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The effect of mangosteen peel compositions as reinforcement components on resin-based brake pad performance with computational bibliometric mapping analysis

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Abstract. This study aims to determine the effect of differences in the composition of mangosteen peels mangosteen peel particles as a reinforcing component in resin-based brake pads. The manufacture of a brake pad is done by mixing mangosteen peel particles with resin (bisphenol A-epichlorohydrin, and cyclo aliphatic amine (1:1 ratio). Mangosteen rind has a high carbon fiber content as a reinforcing material. Mangosteen rind particles, liquid resin, and hardener were mixed in various ratios of 10:5:5 (MA), 8:5:5 (MB), 6:5:5 (MC), and 4:5:5 (MD). The physical properties and mechanical properties were investigated. The results showed that the friction coefficient of the brake pads made from MA, MB, and MC were 0.69×10^{-5}, 0.68×10^{-5}, and 0.67×10^{-5}, respectively. MD specimens do not allow friction tests due to their highly elastic properties. MA has the lowest wear rate of 0.64, the maximum friction coefficient of 0.69, and the highest hardness level based on mechanical tests. MA specimens have the best ratio of resin to mangosteen peel mixture. This is because, the more the number of mangosteen rind particles used, the harder the brake pads will be. Materials with higher hardness have less mass loss and a higher coefficient of friction. The completion of the research shows that mangosteen peel has a high enough effect as an environmentally friendly brake pads reinforcement material.

Keywords: agricultural waste, brake pad, mangosteen peel, resin-based brake pad

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1. Introduction

The brake system is a mechanism to slow down the speed of a vehicle so that the speed of the vehicle can be controlled [1]. One of the brake systems used is brake pads. Brake pads are one of the most important parts of a vehicle. The working principle of brake pads is to convert kinetic energy into heat by rubbing the disc with the brake pads when the two components are in contact [2] When the vehicle is traveling at high speed, brake pads play a very important role because it supports the safety of the driver and passengers.

The friction material is an important component of brake pads in addition to fasteners, fillers, and reinforcing elements. Friction materials play an important role in brake-bearing properties such as fade resistance, friction coefficient management, and porosity reduction. The composition of brake pad material generally consists of 60% asbestos, causing environmental pollution problems and health problems [3]. Asbestos-based brake pads are widely sold commercially at low prices and guarantee the durability of the brake pads. However, the friction of the powder in the form of small particles is very dangerous for human health because of the asbestos content. The use of asbestos is avoided because of its carcinogenic properties [4]. Therefore, brake pads supported by asbestos-free materials should be avoided.

One way to replace the asbestos material is to make brake pads from organic materials. There have been many studies on resin-based brake pads by mixing them with organic materials, including resin-based brake pads from rice husks [5], corn husks [6], snail shell and rubber seed husks [7], banana fiber [8], cocoa beans shells [3], palm kernels [9], and banana peels [4,8]. However, there are no studies on resin-based brake pads that discuss the manufacture of resin-based brake pads from mangosteen peel.

Table 1 shows previous studies in more detail regarding the manufacture of brake pads using organic materials, especially agricultural waste as reinforcement components. Table 1 presents some data including the types of agricultural waste, supporting components, and the results obtained from the research. These studies show significant results which means that agricultural waste has great potential to replace inorganic materials for brake pads.

Table 1. Previous research in the preparation of brake pads used agricultural waste as a reinforcement component

No.	Type of Agricultural Waste	Supporting Component	Results	Refs
1.	Palm kernel shell (PKS)	Cow bone, Expoxy Resin, and Hardener	PKS has a hardness value of 55.7 HRB each. PKS has a water absorption rate of 5.05%. PKS oil absorption is 2.23%. The VFD has a friction coefficient of 0.735. VFD has a crushing strength of 23 N/mm^2. Low density, strong impact strength, low hardness value, low water resistance, and low oil resistance all contribute to the increase in the PKS particle size.	[10]
2.	Coconut shell	Coconut shell powder, cast	The higher the percentage of grounded coconut powder the lower	[11]

No.	Type of Agricultural Waste	Supporting Component	Results	Refs
		iron filings, silica, and epoxy (liquid resin).	the breaking strength, impact, hardness, compressive strength, and vice-versa respectively. Thus, a high percentage of grounded coconut powder induces brittleness.	
3.	Banana peels	phenolic resin (phenol-formaldehyde)	In the production of brake pads, banana peel particles can efficiently substitute asbestos.	[4]
4.	Lemon peels	Calcium hydroxide, epoxies, aluminum oxides, graphite, iron oxides, and calcium hydroxide	Brake Pads lemon peels have 1.55–2.00 g/cm^3, hardness 26–32 (Barcol hardness), percentage wear loss of 13.45–19.14%, percentage water loss of 0.96–1.38%, and an oil absorption of 0.01-0.02% are obtained, which is superior to commercial brake pads.	[12]
5.	Risk Husk	Bisphenol A-epichlorohydrin and cyclo aliphatic amine	The inter-packing distance, interfacial bonding, and thermal softening of the rice husk resin-particle matrix are all affected by particle size. The brake pads' compressive strength is increased by small particles. Reduced pore formation, less mass loss, improved wear rates, a greater coefficient of friction, and a rougher brake pad surface are all benefits of reducing particle size.	[5]
6.	Durian Peels	Banana midribs	The findings of the comparison between commercially available brake pads show that agricultural waste has the potential to replace friction components in brake pads. The hardness, wear, and friction coefficient of a brake pad using durian peels are the highest.	[13]
7.	Palm Ash	PCB waste, phenolic resin, and aluminum.	The higher the palm ash content, the better the wear and mechanical qualities. The wear qualities of palm ash brake pads are equivalent to	[14]

No.	Type of Agricultural Waste	Supporting Component	Results	Refs
			those of conventional brake pads.	
8.	Groundnut shell	Phenolic resin	Increases in groundnut shell density, compressive strength, and oil absorption are all attributed to increased oil absorption, water absorption, and density. The compressive strength was increased by using large groundnut shell particles.	[15]
9.	Corn Husks	Phenolic Resin (Phenol-Formaldehyde), Silicon Carbide, Steel Dust, Graphite, and Corn Husk	Brake pads with corn husks provide better compressive strength, higher hardness, lower porosity, and lower wear rates. Corn husks can be used in the production of asbestos-free brake pads according to the ratio of commercial brake pad yields	[16]
10.	Sawdust	Slag waste, resin, epoxy, graphite, and silicon carbide.	The addition of sawdust has an impact on the level of wear and degradability of the brake pad. Sawdust brake pads have high ash content, low density, low compressive strength, and high levels of degradability/wear.	[17]

Mangosteen peel has a fairly high carbon content, as do coconut shell and corn cob, which is around 48.81%. In addition, mangosteen peel has a higher carbon fiber content than coconut shell and corn cob. This carbon fiber content indicates the maximum amount of carbon that can be produced from biomass after the pyrolysis process. The high amount of carbon fiber is due to the fact that biomass has a fairly high lignin content. As is well known, one of the materials for making brake pads is carbon fiber [18]. Carbon fiber was chosen because it is very strong and heat resistant, considering the friction that occurs in commercial motorcycle brake pads, which is 150˚C-250°C [19]. Mangosteen peel has a fixed carbon content of 26.60% and carbon of 48.81% [20], which is considered suitable to be used as a material for making brake pads.

Therefore, this study was conducted to analyze the use of mangosteen peel as a material for making brake pads. This study aims to determine the effect of differences in the composition of mangosteen peels as a fiber reinforcement component on the performance of resin-based brake pads. The novelty of this research is the use of mangosteen peels as reinforcement for the manufacture of resin-based brake pads. The completion of this research is expected to reduce the use of brake pads made of asbestos which is dangerous and the increasing use of brake pads made of organic materials.

2. Method

The research was carried out in several stages, each stage of the research carried out is shown in Fig. 1. The research was conducted in 3 core stages, namely brake pad production, computational bibliometric mapping analysis, and test of brake pads. The brake pads that have been made are tested in several types of tests, namely physical, mechanical, and chemical properties tests.

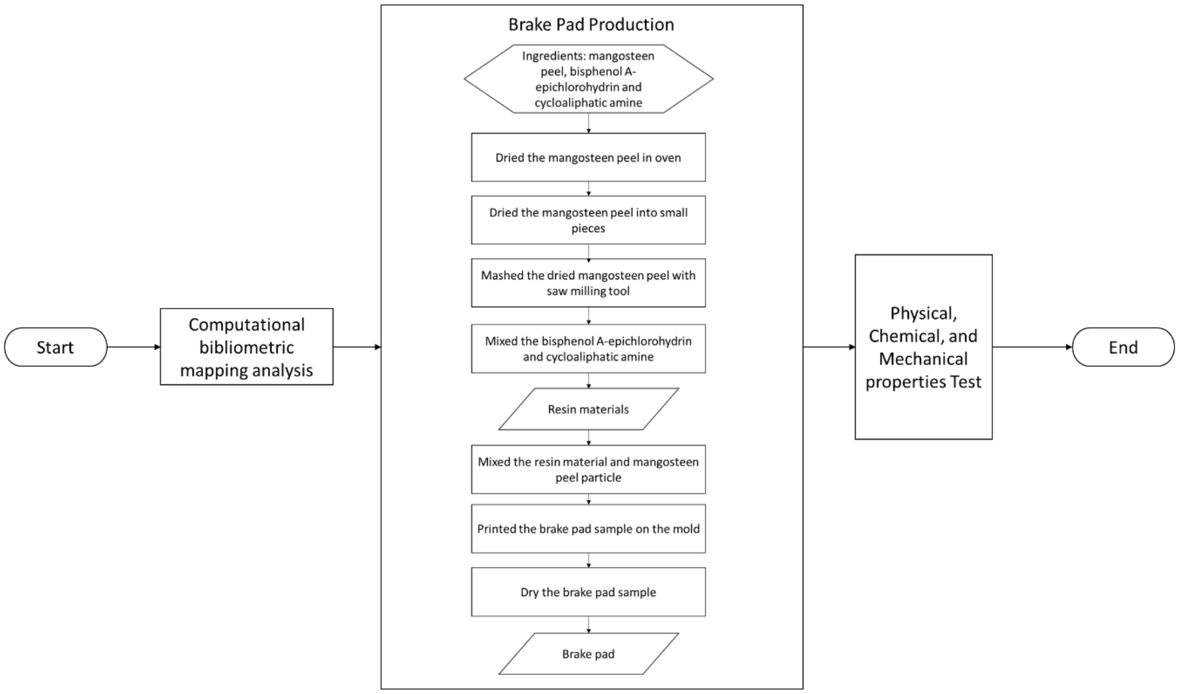

Fig. 1. Flow chart of research stages

Brake pad production. The brake pads are made from mangosteen peel from Subang, Indonesia. The mangosteen peel that had been collected was then dried in an oven (Kirin Griya Indotama, Indonesia) at a temperature of 150°C. The time needed to dry the mangosteen peel was 2 hours. The dried mangosteen peel is then cut into small pieces and mashed using a sawmilling tool. Therefore, the specific particle size required is obtained. After being mashed, the mangosteen peel powder was added to a sieve shaker (Niaga Kusuma Lestari, Indonesia). After the mangosteen peel particle has been prepared, the next step is to make a brake pad.

The brake pad is made from a mixture of mangosteen peel particles and resin material. The resin materials used are bisphenol A-epichlorohydrin (as a binder) and cyclo aliphatic amine (as a hardener). The two resin materials were mixed evenly in a ratio of 1:1. Particles of mangosteen peel, Bisphenol A-epichlorohydrin, and cyclo aliphatic amine were then mixed in various ratios, namely 10:5:5 (MA), 8:5:5 (MB), 6:5:5 (MC), and 4:5: 5 (MD). The choice of composition ratio was due to referring to our previous study [13]. After that, the brake pad samples went through a printing process and drying process for 5 days at room temperature and pressure. The brake pad as a model object has a size of 1×1×1 cm based on the size of the silicone mold used.

Physical, chemical, and mechanical properties test. The particle size and shape of the raw material (BPP and ES particles), as well as the outer surface and inner surface of the brake pad samples, were investigated using a digital microscope. Fourier transform infrared is used for chemical characterization to assess elemental structure products (FTIR, FTIR-6600, Jasco Corp., Japan). Meanwhile, the mechanical characterization consists of the following:

Compressive and puncture strength. A Screw Mount Test equipment (Model I ALX-J, China) with a digital force measurement instrument was used to perform the compression test (Model HP-500, Serial Number H5001909262). The brake pads were subjected to a constant displacement rate of 2.6 mm/min during the test. At the same time, the compressive force is recorded, resulting in a curve that depicts the texture profile. The compressive strength is then calculated using the maximum point of the compressive stress-strain curve. Furthermore, the highest applied force (in Newtons (N)) is utilized to determine the sample's hardness during the test. The Shore Durometer instrument (Shore A Hardness, in size, China) was used in the puncture strength test process. The hardness scale used in the tool is 0 to 100. Density can be calculated using Equation (1):

$$\rho = \frac{m}{v}. \tag{1}$$

In the process of recording, the results of the puncture test are stored in a C language program with the algorithm (see Fig. 2), and an example of the program output is shown in Fig. 3 (a, b).

```c
#include <stdio.h>
#include <string.h>
#include <math.h>

typedef struct punctureStrength {
    char sampel[255];
    int resulOfPuctureStrength[40];
    double averange;
} punctureStrength;

int main() {
    int totalVarious, i, j, totalTestPunctureStrength, count = 0;
    double average;

    printf("Input total various composition of sample : ");scanf("%d", &totalVarious);
    punctureStrength variousComposition[totalVarious];

    printf("Input total test puncture strength : ");scanf("%d", &totalTestPunctureStrength);

    for (i = 0; i < totalVarious; i++) {
        printf("Input name of sample : ");
        fflush(stdin);
        gets(variousComposition[i].sampel);
        for (j = 0; j < totalTestPunctureStrength; j++) {
            printf("Input result %d: ", j+1);
            scanf("%d", &variousComposition[i].resulOfPuctureStrength[j]);
            printf("\n");
        }
        printf("\n");
    }
    //count of average
    for (i = 0; i < totalVarious; i++) {
        for (j = 0; j < totalTestPunctureStrength; j++) {
            count = count+variousComposition[i].resulOfPuctureStrength[j];
        }
        average = (double) count/totalTestPunctureStrength;
        variousComposition[i].averange = average;
        count = 0;
    }

    //result of average

    for (i=0; i < totalVarious; i++) {
        printf("Sampel name : %s\n", variousComposition[i].sampel);
        printf("Averange pucture strength %s: %lf\n", variousComposition[i].sampel, variousComposition[i].averange);
    }

    return 0;
}
```

Fig. 2. Puncture strength test calculation algorithm

```
Input name of sample : MD
Input result 1: 95

Input result 2: 95

Input result 3: 95

Input result 4: 99

Input result 5: 96

Input result 6: 98

Input result 7: 98

Input result 8: 95

Input result 9: 98

Input result 10: 99
```

```
Sampel name : MA
Averange pucture strength MA: 92.600000
Sampel name : MB
Averange pucture strength MB: 93.100000
Sampel name : MC
Averange pucture strength MC: 96.500000
Sampel name : MD
Averange pucture strength MD: 96.800000
```

(a) Input program (b) Output program

Fig. 3. The results of the calculation of the puncture strength test with the C program

Specific gravity. The Archimedes principle was used to conduct the density test. The sample's weight is first determined in the open air. Weighing took place after the test object had been submerged in water for 48 hours. The difference in weight determines the density of the sample. The formula for calculating density is Equation (2).

$$Density = \frac{W_o}{W_o - W_1} \times 1000 \left(\frac{kg}{m^3}\right), \tag{2}$$

where W_o is weight in the air (g) and W_t is weight in water (g).

Water absorption rate. A 24-hour water test was used to examine the specimens' water adsorption behavior. The dried sample weights were measured after a 24-hour soaking at room temperature. The specimens were weighed after the extra tear was drained. Equation (3) was used to obtain the absorption percentage.

$$Absorption\ (\%) = \frac{M_1 - M_0}{M_0} \times 100, \tag{3}$$

where M_1 is mass after immersion and M_0 is mass before immersion.

Friction test. Before friction testing, the brake pad was polished to eliminate the resin layers on the surface. The friction of the brake pad was tested by sliding it against sandpaper (80 grit; Dae Sung CC-80Cw) with a mass load of 9 kg at a speed of 25 cm/s for 20 minutes. Every two minutes, the weight of the brake pads was measured. The wear rate was calculated using Equation (4).

$$Wear\ Rate\ (M) = \frac{(M_a - M_b)}{t \times a}, \tag{4}$$

where M_a is the initial weight of the brake pad (g), M_b is the final weight of the brake pad (g), t is time (s), and a is the friction cross-section area (mm^2).

The friction coefficient (μ) was the ratio of friction force (*f*; Newton) to applied force (*N;* Newton) that is shown in Equation (5).

$$\mu = \frac{f}{N}. \tag{5}$$

3. Result and discussion

Computational literature with mapping analysis on mangosteen peel research. Before this research, we conducted a literature study on related research. We analyzed research on the use of mangosteen peel. Research data was collected through publishing or perish 7 which was taken from the google scholar database. All articles taken were articles published in google scholar indexed journals from 2012 to 2021 by specifying the keyword "Mangosteen Peel". This literature study was conducted to seek new research on mangosteen peel.

Research on the use of mangosteen peel is still relatively small, namely over 10 years (2012-2021), and there are a total of 91 publications. Figure 4 shows the development of mangosteen peel research from 2012 to 2021. The highest number of mangosteen peel studies occurred in 2019 and 2021 with a total of 14 publications. In 2012 there were only 7 studies and it decreased drastically in 2013 when there were 2 publications in one year. In 2014 there was an increase in publications, namely 8 publications. In 2015-2018 research on mangosteen peel experienced a high enough increase to reach 14 publications. However, in 2019-2020, it decreased again, namely 11 publications and in 2021 it increased to 14 publications.

In previous studies on mangosteen peel, it is known that research on mangosteen peel has several interrelated terms, namely peel powder, mangosteen extract, antioxidant activity, gel, adsorbent, removal, and carbon, as shown in Fig. 5 regarding network visualization [21]. These interrelated terms indicate with what terms the mangosteen peel research is carried out so that we can look for other terms that can be related to the mangosteen peel research [22].

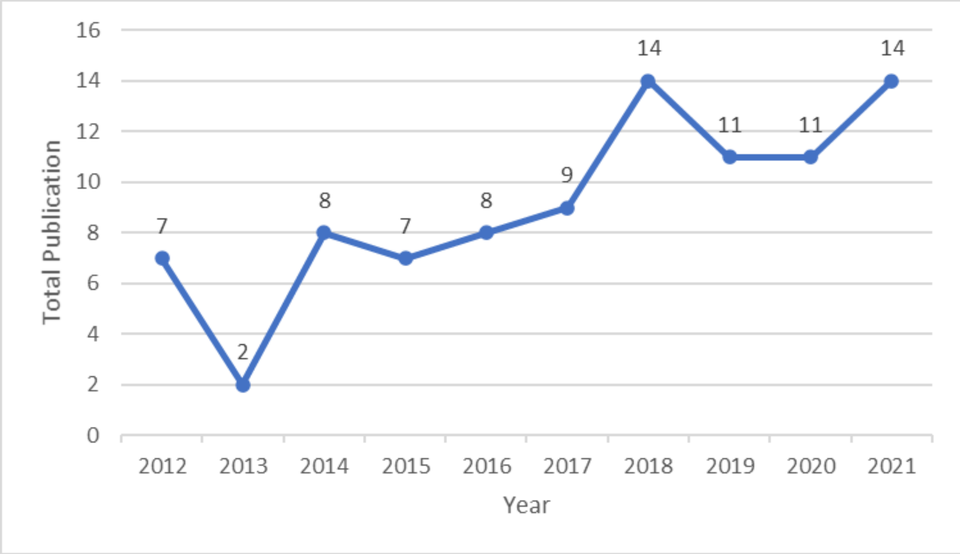

Fig. 4. The development of research on the use of mangosteen peel in the last 10 years (2012-2021)

Figure 6 shows the density visualization in a study on mangosteen peel. The brighter the yellow color in the term circle, the more research on that term is carried out [23]. Figure 6 shows that mangosteen peel is the most widely used as mangosteen peel extract, followed by research on mangosteen peel as carbon. Figure 7 clarifies the number of terms found when the computational mapping analysis is carried out. Based on Fig. 7, it is known that 11 types of mangosteen peel utilization have been carried out in previous studies, namely peel powder, adsorbent, antioxidant activity, mangosteen peel powder, gel, antioxidant, removal, activated carbon, carbon, extract, and mangosteen peel extract. The use of mangosteen peel as mangosteen peel extract was found the most, namely 13 times, followed by carbon base material, which was 6 times, and the least research that discussed the use of mangosteen peel as peel powder was only 3 times.

From the results of computational literature analysis using the mapping visualization technique of research data from 2012-2021 published in google scholar indexed journals, it is known that research on the use of mangosteen peel as a reinforcing fiber material for the manufacture of resin-based brake pads has not been carried out. Therefore, this study has a fairly large novelty value. This is because one of the benefits of mapping analysis research is to find out the novelty of a study [24].

Fig. 5. Network visualization of mangosteen peel research

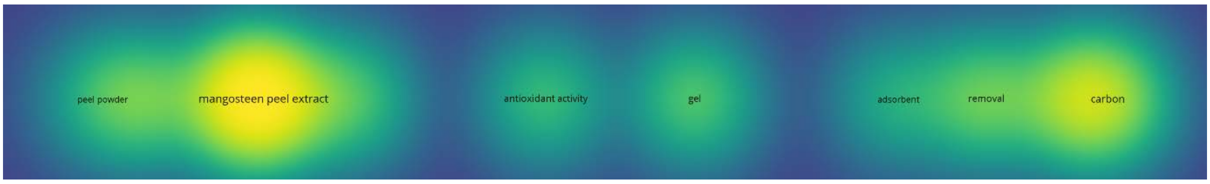

Fig. 6. Density visualization research on mangosteen peel

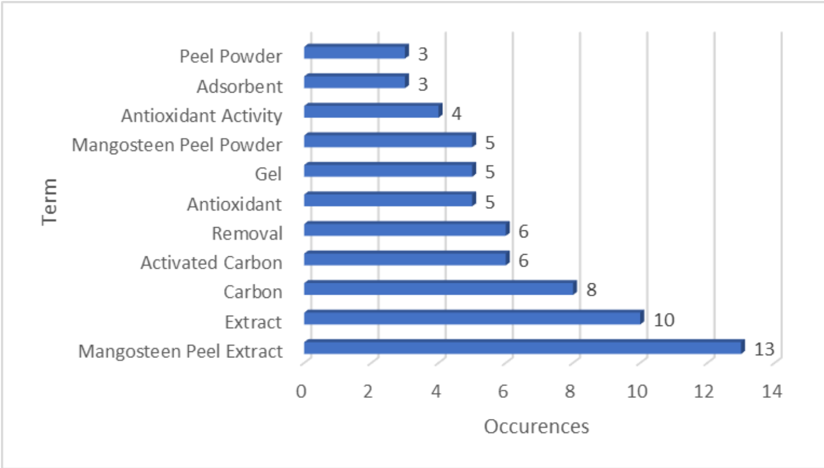

Fig. 7. Utilization of mangosteen peel in the previous studies

Figure 8 depicts a resin-based brake pad research visualization network. According to Fig. 8, resin-based brake pad research is often associated with terminology like bearing materials, bearing development, and epoxy resin as the most extensively used material in the fabrication of resin-based brake pads [25]. These terms explain the process of researching resin-based brake pads. This enabled us to explore more terms relating to resin-based brake pad research. Figure 9 shows the phrases epoxy resin and pad material, which are related to research on resin-based brake pads with the greatest number of densities [25].

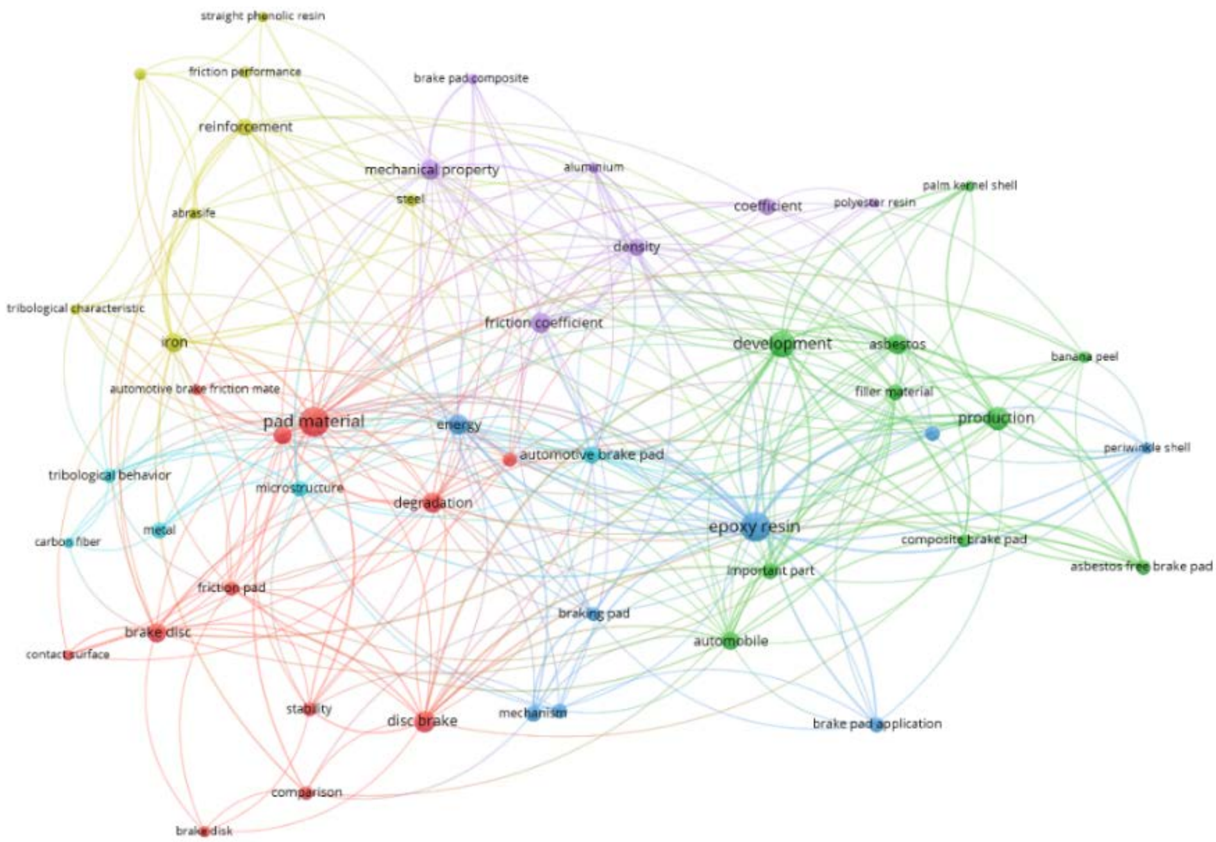

Fig. 8. Network visualization of resin-based brake pad (adopted from Nandiyanto et al. [25])

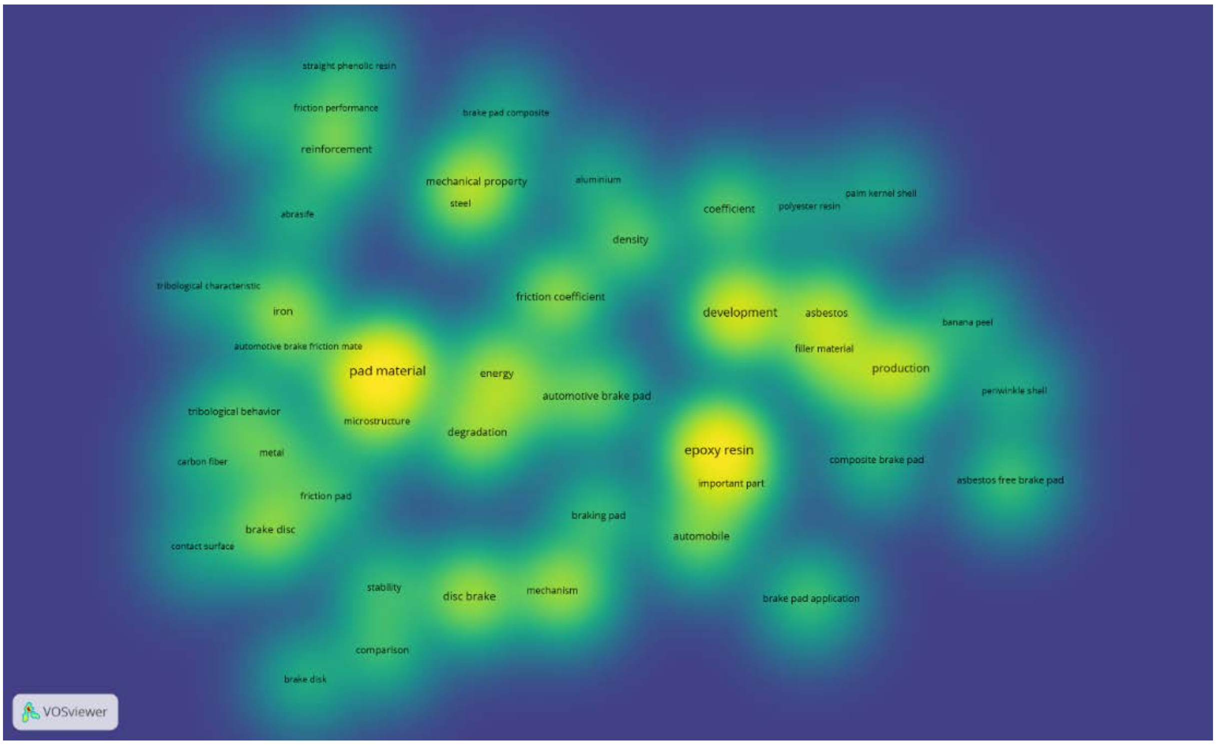

Fig. 9. Density visualization of resin-based brake pad (adopted from Nandiyanto et al. [25])

Figure 10 shows the FTIR analysis. The FTIR was then compared to the literature regarding FTIR spectrum data for organic component [26] and the application of resin as brake pad [27]. The presence of an absorption band in the wavelength of 2871 cm^{-1} is symmetric stretching vibrations of methyl (CH_3). The absorption band in the wavelength range of 1760 – 1741 cm^{-1} is a stretching vibration of the unconjugated carbonyl (C=O) group. The absorption band at 1690 cm^{-1} is the stretching vibration of conjugated carbonyl (C=O). Absorption band in the wavenumber's range of 1654 – 1523 cm^{-1} that is C=C. CH_2-bending is shown in wavenumbers 1409 cm^{-1} dan CH_3- bending is presented on wavenumbers 1367-1322 cm^{-1}. In the range, 1278 – 1046 cm^{-1} of the absorption band is stretching vibration of C-O. Wavenumber 1011 cm^{-1} is C-OH stretching. The absorption band of the component at 908 cm^{-1} is functional groups -HC=CH-(*trans)* out of the plane, 772 cm^{-1} is -HC=CH-(*cis*) out of the plane, and wavenumbers at 677 cm^{-1} is –$(CH_2)_n$; -HC=CH- bending [28]. The presence of an epoxy group is indicated by a peak in the 950 to 860 cm^{-1} range [30]. Spectrum mangosteen peel in Fig. 10a had no absorption at 950-860 cm^{-1} because it was not prepared using resin.

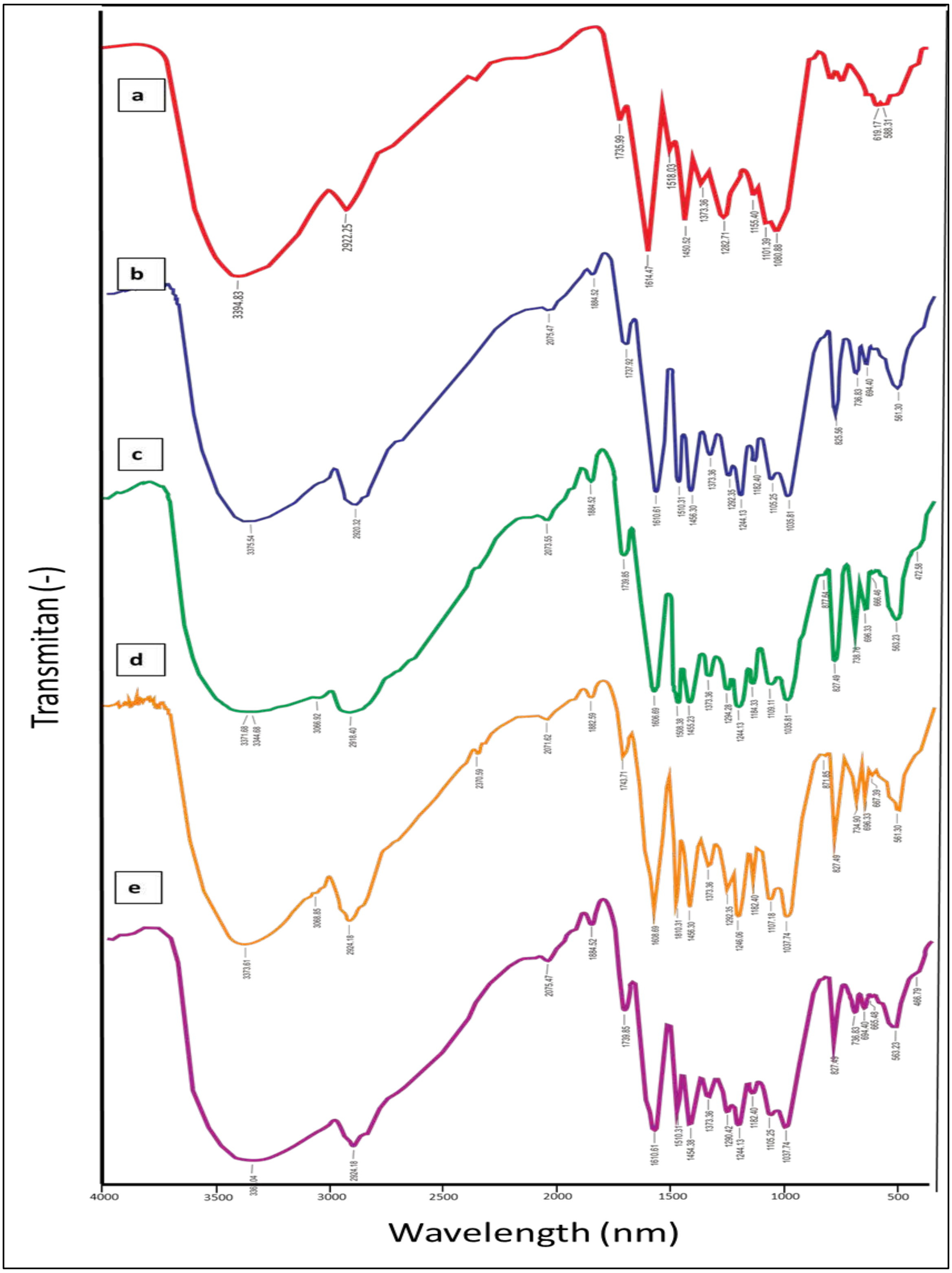

Fig. 10. FTIR spectrum of fabricated brake pad from a) mangosteen peels; b)MA; c)MB; d) MC; and e) MD

Figure 11a shows a microscopic image of mangosteen peel particles. The mangosteen peel particles show an inhomogeneous particle size (see Fig. 11a). Ferret analysis was used to perform the particle size analysis of mangosteen peel as shown in Fig. 11b. Figure 11b shows the results of Feret's analysis, where the mangosteen peel particle size is in the range of 100-500 μm with an average size of 281.5192 μm.

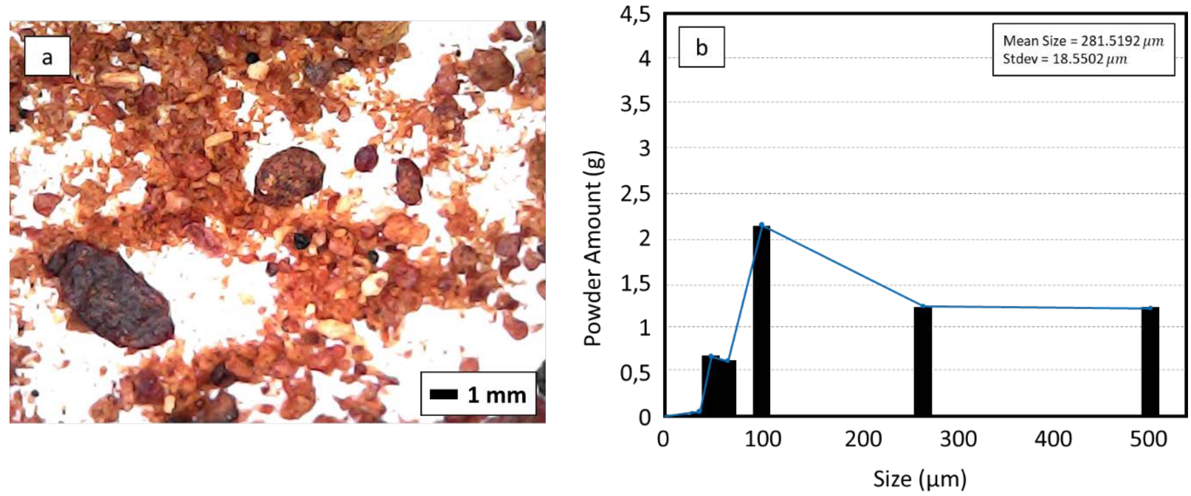

Fig. 11. Photographic image and particle size distribution of mangosteen peel particles (a-b)

Figures 12 (a-d) show the fabricated brake pads based on MA, MB, MC, and MD, respectively. Brake pads that have been fabricated have color differences that are not too noticeable. All brake pads with different compositions of mangosteen peel particles have a color close to black with a little part of brownish powder. From the microscope image, there are yellow and black areas that show mangosteen peel particles and the shiny areas are resinous. Figures 12 (e-l) shows the surface view (outside and inside) of the brake pads. Based on Figs. 12 (e-l) all fabricated brake pads have an uneven surface and have pores. The results of the observations that have been made, brake pads made from MA or brake pads that have a high content of mangosteen peel particles have smoother inner and outer surfaces when compared to other specimens. Therefore, the use of mangosteen peel particles in the manufacture of brake pads results in a smoother brake pad structure in the final product.

The characteristics of the specific gravity of the brake pads to support the analysis of the texture profile on the brake pads are shown in Fig. 13. Based on the specific gravity plots of various brake pad specimens, the MB base brake pads have the highest specific gravity value of 1.16 g/cm^3. The specific gravity of the MC-based brake pads is 1.15 g/cm^3, the MA-based brake pads are 1.01 g/cm^3. Meanwhile, the MD-based brake pads have the smallest specific gravity value of 0.99 g/cm^3.

The high specific gravity values in the brake pad composite matrix phase correlated with the density level of the filler particles whose distribution properties became more homogeneous [31]. Thus, this can be attributed to the most acceptable impact of brake pad reception on brake pad characteristics. However, apart from this, the specific gravity of other specimens could be better because the weight of the brake pad is lighter, so it can meet the standard as well. In this case, all specimens have lower specific gravity than commercial brake pads of 1.890 g/cm^3 but still exceed the requirements [6].

Smaller particle sizes result in fewer pores and a finer structure in brake pads. The pores of the brake lining are also influenced by particle size [5]. Because less connection between materials generates more room, brake pads with a large particle size also have larger pores. The performance of the brake pad degrades as the pores grow larger, and vice versa. This occurs because the outer bond between materials is stronger, resulting in improved brake pad performance [5].

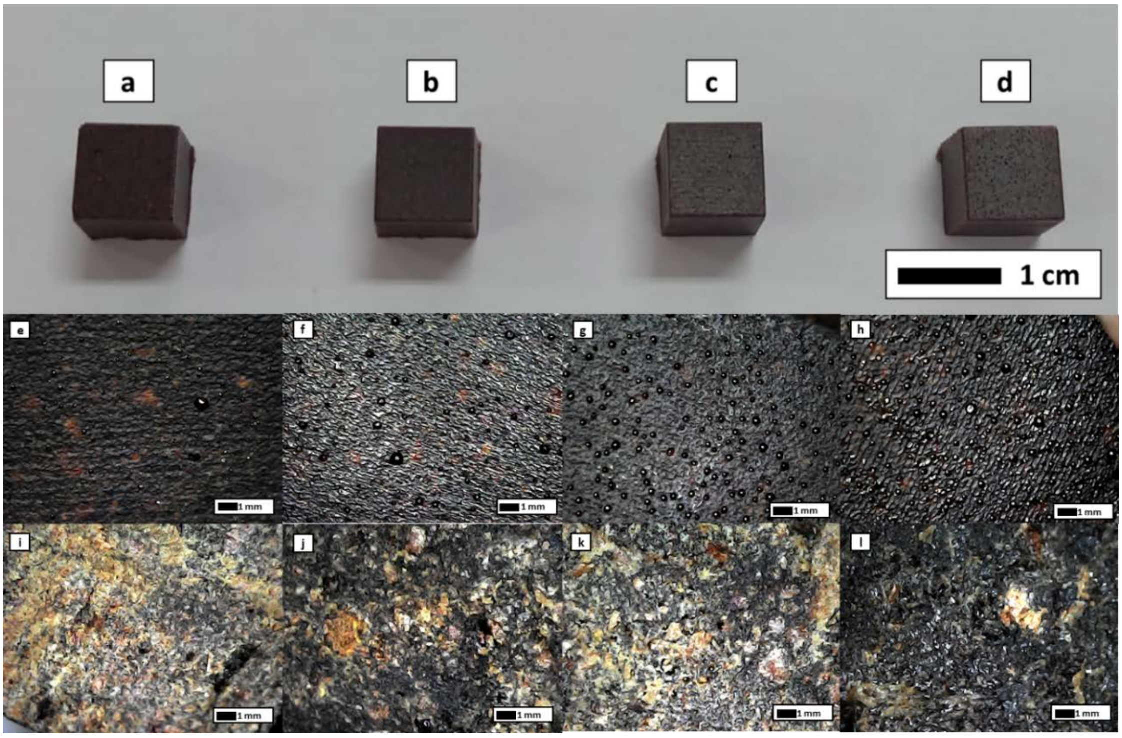

Fig. 12. A photo of the brake pad that was successfully made. Figures (a-d) are MA, MB, MC, and MD-based brake pads, respectively. Figures (e-h) are the outer surfaces of the brake pads and (i-l) are the inner surfaces of the brake pads of MA, MB, MC, and MD, respectively

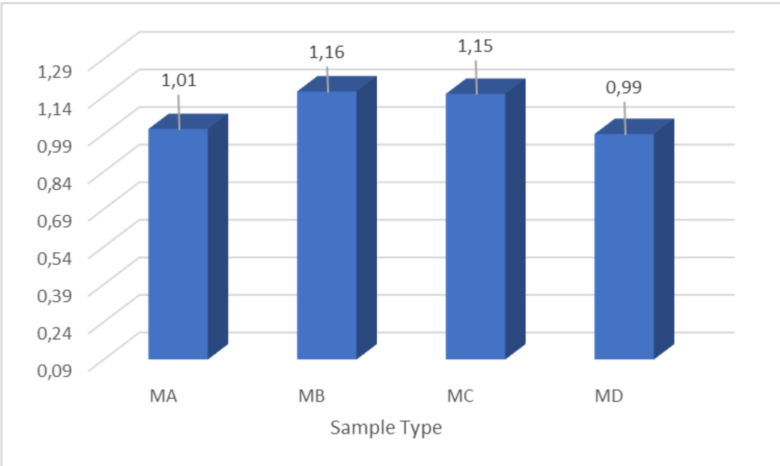

Fig. 13. The plot of specific gravity of various brake pad specimens

Mechanical characteristics. Figures 14(a-b) shows the results of the compression test for each sample brake pad (MA, MB, MC, and MD). Based on Fig. 14 shows that the greater the compressive resistance of the material, the higher the compressive stress obtained from the compression test. Figure 14(a) shows the highest average compressive stress-strain is MA and the lowest is MD. Figure 14(b) shows in more detail each value of the various MA, MB, MC, and MD specimens respectively, namely 0.101, 0.099, 0.095, and 0.094 N/cm^2. Therefore, based on the compression test, the hardest specimen is MA.

The effect of the heating temperature is unavoidable during the operation of the brake pads [32]. Although, initially attention was paid to the material requirements of the brake pads and the importance of meeting the required aspects.

Table 2 shows the results of the puncture test for each sample of brake pads mangosteen peels. A puncture test was performed to confirm the results of the compressive test results.

The puncture test shows that the smaller the average puncture test value that has been obtained, the higher the hardness [5]. In the puncture test, the hardness value of the sample obtained shows the depth of the needle that has been inserted into the sample. A deeper puncture indicates a more brittle specimen [5].

Table 2 shows the results of the puncture test following the results of the compressive test that has been carried out. The combination of components that has the highest level of hardness is MA. Based on the pressure and puncture test data, a brake pad with MD particle composition has the lowest level of hardness. The composition of MB particles is in second place with a prick test value of 93.1 and MC is in third place with a puncture test value of 96.5. This shows that the more mangosteen peel as a reinforcement component is used, the higher the hardness of the brake pads. Mangosteen peel has a high carbon content of about 48.81 percent. Carbon fiber is one of the reinforcing materials that has proven to be good for use in the manufacture of brake pads [18].

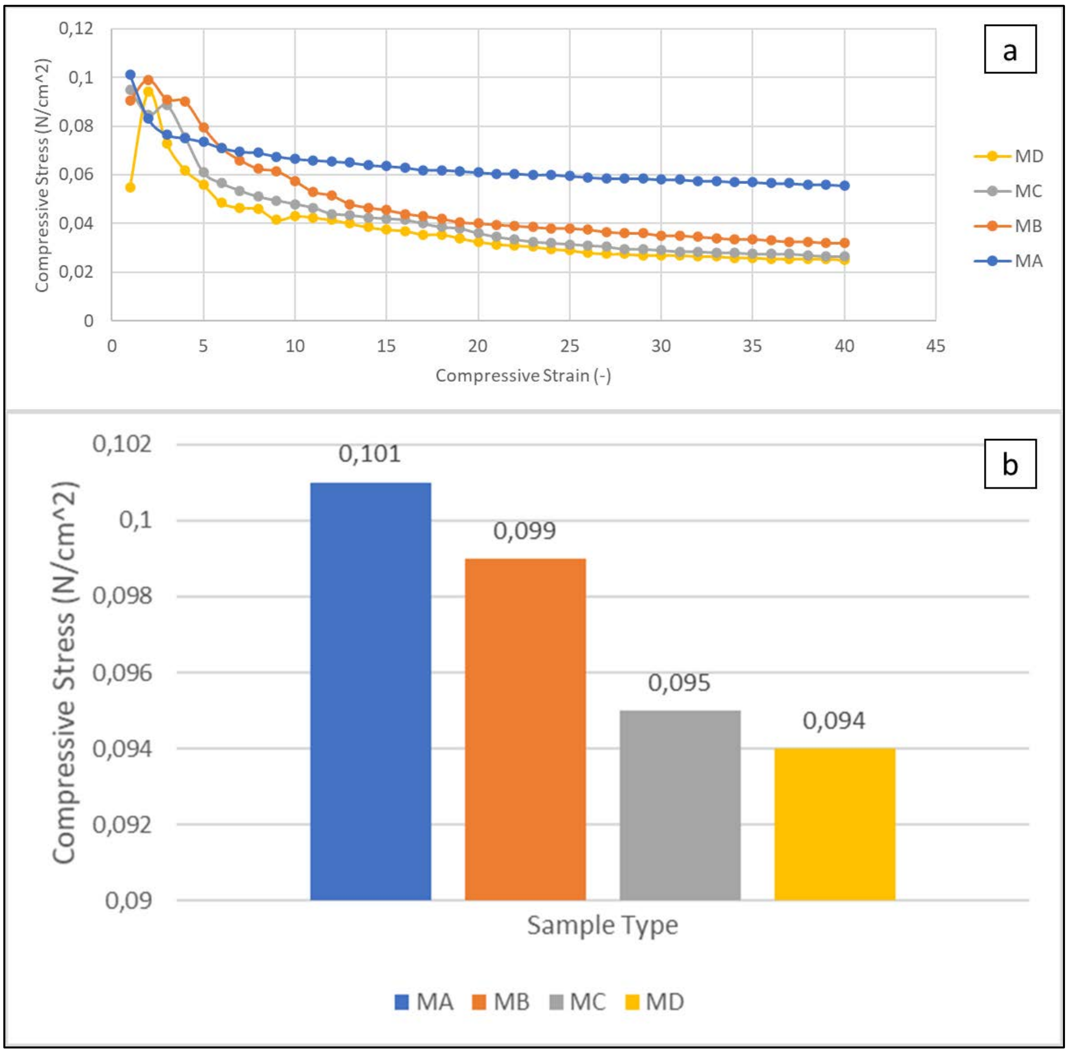

Fig. 14. The results of the compression test are as follows: (a) compressive stress-strain curve and (b) compressive strength

Table 2. Brake pad specimen puncture strength test results

Sample	Durometer shore a hardness scale of brake pad
MA	92.6
MB	93.1
MC	96.5
MD	96.8

The change in mass of each brake pad sample (MA, MB, MC) during the friction test is depicted in Fig. 15. Only three specimens, MA, MB, and MC, were subjected to the friction test. The MD specimen does not allow for a friction test due to its extremely elastic nature, which means it may readily bend from one shape to another, making it impossible to conduct a friction test [33]. During friction testing, the brake pads (as in the braking drum/disc model) are forced to make contact with the sandpaper, converting kinetic energy into heat energy and generating heat and friction [34]. During this process, debris is also produced. A drop in the mangosteen peel particle ratio in double reinforcement induced a decrease in the hardness properties, which resulted in an increase in mass loss.

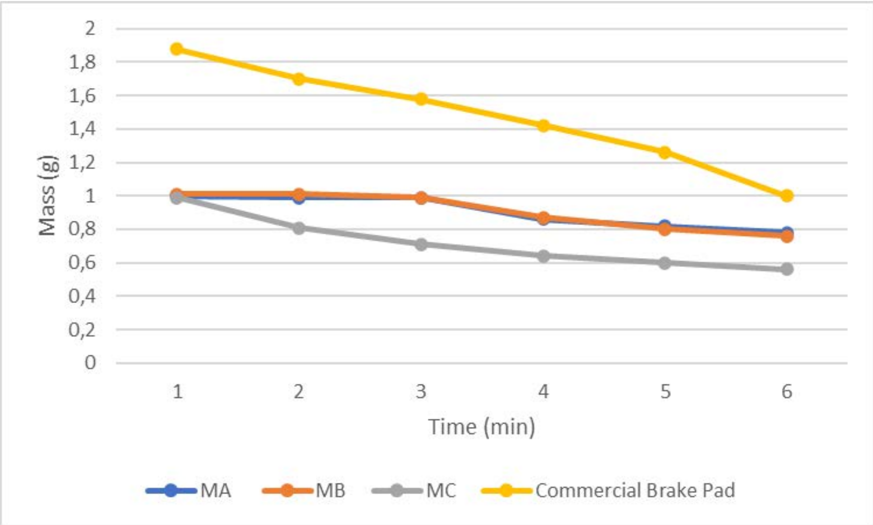

Fig. 15. Graph of change in brake pad loss mass during friction test

The findings of the mass loss rate, friction coefficient, and brake pad wear are summarized in Table 3. Lower mass-loss rates are linked to lower wear rates and greater friction coefficients in friction testing. The lower the wear value of a brake pad specimen, the higher the friction coefficient value [35]. The MA ratio composition brake pad has the lowest wear rate of 0.64 and the maximum friction coefficient of 0.69 (see Table 3). The friction coefficients of brake pads constructed of MA, MB, and MC, respectively, are 0.69×10^{-5}, 0.68×10^{-5}, and 0.67×10^{-5}. Commercial brake pads have a coefficient of friction of 0.61×10^{-5}. Among all commercial brake pad and brake pad specimens, the MA specimen had the best mix of resin and mangosteen peel ratio. All samples exhibit better characteristics than commercial brake pads based on mass loss, friction rate, and coefficient of friction test findings. The results have been compared with commercial standards although with mass production further research is needed.

Brake pads with a lower mass-loss rate and greater friction coefficient characteristics are brake pads with hardness characteristics, according to the findings of the research.

According to research conducted by Dhanasekaran and Gnanamoorthy [36], materials with a higher hardness have a smaller mass loss and a higher coefficient of friction.

In addition, that is true that it is important to analyze or regulate the shape and size of reinforcing particles as we documented in our previous study [5]. Further analysis of the effect of the shape and sizes of the mangosteen peel particles will be done in our future work.

Table 3. The mass-loss rate, wear rate, and friction coefficient of specimens of various compositions

Sample	Initial Mass (g)	Final Mass (g)	Mass loss rate (%)	t (s)	A (mm^2)	Wear Rate ($g/s.mm^2$) ($\times 10^{-5}$)	Friction Coefficient ($\times 10^{-5}$)
MA	1.01	0.78	3.8	360	100	0.64	0.69
MB	1.10	0.76	5,2	360	100	0.94	0.68
MC	1.01	0.56	7.4	360	100	1.25	0.67
Commercial	1.88	1.00	7.8	360	100	2.44	0.61

4. Conclusion

This study was conducted to analyze the effect of differences in the composition of the mangosteen peel as an environmentally friendly reinforcement component in resin-based brake pads. The brake pad was made by mixing mangosteen peel particles, bisphenol A-epichlorohydrin, and cyclo aliphatic amine in various ratios of 10:5:5 (MA), 8:5:5 (MB), 6:5:5 (MC), and 4:5:5 (MD). The physical properties and mechanical properties of each brake pad specimen were investigated. The results showed that MA specimens had the highest hardness, followed by MB, MC, and MD respectively. This research shows that the number of mangosteen peel particles affects the hardness of the brake pad. The higher the ratio of using mangosteen peel, the harder the brake pad was obtained. The mangosteen peel contains carbon fiber, which is one of the effective reinforcing materials in the manufacture of brake pads because it is very strong and heat resistant.

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