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Brake Wear Particle Size and Shape Analysis of Non-Asbestos Organic (NAO) and Semi Metallic Brake Pad

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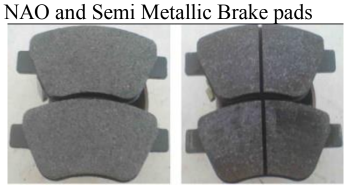
Graphical abstract

NAO and Semi Metallic Brake pads



Abstract

Brake wear particles resulting from friction between the brake pad and disc are common in brake system. In this work brake wear particles were analyzed based on the size and shape to investigate the effects of speed and load applied to the generation of brake wear particles. Scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDX) was used to identify the size, shape and element compositions of these particles. Two types of brake pads were studied which are non-asbestos organic and semi metallic brake pads. Results showed that the size and shape of the particles generatedvary significantly depending on the applied brake load, and less significantly on brake disc speed. The wear particle becomes bigger with increasing applied brake pressure. The wear particle size varies from 300 nm to 600 µm, and contained elements such as carbon, oxygen, magnesium, aluminum, sulfur and iron.

Keywords: Brake wear particle, wear debris, particle size, brake pressure, brake disc speed.

1.0 INTRODUCTION

Brake pads are grouped into three categories depending on the materials they are made of. The categories are non-asbestos organic (NAO), semi metallic, and low metallic (LM). According to Sander *et al.* the non-asbestos organic (NAO) brake pads have low wear rates and low brake noise but it is not suitable for high temperature use because it will lose braking capacity [1,2]. Semi-metallic brake pads contain high steel fiber and iron powder and operate at low wear rates but the pads are noisier than the other types of brake pads. Low metallic brake pads have a high friction and good braking capacity at high temperatures because the pads contain high abrasive.

During braking, the friction between disc and pads will cause the pads to wear. Structure and hardness of the friction layer that covers the surface pad or disc can be a factor that controls wear rates and friction levels. As the brake pads wear, the particles produced are in the form of particles. These wear particles collectively are referred as wear debris. In more modern pads, the wear debris generated during sliding process contains more species as the braking materials used in the pads become more complex.

Kukutschova *et al.* reported that the wear of the brake lining depends on sliding speed, applied pressure and temperature. They also reported that the friction layer on surface of the brake lining has similar chemistry with the wear debris. Also,the brake wear particles from the semi-metallic pads was found have an average size of approximately 200 µm measured by SEM. The largest particle size measured was around 800 µm and the smallest around 2 µm. EDX analysis of the wear debris showed that all the elements in the debris were carbon, oxygen, aluminum, magnesium, sulphur, silicon, barium, antimony, iron, copper, calcium, potassium, zirconium and bromine [3].

Wahlstrom *et al.* tested low-metallic and non-asbestos organic (NAO) brake pads against grey cast iron disc. Analysis from both tests concluded that the particle concentration that went airborne was of particle sizes of around 280 nm and 350 nm. SEM images of the wear particles showed there were three categories of particles sizes which are ultrafine, fine and coarse fractions [4].

Mosleh*et al.* analyzed the effects of sliding speed and contact pressure in the generation of brake wear particles from a typical truck disc brake pad material against gray cast iron. They reported that the wear particles size becomes bigger as the brake pressures increased. They also showed the sub-micron and micron-sized particles agglomerate with large particles in a variety shapes [5].

Many studies are also done to demonstrate the relation between the airborne particles in atmosphere and health effects. Particle size is an important factor that must be investigated to understand how the particles can affect human health. According to the studies, some of the wear debris that were generated from brake wear will become airborne. Garg *et al.*found that 35% of the brake wear debris become airborne [6], while Sanders *et* *al.*reported that 50% of the wear debris become airborne [1,2]. Wahlstrom *et al.*reported that most coarse particles that have diameters 2.5-10 µm are easily exposed to the nose and throat, while fine particles that have diametersof 0.1-2.5 µm and ultrafine particles that have diametersless than 0.1 µm directly pass into the lungs [7].

Wear debris from brakes consist of hazardous elements that might affect living organisms and could lead to carcinogenesis. Different types of brakes will generate different amounts of chemical elements [8].They have found that the particles are a potential danger to the environment and human health. Ultrafine particles have more potential than larger particles to cause pulmonary inflammation, tissue damage and lung tumors although both have the similar composition. It can easily be deposited deeper into the respiratory tract because the sizes of the particles are too small [9]. It could also significantly cause other health problems which include chronic respiratory disease, asthma and acute respiratory symptoms, causing premature mortality. Other than that, the particles generated from the braking process contain hazardous elements that can cause danger to living organisms. Due to high number of vehicles worldwide, emission of brake wear particles to the environment may contribute to water and air pollution and cause several adverse health effects [6,9].

The objectives of this investigation are to analyze the effects of different loads and speeds in generating wear particles and to characterize the sizes and shapes of the generated wear particles.

■2.0 EXPERIMENTALSET UP

An experimentalrig was designed and built as in Figure 1 to measure the amount of brake debris produced, and to characterize the debris, following [10,11]. The rig is capable of constant speed and constant pressure experiments. The test rig use grey cast iron disc mounted vertically on the shaft which is driven by an AC motor that can provide maximum power output of about 11 kW. A speed controller is used to control the speed of the rotating shaft. A hydraulic unit capable of up to 70 bars or 7 MPa, was used to apply pressure to the brake system. Two types of brake pads were used in these investigations which are non-asbestos organic and semi metallic brake pads.

The tests were conducted at constant speed and constant brake pressures, for each type of the brake pads. For constant speed tests, experiments were conducted for three different brake pressures of 0.5, 1.0 and 1.5 MPa ata constant speed of 50 rpm. While for the constant pressure tests, experiments were conducted at three different speeds of 50, 75 and 100 rpm at a constant brake pressure of 0.5 MPa. All experiments were conducted for 15 minutes. Brake wear debris generated from the braking process was collected and examined.

Figure 1 Brake test rig that used for the experiments.

Analysis of the particles generated was conducted using scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDX) to determine the size, shape and elemental composition of the brake wear particles. The SEM images provide more accurate information about the wear debris size since the particle agglomeration or adhesion and dispersion can be easily observed. The SEM allows more of the specimen to be in focus at one time because it has a large depth of field. The SEM also has much higher resolution of magnification, so that the image of the brake wear particles can be seen clearly. EDX provides the composition of elements that are contained in the brake wear particles.

■3.0 RESULTS AND DISCUSSION

3.1 Non Asbestos Organic (NAO) Brake Pad

The constants speed test was conducted at 50 rpm with three hydraulic pressuresof 0.5 MPa, 1.0 MPa and 1.5 MPa. The debris from each test was collected and analyzed using scanning electron microscope (SEM). Based on the analysis done using SEM, range sizes measured for the first test using 0.5 MPa pressure were around 40 µm to 100 µm (Figure 2). For the second test using 1.0 MPa pressure, the range sizes were between 100 µm and 140 µm (Figure 3). Most of the particles had size around 120 µm to 300 µm when test conducted with the 1.5 MPa pressure (Figure 4).

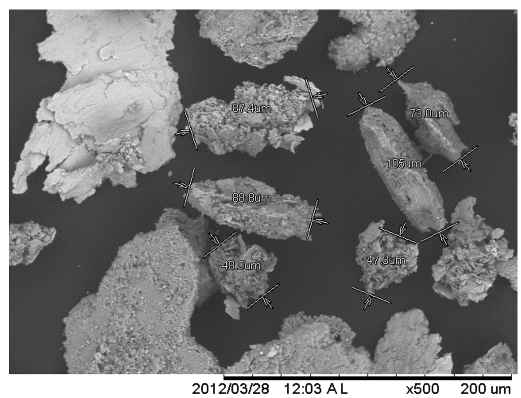


Figure 2 Constant speed test (50 rpm) with braking pressure of 0.5 MPa producing particlesof sizes of 40 µm to 100 µm.

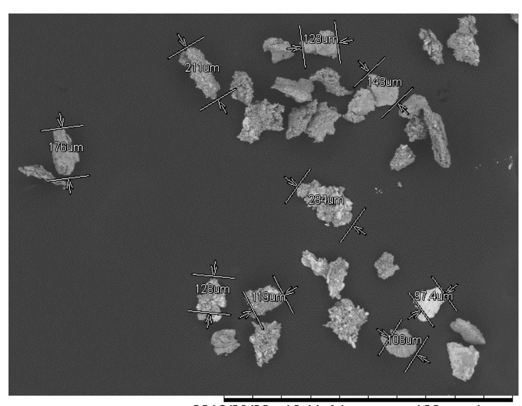


Figure 3 Constant speed test (50 rpm) with braking pressure of 1.0 MPa producing particlesof sizes of 100 µm to 140 µm.

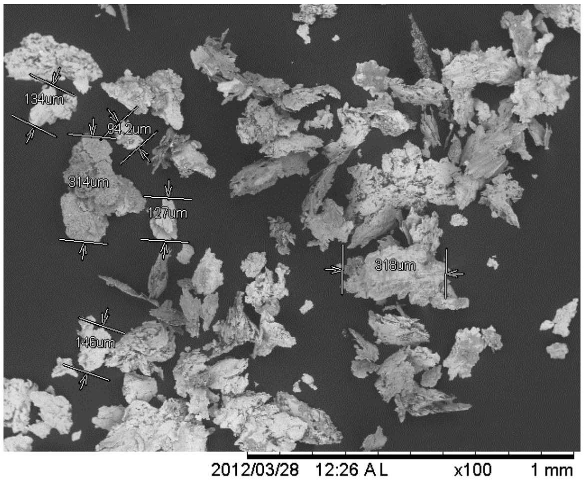


Figure 4 Constant speed test (50 rpm) with braking pressure of 1.5 MPa producing particlesof sizes of 120 to 300 µm.

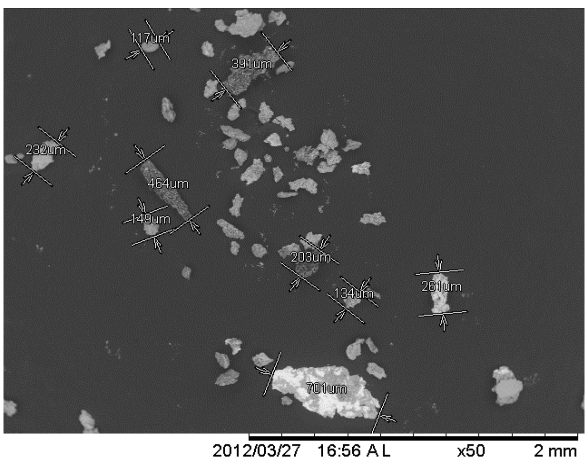


Figure 5 Constant pressure test (0.5 MPa) at 50 rpm producing particlesof sizes of100 to 200 µm.

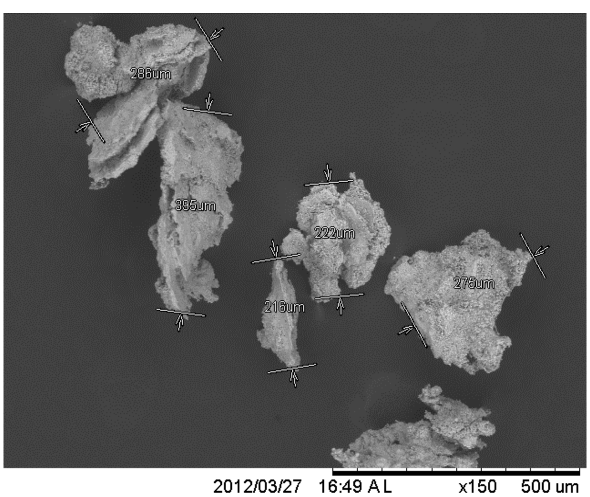


Figure 6 Constant pressure test (0.5 Mpa) at 75 rpm producing articles of sizes from 200 to 300 µm.

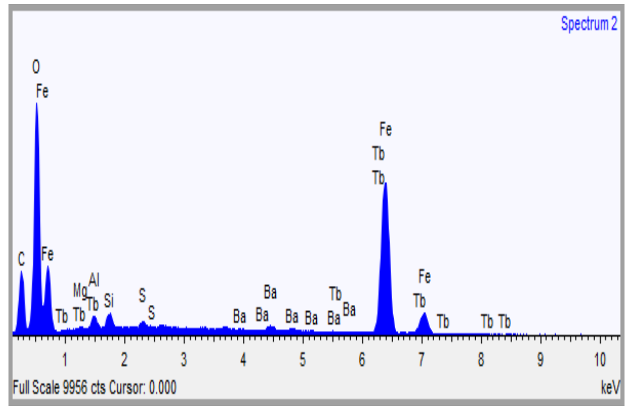


Figure 7 Element spectrum using EDX in the brake wear debris

Constant pressure test was performedat 0.5 Mpa with three different speeds of 50, 75 and 100 rpm to investigate the influence of speed on wear particle generation. The results of the SEM images showed that the wear particles generated from all the three tests wereparticles sizes in the range of100 and 300 µm. Figures5 and 6 show the size range of the particles that were generated from the constant pressure test.

Figure 7 shows the element spectrum usingEDX analysis from a sample of wear debris collected from the non-asbestos organic brake pads. Table 1 shows the weight and atomic percentage of the elements that were detected in the composition of the brake wear debris, which included carbon, oxygen, magnesium, aluminum, silicon, sulfur, iron, barium and terbium.

Table 1 Composition of NAO brake wear particles by EDX

Element	Weight %	Atomic %
Carbon	17.618	34.680
Oxygen	30.570	45.176
Magnesium	0.114	0.110
Aluminum	0.727	0.637
Silicon	0.791	0.666
Sulfur	0.347	0.256
Iron	40.163	17.003
Barium	1.422	0.245
Terbium	8.249	1.227

3.2 Semi Metallic Brake Pad

Another series of tests were conducted for the semi metallic brake pads. The constant speed tests were conducted at 50 rpm andbraking pressures of 0.5, 1.0 and 1.5 MPa. The SEM analysis shows that the range particlesizesrangefrom 100 to 200 µm for 0.5 Mpa braking pressure as shown in Figure 8. For braking pressure 1.0 MPa, most of the brake wear particles are of sizesbetween 150 to 250 µm (Figure 9), and for the 1.5 MPa braking pressure thr wear particlesare between 250 and 550 µm (Figure 10).

The constant pressure test was performed at 0.5 Mpa at three different speeds of 50, 75 and 100 rpm to investigate the influence of speed on wear particle generation. SEM images showed that the particles size generated from this seriesof tests had the size range of between 100 µm and 300 µm. Figures 11 and 12 show the sizes of the particles that were generated from the constant pressure test.

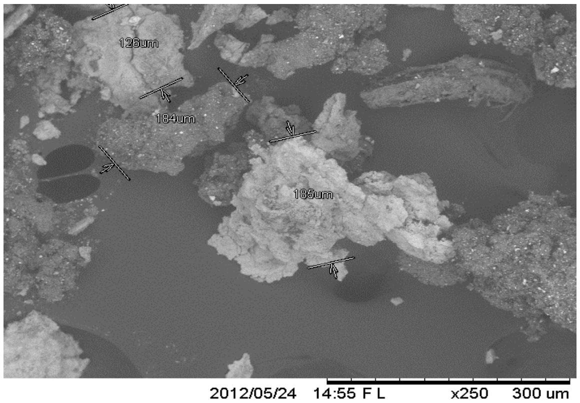


Figure 8 Constant speed test (50 rpm) producing particles of sizes 100 to 200 µm with 0.5 Mpa braking pressure.

EDX analysis of the sample of wear debris collected from semi-metallic brake pad is shown in Figure 13 and Table 2. The elements that were detected in the semi-metallic brake debris were carbon, oxygen, magnesium, aluminum, silicon, sulfur, calcium, iron, barium and terbium.

Table 2 Composition of semi metallic brake wear particles by EDX

Element	Weight %	Atomic %
Carbon	20.918	51.853
Oxygen	8.110	15.092
Magnesium	0.240	0.294
Aluminum	0.710	0.784
Silicon	0.818	0.867
Sulfur	0.734	0.682
Calcium	0.292	0.217
Iron	49.832	26.567
Barium	7.077	1.534
Terbium	11.269	2.111

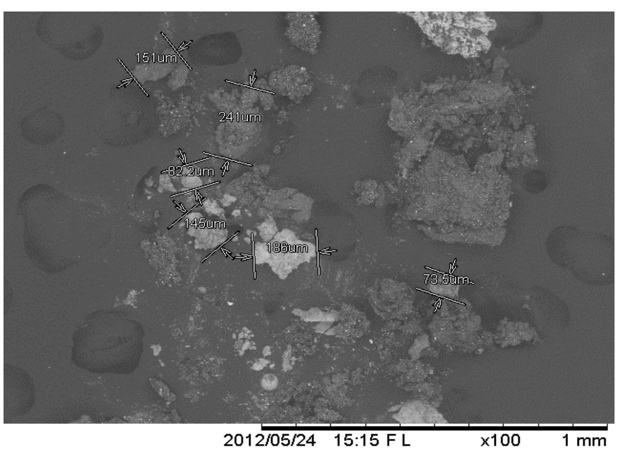


Figure 9 Constant speed test (50 rpm) producing particles of sizes 150 to 250 µm with 1.0 Mpa braking pressure.

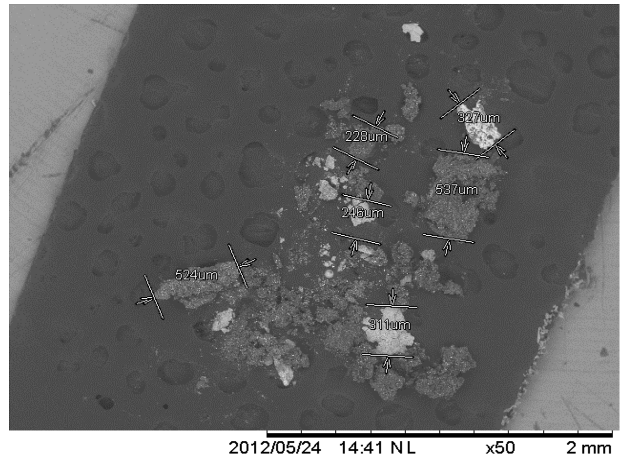


Figure 10 Constant speed test (50 rpm) producing particles of sizes 250 to 550 µm with 1.5 Mpa braking pressure.

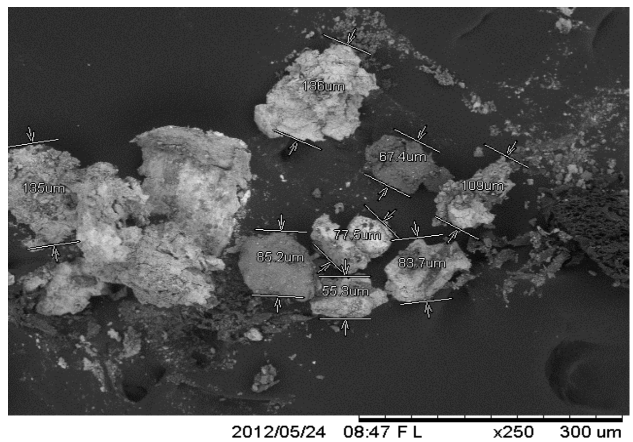


Figure 11 Constant brake pressure test (0.5 MPa) at 100 rpm produced wear particles of sizesfrom 100 to 300 µm.

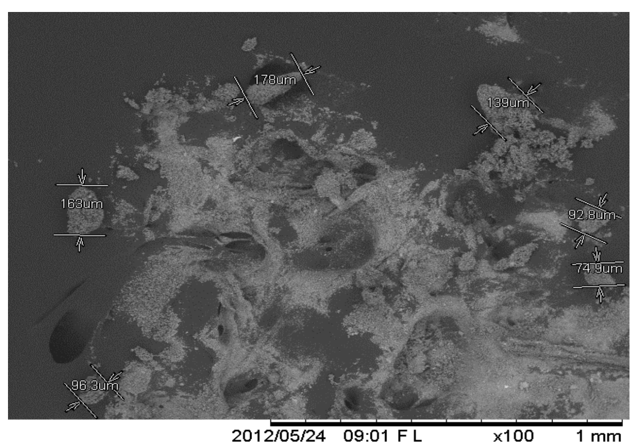


Figure 12 Constant brake pressure test (0.5 MPa) at 100 rpm produced wear particles of sizesof about 200 µm.

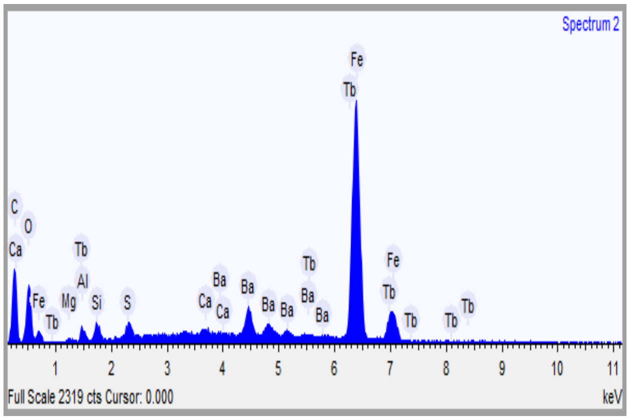


Figure 13 Element spectrum using EDXfor semi metallic brake wearparticles.

After comparing all the results, the size and shape of the brake wear particles can be said to depend on the applied pressure to the brake. For both experiments using NAO brake pads and semi-metallic brake pads, the pressure applied affected the size and shape of wear particles generated more significantly compared to speed. When the pressure load increases, the wear particles size became bigger. This can be seen in the SEM images for the constant speed tests as shown in Figures 2, 3 and 4 and Figure 8.and 10.

On the other hand, the rotational speed of the disc brake did not give significant effect to the size and shape in of the wear particles. Both NAO and semi-metallic brake pads produced similar results in terms of the size and shape of the particles generated. The main difference for NAO and semi-metallic brake pads are only in the chemical compositions of the particles.

Based on the analysis using SEM images, there are three categories of particle sizes which is ultrafine (diameter < 0.1 µm), fine (0.1 µm < diameter < 2.5 µm) and coarse (2.5 µm < diameter < 10 µm). The average particles size for all the experiments is approximately 200 µm. However, SEM analysis shows that there were some particles thatare below 1 µm as shown in Figure 14. Most of the ultrafine and fine particles were agglomerated with the coarse particles. Many of these coarse particles which are mostly visible are covered with smaller wear particles in the ultrafine and fine categories,These tend to aggregate around the bigger debris.

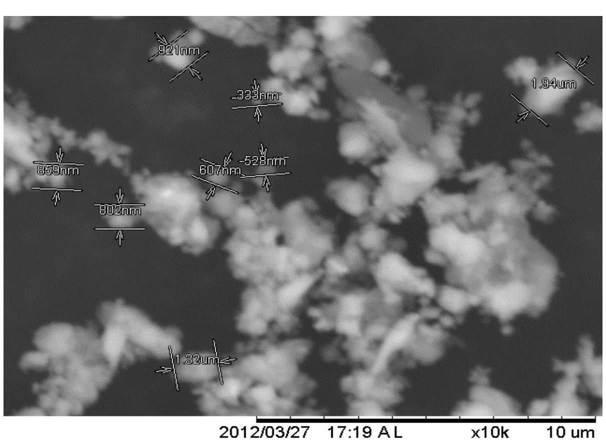


Figure 14 Ultrafine particle agglomerated with coarse particles

The Particle size is the main factor influencing how particles are deposited in the respiratory tract and affect human health. Most coarse particles can enter through the nose and throat, while fine and ultrafine (nano sized) particles can mostly penetrate deep into the lungs [1]. The metal elements content in the particles have also been suggested to have an effect on their toxicity level. During braking, both the brake pads and disc experience wear, generating metallic wear particles. Some of these particles are deposited into the brake hardware, while others become airborne. From this experiment, it is shown that the brake wear debris contributed to generation of $PM_{2.5}$ (Particulate Matter < 2.5 µm in diameter) and PM_{10} (Particulate Matter between 2.5 µm and 10 µm).

Most of the particles generated appearedlike flakeswith many sharp edges as shown in Figure 15and seem to be mechanically generated. These particles indicate that they originate from the disc because the particles consist mainly of iron and iron oxide. On the other hand, some of the coarse particles contain carbon, oxygen, magnesium, aluminum and iron which indicated that they originate from the brake pads.

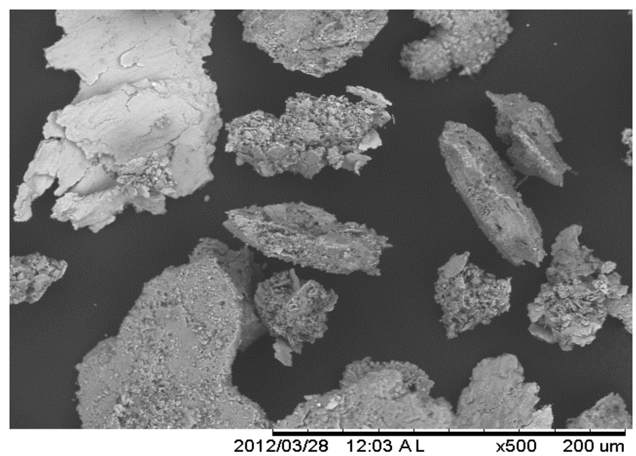


Figure 15 Generated wear particles mostly are flakes in shape

■4.0 CONCLUSION

The effect of different load and speed in generating wear particles was investigated using a brake test rig. Characteristics of the wear particles based on size and shape was analyzed using scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDX). Two types of brake pads analyzed in this project were non-asbestos organic (NAO) and semi-metallic brake pads.

The following conclusions can be made:

- Average particles size generated from the brake wear was about 200 µm. The size of the smallest particles measured was around 300 nm and the largest was around 700 µm.
- The brake contact pressure was the main factor that affects the size of the wear particles. Size of the particles generated increase with the braking pressure.
- Sliding speed does not significantly affect the size and shape of wear particles. Increasing or decreasing the sliding speed give similar results.
- The shape of the generated wear particles are mostly flake like that has sharp edges.
- Particles containing elements such as carbon, oxygen, magnesium, aluminum, sulfur and iron were found. These

chemical and metal elements are considered toxic and thus are dangerous for environment and human health.

Acknowledgement

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