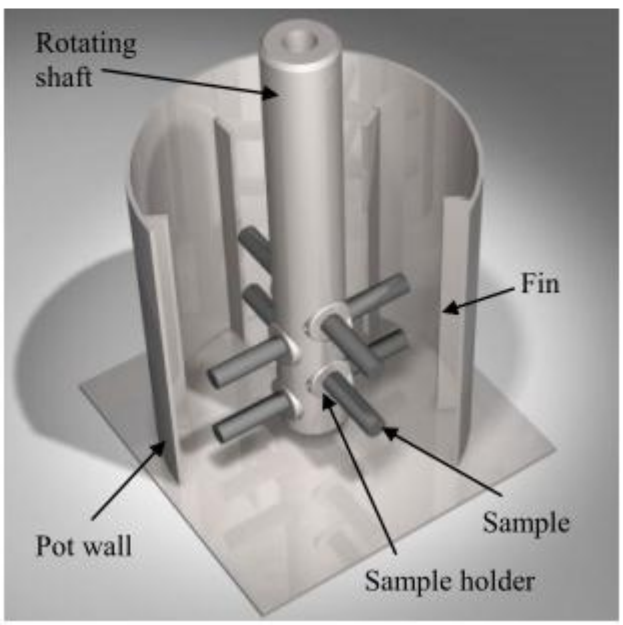

Figure 1. Construction of the pin mill type slurry-pot unit with round samples. [1]

Table 1. Sample rotation scheme and run durations used in the tests.

	Sample levels			
time [min]	**One or two samples on one level**			
0-5	L1	L2	L3	L4
5-10	L4	L1	L2	L3
10-15	L3	L4	L1	L2
15-20	L2	L3	L4	L1

The samples can be either full-length going through the sample holder and the shaft, or half-length so that two separate samples can be used on each level. Therefore, the tests can be done either with four full-length samples or eight half-length samples. In the current tests, both full- and half-length AISI 316 samples were used. Fig. 2 presents the dimensions of both sample types. The test material was kept the same as one of the purposes of these tests was to further develop the testing method and the testing device [1]. Due to the limitations of the number of samples available for the tests, same samples were used in multiple tests.

Granite gravel from Sorila quarry in Finland was used as the abrasive. The used particle size distributions were 4/6.3 mm, 6.3/8 mm and 8/10 mm. The maximum abrasive size that can be used with the current sample assembly is limited by the 10 mm space between the samples and the fins shown in Fig. 1.

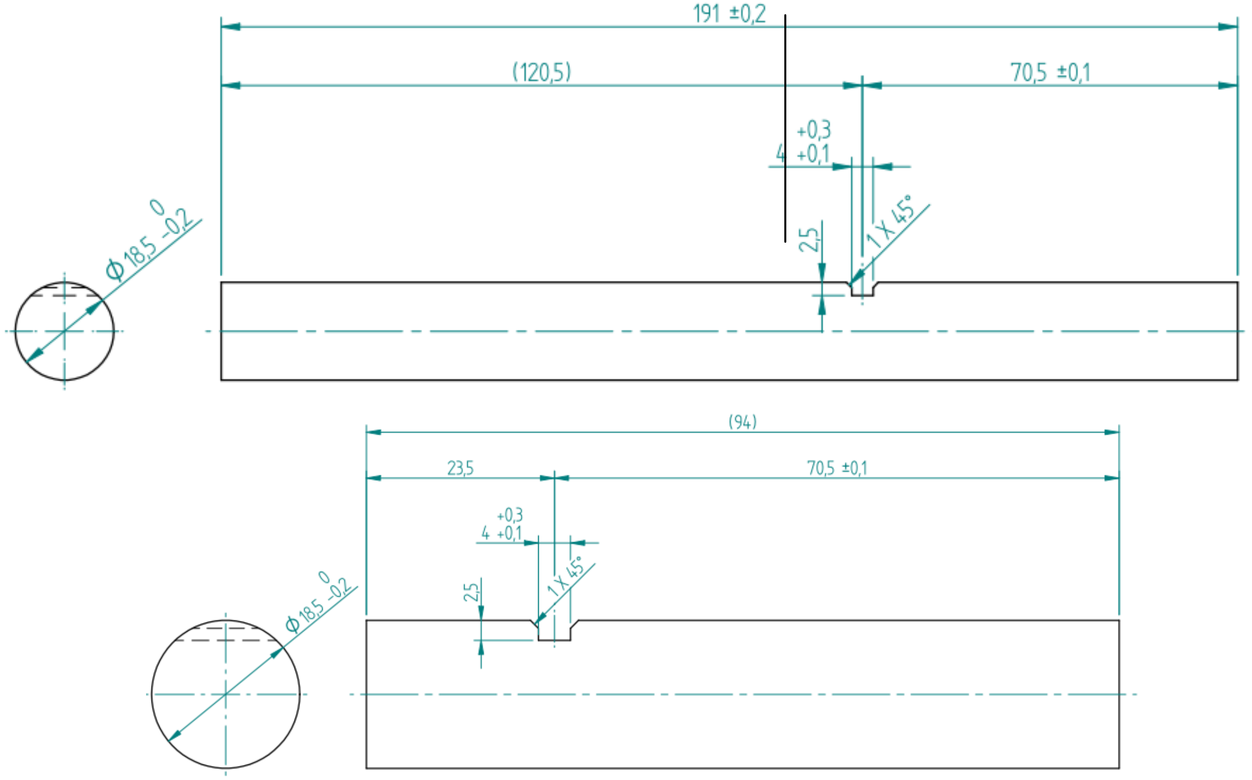

Figure 2. Dimensions of round full-length (upper) and half-length (lower) samples. The 4 mm wide notches in the samples are for fixing them to the sample holder with a set screw.

In the tests, the amount of gravel was varied from one to three kilograms. Thus, the slurry concentration varied from 9 to 23 wt-%, when 10 liters of water was added. Moreover, the rotation speed of the main shaft was varied from 1000 to 2000 rpm. In terms of sample tip speed, the rotation speed varied from 10 to 20 m/s. At the highest slurry concentration the rotation speed had to be reduced by 50 rpm due to the power limitations of the motor running the slurry-pot. Due to the pin mill sample configuration the peripheral speed along the sample length varies. At 2000 rpm the sample speed is 6 – 20 m/s along the sample length. Table 2 presents the test program.

Table 2. Testing parameters. Test 'Weight1' = 'Speed3'.

	Speed of		Abrasive		Slurry	Sample
Test ID	main shaft	sample tip	size	weight	concentration	length
Speed1	1000 rpm	10 m/s	8/10 mm	1 kg	9 wt%	half
Speed2	1500 rpm	15 m/s	8/10 mm	1 kg	9 wt%	half
Speed3	2000 rpm	20 m/s	8/10 mm	1 kg	9 wt%	half
Size1	2000 rpm	20 m/s	4/6.3 mm	1 kg	9 wt%	full
Size2	2000 rpm	20 m/s	6.3/8 mm	1 kg	9 wt%	full
Size3	2000 rpm	20 m/s	8/10 mm	1 kg	9 wt%	full
Weight1	2000 rpm	20 m/s	8/10 mm	1 kg	9 wt%	half
Weight2	2000 rpm	20 m/s	8/10 mm	2 kg	16 wt%	half
Weight3	1950 rpm	20 m/s	8/10 mm	3 kg	23 wt%	half

3. RESULTS AND DISCUSSION

3.1. Sample speed tests

According to the test program three different speeds ranging from 10 to 20 m/s were used with large 8/10 mm granite particles. The same eight half-length samples were used in all three tests. Before the first test the samples were pretested at

2000 rpm to make sure that fresh sample surface will not have a big influence on the result of the first test. The pretest with fresh samples showed almost 8 percent lower mass loss than the following actual tests with the same sample speed.

Fig. 3 presents the average results of the eight samples throughout the tests. The standard deviations of the final results varied from 2 to 4 percent. Also the number of main shaft rotations varied with sample speed as the test time was the same for all tests. Fig. 4 shows the results by mass loss per number of main shaft rotations.

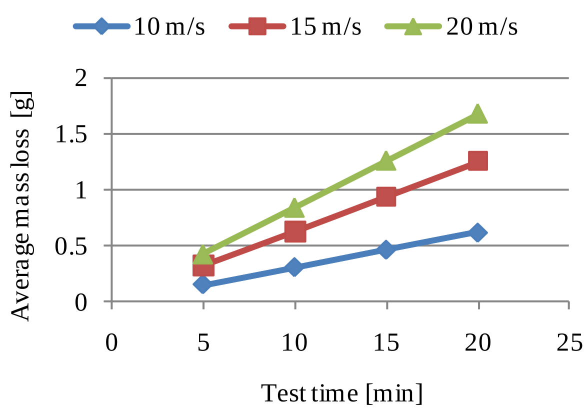

Figure 3. Test results of the sample speed tests for different sample tip speeds.

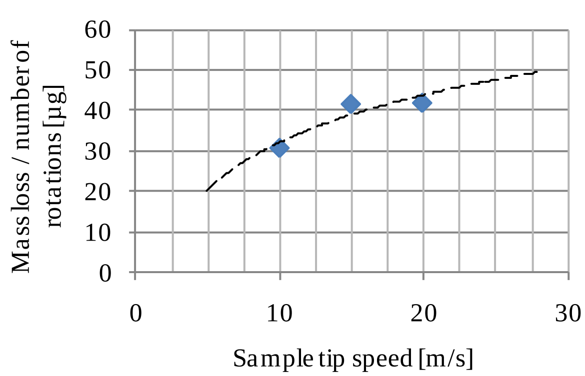

Figure 4. Mass loss per number of main shaft rotations for the tested speeds.

Although the kinetic energy of particles increases with speed, saturation of mass loss per shaft rotations towards higher speeds can be noticed. This can be explained by abrasive comminution [1]. At higher sample speeds the abrasives will be crushed faster to a smaller size. In addition, the edges of the granite particles become more rounded at higher speeds, which also decrease the wear rate [7]. It seems therefore evident that the results are affected by the competition between the kinetic energy and comminution of the abrasives.

3.2. Particle size tests

The particle size tests were done with three different particle sizes ranging from 4 to 10 mm. The running-in of the full length samples was done with 8/10 mm particle size at the same speed as the actual tests.

Fig. 4 presents the averaged results after full 20 minute testing of testing for all tests in the abrasive size order. The standard deviations within each three-sample sets varied between 0.2 and 0.9 percent. In the results, a slight upward tendency with increasing particle size can be noticed. This is quite expected, as smaller particles with lower impact energy tend to cause less erosion wear in the sample [6]. When comparing the particle size test results with the results of the speed and concentration tests, the results have to be divided by two because of the longer sample length. Fig. 5 shows an example how the mass losses develop during a sample rotation test. From the graph it is evident that the wear rate decreases clearly on sample level 3 (L3).

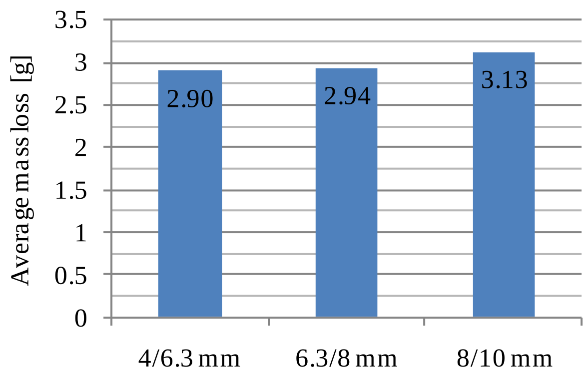

Figure 4. Test results for the different particle sizes.

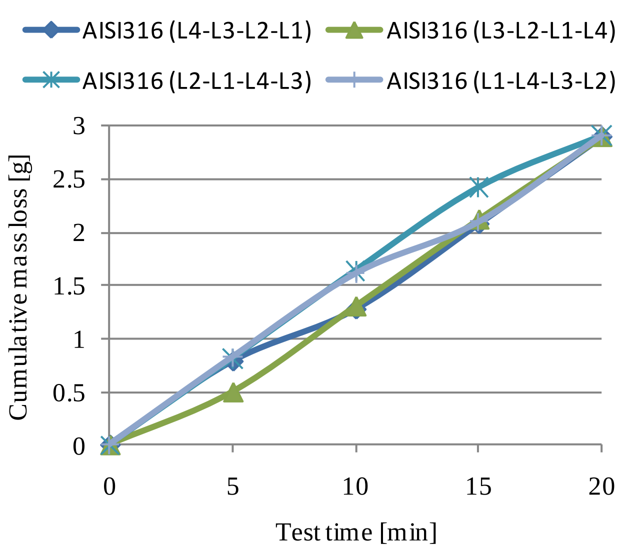

Figure 5. Cumulative mass loss in a sample rotation test with 4/6.3 mm particle size.

Although in these tests was the varied parameter, it is not the only changing parameter. With the increase in the particle size, the number of particles decreases, as the slurry mass concentration is kept unchanged, i.e. the total weight of the particles is the same. When this is taken into account and the total mass loss is divided by an estimate of the initial particle count, a strong trend is clearly visible in Fig. 6, which presents the results as mass loss per particle count.

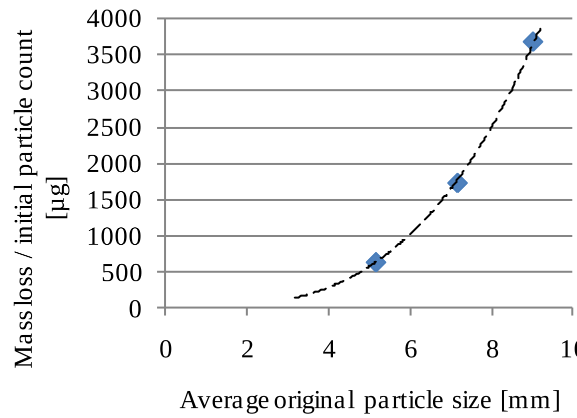

Figure 6. Mass loss per initial particle count for the tested particle sizes.

3.3. Slurry concentration tests

For the slurry concentration tests two new tests (‘Weight2’ and ‘Weight3’) were made. The results of test ‘Speed3’ were used as test ‘Weight1’, as denoted in Table 2. The same half-length samples were used as in the speed tests, so no running-in was needed. To study the wear surfaces after higher concentration tests, i.e. tests with 16 and 23 weight percent, two fresh and untested samples per each test were used and studied with a stereo microscope after the tests.

Fig. 7 presents the average results of the eight samples throughout the tests. The standard deviations of the final results ranged from 2.6 to 3.8 percent. The results are quite as expected, i.e., higher concentration means more particles in the slurry, which again means more mass loss in the sample.

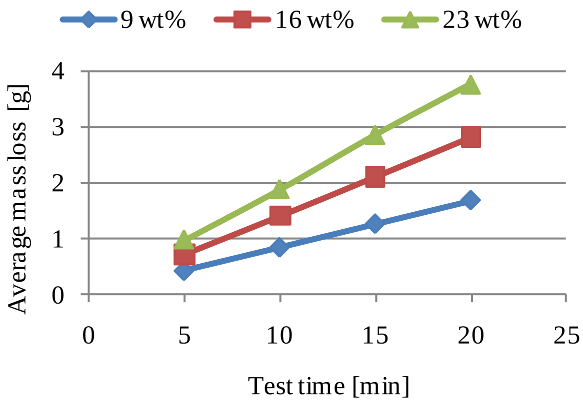

Figure 7. Test results of the slurry concentration tests.

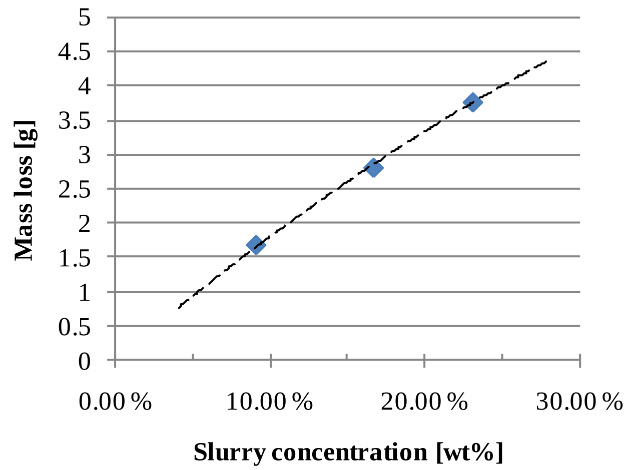

Figure 8. The mass losses at the tested concentrations.

Fig. 8 presents the final mass loss results as a function of abrasive concentration. The trend line is set to start at the zero point of the plot. Although it is not directly evident from the results, it could be expected that with increasing concentration the wear rate stabilizes at a certain level when the particles start to collide more with each other than with the samples. Also embedding of the surfaces with abrasive particles is increased when more particles are present, which can decrease the mass loss as they shield the surface.

3.4. Wear surfaces

During testing the sample tips were rounded heavily. Fig. 9 presents stereo microscope images of the sample tips after tests with 16 and the 23 weight percent concentrations. A clear difference in the material removal at the sample tips can be noticed, as higher slurry concentration causes more severe tip rounding.

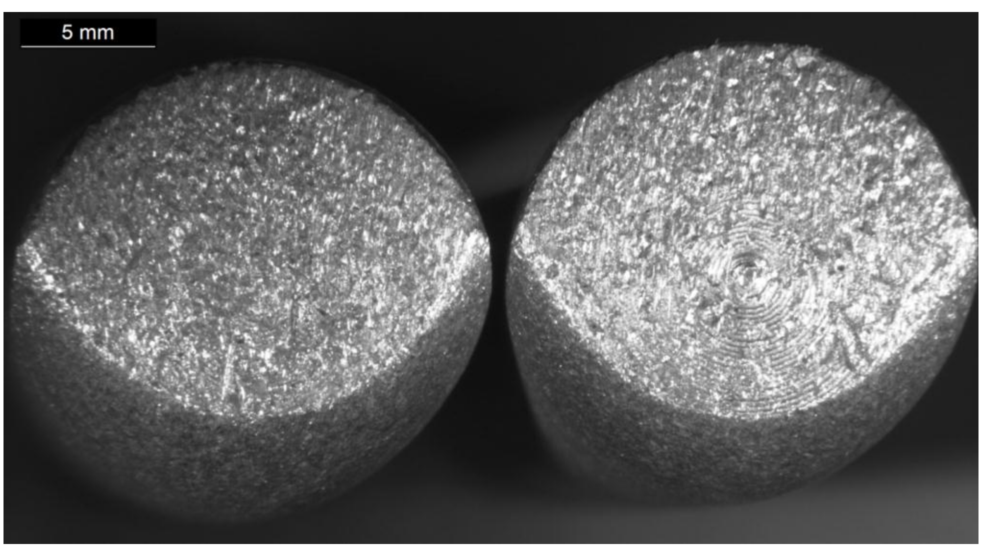

Figure 9. Sample tips after the tests with 23 wt% (left) and 16 wt% (right).

Fig. 10 shows a detail of the wear surface tested with a high abrasive concentration. Superficially the wear surfaces looked essentially the same after each test, but the smaller details of slurry erosion wear, such as the depth of impact craters, length of the abrasive scars or amount of embedded abrasive particles varied according to the test conditions.

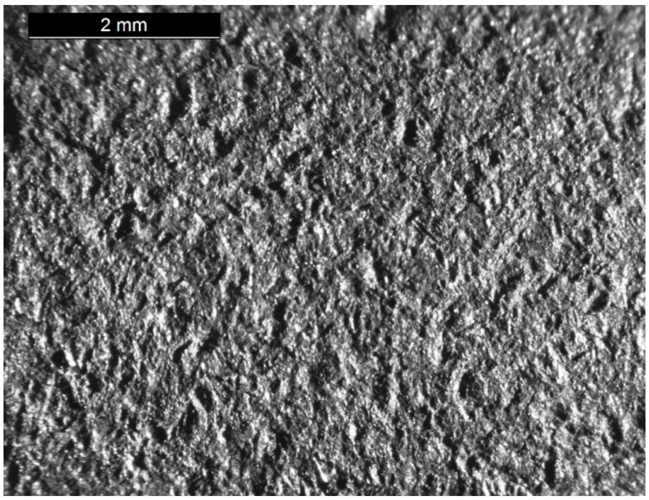

Figure 10. Wear surface after the test with the concentration of 23 weight percent.

Fig. 11 shows an embedded granite particle on the wear surface. Tests with high slurry concentrations left much more embedded particles on the specimen surfaces than the tests with lower concentrations.

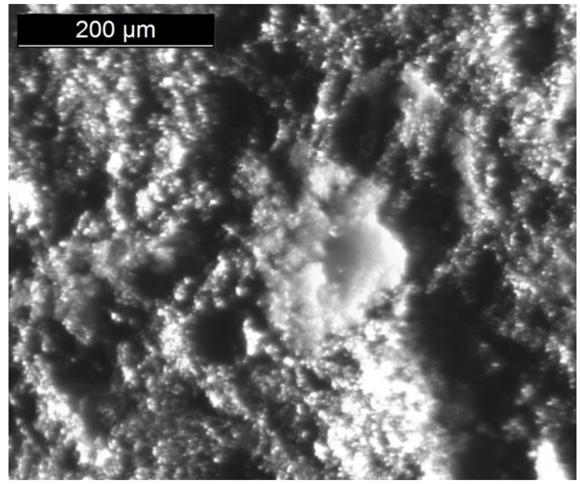

Figure 11. Embedded granite on the wear surface.

Fig. 12 shows short abrasive scar on the wear surface. Abrasive wear scars on the surfaces were short and scarce. Specimens tested with lower concentration had more scars. The figure has been taken horizontally to the sample length, so the scar is oriented in 45 degrees.

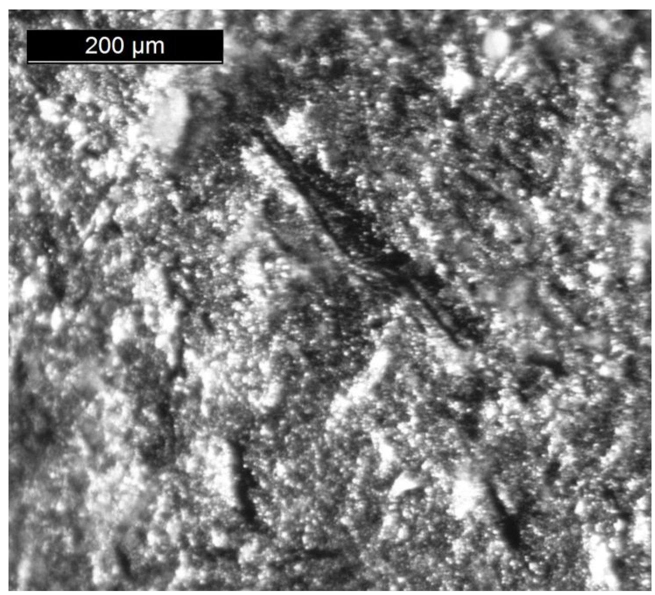

Figure 12. Short wear scar on the wear surface.

4. CONCLUSIONS

- Slurry erosion with large particle sizes was studied with three different sample speeds, particle sizes and slurry concentrations.
- At high sample speeds the mass loss is in general higher than at low speeds. However, the wear rate starts to stabilize at higher sample speeds when all other parameters are kept unchanged. The kinetic energy competes with the comminution of the abrasive particles. At higher speeds the kinetic energy of abrasive particles is higher, but because of increasing comminution the energy per particle (impact) decreases faster.
- The mass loss increases exponentially with particle size. Larger particles have more kinetic energy and they endure comminution longer.
- With increasing slurry concentration the mass losses become higher. At very high concentrations, however, collisions of particles with each other and the amount of embedded particles increase, decreasing the wear rate.

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