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Effects of grain size on the tribological performance of automotive brake pads from waste Thais Coronata shells

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Abstract

The development of non-asbestos automotive brake pads using Thais Coronata shells as reinforcement material was investigated in this study. The aim was to investigate the optimal particle size that can be used for production. Six samples with different grain sizes (63µm, 90µm, 125µm, 250µm, 500µm, and 850µm) were developed from compression molding. The physical, mechanical, and tribological properties of the developed green automotive brake pads were evaluated and compared with two commercial samples. The test results showed that the compressive strength, hardness, and coefficient of friction properties decrease with increase in grain size except for absorption rate, wear, and thermal stability which showed an increase with increasing grain size. The 63µm brake pad exhibited better mechanical and tribological properties than the commercial brake pads. From the friction coefficient analysis, 125µm, 90µm, and 63µm developed samples can be used in heavy-duty vehicles since they fall within the class H (>0.55) type of brake pads.

Keywords: *Brake pads, Eco-friendly, Thais Coronata shells, Grain size, Mechanical and tribological properties*

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1. Introduction

The disc brake system used in modern vehicles forces two flat brake pads against a rotating disc on the application of the braking force thereby reducing the motion of the vehicle. The braking operation often results in the wearing of pads. Hence, efficient reinforcement materials capable of withstanding brake wears should be employed in the production of brake pads. Brake pad materials are classified as metallic, carbon-carbon composites, and organic polymers (Bijwe, 2014). Organic polymeric friction materials are widely used in modern-day passenger vehicles. They consist of reinforcements, friction modifiers, and fillers adequately bonded together by resins. Asbestos was a major reinforcement material used in the production of organic polymeric brake pads. However, due to the toxic nature of asbestos fibers, the focus is now on the use of non-asbestos-based organic brake pads. Non-asbestos organics are made from solely animal-based reinforcements, plant-based reinforcements or a hybrid of plant and animal reinforcements (Ekpruke et al., 2022). These brake pads possess tremendous mechanical and tribological properties and compare well with other commercial products. To ensure high-quality products, it is important to investigate the effect of grain size on the tribological performance of non-asbestos organic brake pads. Research in this area is needed to determine the optimal grain size that can be used in developing high-quality non-asbestos organic brake pads for the purpose of commercialization.

Ossia and Big-Alabo (2021) investigated the effect of particle size on non-asbestos organic brake pads developed from waste snail shells. Different grain sizes ranging from 90µm, 125µm, 250µm, 375µm, and 500µm were used to develop samples of the organic brake pads and their properties were evaluated. It was observed that the mechanical and tribological properties of the developed brake pads decrease with increase in particle size, following a negative index power law model. However, the opposite was observed for the swelling rate. Swelling rate properties increased with increase in particle size and its model followed a positive index power law due to the pores in the matrix.

Ossia et al. (2020) also studied the effect of grain size on the physicomechanical properties of brake pads developed from coconut shells. The coconut shells were grounded into powder using a grinding machine and sieved into different grain sizes of 90µm, 500µm, 600µm, and 850µm, which were then used to produce different samples. They found out that there is improved interfacial bonding between the coconut shells particles and the binder used in the formulation and this property decreases as the grain size increases.

Adegbola et al. (2017) observed that the interfacial bonding of a cow bone organic brake pad increases as the cow bone particle sizes decrease from 850µm to 250µm. Therefore, the 250µm cow bone brake pads gave better mechanical properties compared to other higher particle sizes investigated. The effect of periwinkle shell particle size on the wear behavior of asbestos-free brake pads was investigated by Amaren et al. (2013). The developed brake pads were produced by varying the periwinkle shell particles from 125µm, 250µm, 355µm, 500µm to 710µm and mixed with phenolic resin and other ingredients. The results from the study showed that the +125µm particles of the periwinkle shell gave the optimum wear resistance.
Aigbodion et al. (2010) also evaluated the effect of particle size on the performance of bagasse-based brake pads. The residue fiber from sugarcane was sun-dried, ground, and sieved into grade sizes of 710µm, 350µm, 250µm, 150µm, and 100µm. Different sizes were used to produce bagasse-based brake pads. Different tests were conducted on the produced brake pad and the result obtained showed that particle size can influence the performance properties of the pads and that brake pads produced from bagasse of 100µm sieve grade gave the optimum properties. Other scientific studies in this area can be found in literatures (Abhulimen and Orumwense, 2017; Nandiyanto et al., 2021; Elakhame et al., 2016; Olele et al., 2016; Oladele and Adewole, 2013; Afolabi et al., 2015).

This study involves the use of Thais Coronata Shells (an agro seafood waste, richly abundant in coastal regions) in the development of eco-friendly brake pads. The shells were ground to different grain sizes and used as reinforcements. The present work investigated a finer grain size than what has been studied before. The aim is to consolidate previous findings on the effect of grain size on the performance of resin-based organic brake pads and to also determine the most effective grain size that is suitable for developing asbestos-free automotive brake pads from Thais coronata shells.

2. Materials and methods

The main materials used for the development of the brake pads are as follows: Thais Coronata shells which were sourced locally are used as reinforcement; Epoxy resin *(99% purity; Dachy polymer, Taiwan)* was used as a binder. Calcium carbonate *(99.5% purity; Skyline chemical, USA)* was used as fillers. Iron and copper filings were used as abrasives and thermal conductivity enhancers respectively. Methyl ethyl ketone peroxide (MEKP) *(98% purity; Akzonobel, China)* was added as a catalyst, and carbon black *(99.9% purity; Loba Chemie PVT Ltd., India)* was used as a friction modifier. The uncrushed Thais Coronata shells used in the development of the brake pad samples are shown in Figure. 1 and the percentage composition by weight of the various materials used in the formulation is shown in Table 1.

Fig. 1: Thais Coronata shells

Table 1. Percentage composition by weight of various materials used in formulation.

S/N	Materials	Composition (%wt)
1	Thais Coronata Shells (reinforcement)	54.7
2	Epoxy resin & Hardener (binder)	30
3	Calcium carbonate (filler)	9.7
4	Methyl ethyl ketone peroxide (catalyst)	2.8
5	Fe filings (abrasive)	1.0
6	Copper filings (thermal conductivity enhancer)	1.3
7	Carbon black (friction modifier)	0.5

2.1 Material preparation

The Thais Coronata shells were sourced locally from Bille, a riverine community in Rivers State, Nigeria. The shells were washed thoroughly to remove dirt and sundried for one week to remove moisture. The dried shells were crushed into smaller pieces using a pestle and mortal and finally pulverized using the Denver laboratory ball milling machine. The ground shells were sieved into different grain sizes of 63µm, 90µm, 125µm, 250µm, 500µm and 850µm with the aid of the Sieve shaking machine and sieve stack.

2.2 Development of brake pad composites

A weighted percentage of the Thais Coronata shells, $CaCO_3$, carbon black, Fe, and Cu filings were taken and mixed thoroughly in a neat bowl (Mix A). A homogeneous mixture of the resin and hardener (taken in ratio 2:1) together with the MEKP was also obtained in a separate bowl (Mix B). Mix B was poured into Mix A and stirred thoroughly to obtain a homogenous mixture. The homogeneous slurry was poured into a laboratory circular mold for compression molding at a pressure of 13MPa. The developed samples were subjected to heat treatment in an electric oven for 3 hours of curing time at a temperature of 165ºC.

2.3 Mechanical Characterization of cast samples

After developing the samples, they were prepared for oil and water absorption, compression, hardness, friction, and wear tests.

2.3.1 Absorption rate (Oil and water)

The oil and water absorption tests were determined following ASTM D570-98 (ASTM, 2010) standard testing procedures.

2.3.2 Compressive strength

The compressive strength of the developed samples was tested using a universal testing machine *(COMTEST: UTM-3000, Germany)* with a maximum strength capacity of 100kN. The compressive strength test was done in accordance with the specifications of ASTM D695-02a (ASTM, 2002a).

2.3.3 Hardness

The shore D hardness Tester *(PCE-D, India)* was used to determine the hardness of the samples. The hardness values at three different test points of the samples were obtained and the average was taken according to the ASTM D2240 (ASTM, 2021) standard procedures.

2.3.4 Friction and wear tests

Friction and wear tests were conducted on a pin-on-disk tribometer *(CSM Instrument, Austria)* using ASTM D99-05 (2005) test method. The sample weight before and after the friction test was taken and the wear rate was calculated as a ratio of weight loss over the sliding distance.

2.3.5 Thermogravimetric analysis

Thermogravimetric analysis (TGA) was conducted on the developed green brake pad samples and the commercial samples (control 1 and 2) following the ASTM 1131-03 test procedures (2014). The brake pad samples were heated from ambient to 500°C in nitrogen in a thermogravimetric analyzer (*TA instrument; TGA 5500, US*) and the resultant percentage weight loss was calculated.

3. Results and discussion

3.1 Liquid absorption

Fig. 2 shows the oil and water absorption rate of the newly developed brake pads concerning particle sizes. The present paper incorporates a more practical investigation of the brake pad by evaluating its performance at a temperature of 100°C (hot water test). The aim is to study the behaviour of the brake pads under high braking temperatures in a moist environment. It was observed that the samples absorbed more water under a temperature of 100°C than under the ambient temperature. This is because the intermolecular bond of the composite matrix was broken at that temperature resulting in increased permeability of the composite. From Fig. 2, it is also shown that there is an increase in absorption rate as the grain size increases. This may be attributed to the fact that the larger grain-size composites are relatively more porous than the smaller grain-size composites. This absorption trend was also observed by Ibhadode and Dagwa (2008) on palm kernel shell composites and Ossia et al. (2020) on coconut shell composites. The two control samples also showed significantly low absorption rates as the 63µm Thais Coronata grain-sized composite as observed in Fig. 2.

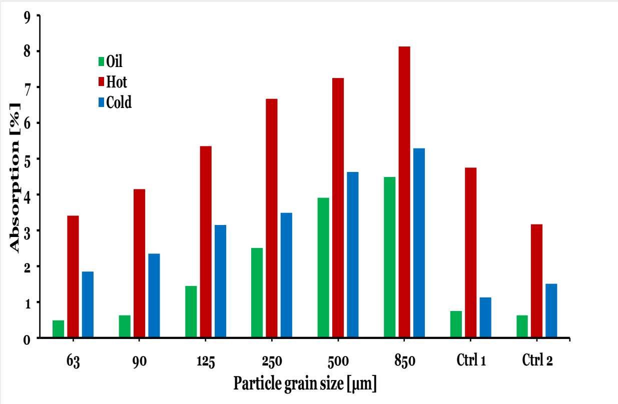

Fig. 2: Absorption rate of developed brake pads with different grain sizes

3.2 Hardness

Fig. 3 shows the variation of the brake pad hardness with grain size. There is a decrease in the hardness of the brake pads as the particle size increases. This is because the particles bonded less compactly as the grain size increased. The sample with a grain size of 63µm had the highest hardness value of 80 while the two control samples has hardness of 64 and 60 respectively. Based on the well-known Archard wear model, wear volume is inversely proportional to hardness while being directly proportional to load and sliding distance (Frerot et al., 2018). This implies that the higher the hardness of the material the lower the wear rate. Therefore, the developed sample with particle size of 63µm has the potential to exhibit better wear rate properties than the higher grain-sized samples and the two commercial samples used as control.

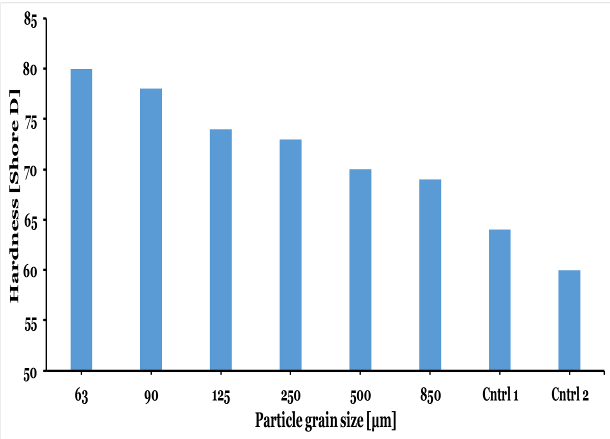

Fig. 3: Hardness properties of developed brake pads with different grain sizes

3.3 Compressive strength

The compressive strength of the developed brake pad samples decreased with increase in grain size as shown in Fig. 4. This is similar to the relationship between hardness and grain size. As the grain size increases, the strength of the interfacial bonding decreases and the nucleation sites for mechanical failure multiply. Hence, the samples with larger grain sizes fail at lower compressive loads as a result of weaker matrix bonding due to the presence of particle voids leading to more crack initiation and propagation sites. The 63µm grain size sample gave the highest compressive strength of 3.94MPa.

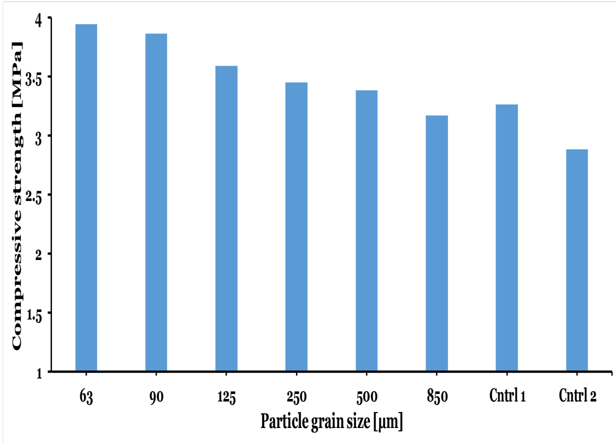

Fig. 4: Compressive strength of developed brake pads with different grain size

3.4 Coefficient of friction

The coefficient of friction history of all the samples is characterized by 2 phases: transient and steady state. The transient phase is marked by an increase in friction from the minimal value to the onset of the steady-state phase while the steady-state phase moves from the end of the transient phase and maintains an almost constant friction value till the end of the sliding contact.

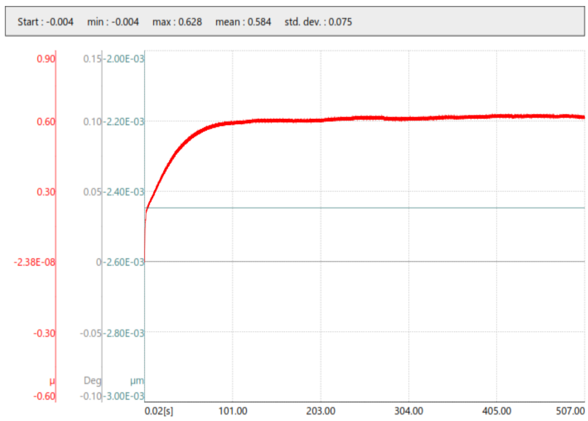

Fig. 5: Coefficient of friction of developed brake pad with 63µm particle size

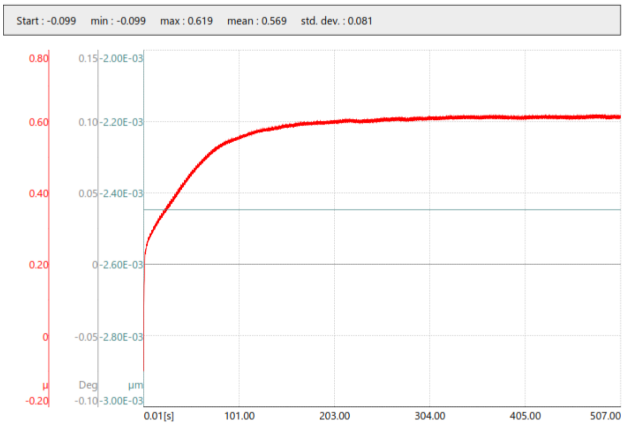

Fig. 6: Coefficient of friction of developed brake pad with 90µm particle size

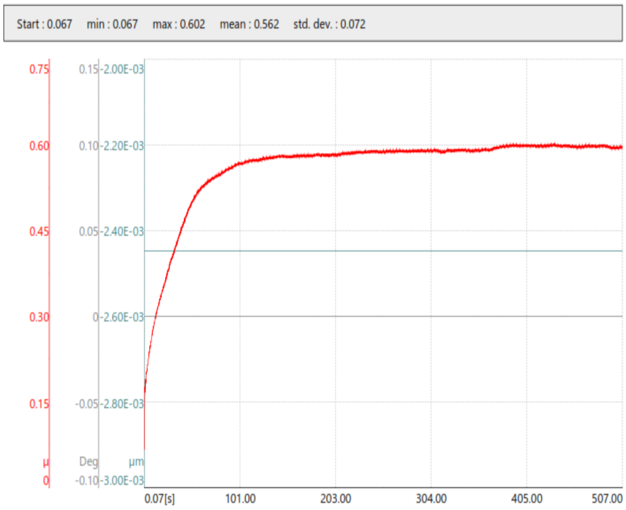

Fig. 7: Coefficient of friction of developed brake pad with 125µm particle size

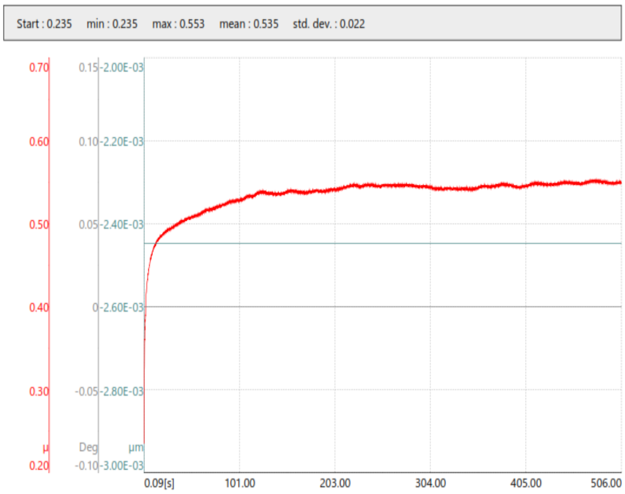

Fig. 8: Coefficient of friction of developed brake pad with 250µm particle size

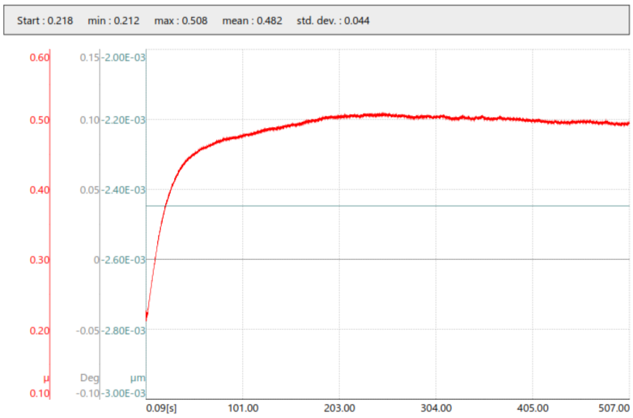

Fig. 9: Coefficient of friction of developed brake pad with 500µm particle size

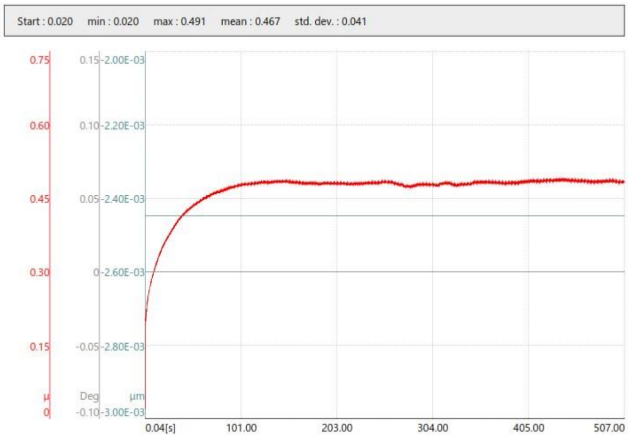

Fig. 10: Coefficient of friction of developed brake pad with 850µm particle size

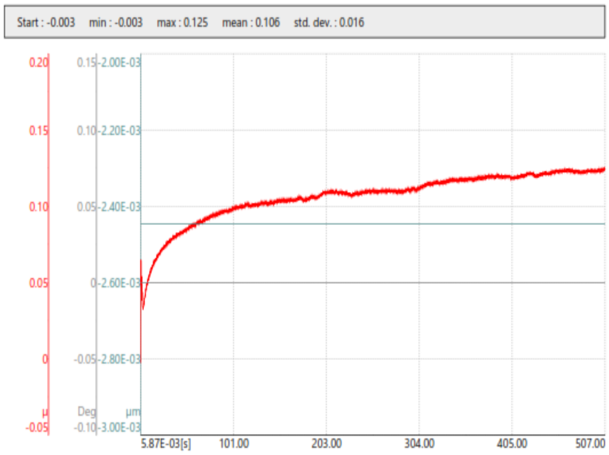

Fig. 11: Coefficient of friction of commercial brake pad (control 1)

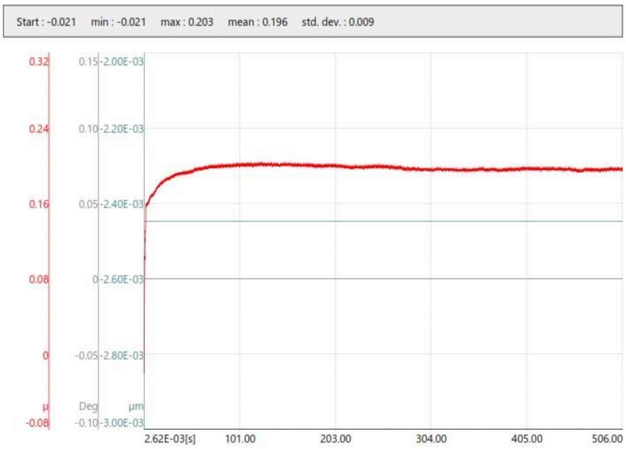

Fig. 12: Coefficient of friction of commercial brake pad (control 2)

It can be observed from Fig. 5-10 that the average coefficient of friction for the 63µm, 90µm, 125µm, 250µm, 500µm and 850µm grain size brake pads are 0.584, 0.569, 0.562, 0.532, 0.482 and 0.467 respectively. This show that the coefficient of friction of the developed organic brake pad decreases with increasing grain size. Fig. 11 and 12 show the frictional coefficients of the commercial brake pads used as control. The average frictional coefficient of Control 1 (Fig. 11) and Control 2 (Fig. 12) are 0.106 and 0.196 respectively. The frictional responses (Fig. 5-12) show that the green brake pads offer superior grip at the rubbing interface relative to the commercial brake pads. This frictional property improved with decreasing particle size. A similar result for friction coefficient variation with particle size was observed in the works of Ossia et al. (2021), Amaren et al. (2013), Akgbodion et al. (2010) and Sasaki (1995). However, the findings contradict the study of Yawas et al. (2016) on periwinkle shells.

Based on the standards for friction identification of brake linings and brake blocks developed by the Automotive Society of Engineers (SAE 2012) and the classification of friction materials by associated friction coefficient by Blau (2001), the commercial brake pads (Fig. 11-12) can be rated as Edge Code-D whereas the 850µm sample (Fig. 10) is Edge-Coded-G, 500µm sample (Fig. 9) is Edge Coded-G, 250µm sample (Fig. 8) is Edge-Coded-G, 125µm sample (Fig. 7) is Edge-Coded-H, 90µm sample (Figure 6) is Edge-Coded-H and the 63µm sample (Fig. 5) is Edge-Coded-H. The implication is that the 125µm, 90µm, and 63µm samples can be used in heavy-duty vehicles since they fall within the class H (> 0.55) type of brake pads.

3.5 Wear rate

The wear rates of the brake pads were observed to increase with an increase in particle size as shown in Fig. 13. All the developed brake pad samples exhibited lower wear properties than the commercial samples used as control. To further improve the wear rate, the composition of iron filings in the matrix composites should be increased.

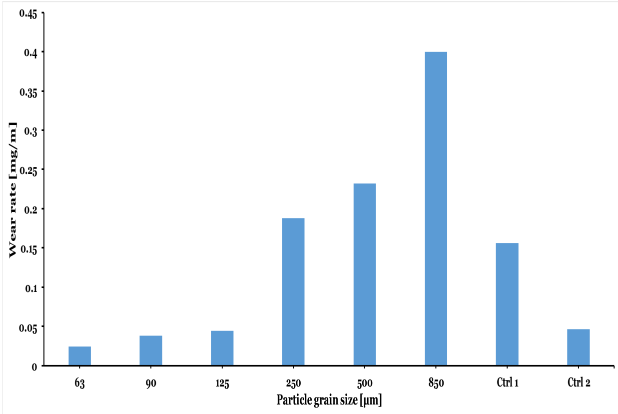

Fig. 13: Wear rate of developed brake pads with different grain sizes

3.6 Effect of grain size on thermal stability

It was observed that the thermal stability of the brake pad samples increases with increase in particle size as shown in Fig. 14. The low thermal stability may be due to the coalescing and highly reactive nature (highly soluble with low melting point) of the smaller grain-size samples. The commercial samples performed better in the area of thermal stability than the developed green brake pad samples. It was observed that about 86.99% and 85.93% residue of the commercial samples (control 1 and control 2) was left on average at a temperature of 500°C while about 63.7% residue of the 63µm sample was left on average at a temperature of 500°C as shown (Fig. 14). This shows that the green brake pad samples decomposed faster on the application of heat than the commercial samples. However, the rate of decomposition was found to be directly proportional to particle size as the largest grain size sample (850µm) had an average residue of 80.33% left, unlike the 63.7% residue of the 63µm sample.

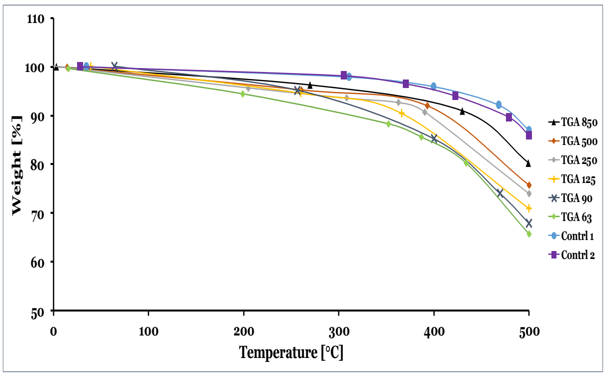

Fig. 14: Thermal stability of developed brake pads with different grain sizes

A sample of the finished 63µm particle-size brake pad mounted on the back plate ready for installation on a brake disc is shown in Fig. 15.

Fig. 15: The finished brake pad sample with 63µm particle grain size

4. Conclusion

The study investigated the use of waste Thais Coronata shells reinforcement material for the development of environmentally friendly brake pads. The mechanical and tribological properties of the developed green brake pads, such as hardness, compressive strength, friction coefficient, and wear rate decreased with increase in particle size. However, it was found that the larger particle-sized composites are more thermally stable than the samples with smaller particle sizes. Similarly, the absorption rate and wear rate properties increase with increase in grain size. The developed brake pads exhibited better frictional grip at the rubbing interfaces compared to the commercial brake pad. The 63µm brake pad gave the overall best properties and can be used as a possible replacement for the carcinogenic commercial brake pads.

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