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THE EFFECT OF SENGON WOOD POWDER PARTICLE SIZE AND COMPOSITE COMPOSITION ON THE PERFORMANCE OF NON-ASBESTOS BRAKE LININGS

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Abstract. . The purpose of this study was to determine the effect of particle size and composite composition on the mechanical properties of non-asbestos brake linings. This type of research uses quantitative experiments. There are 3 kinds of variables used, namely a) independent variables consisting of particle size and composite composition; b) dependent variables consisting of hardness value and wear rate value; c) controlled variables consisting of shore D durometer method and Wear Rate with 800 rpm, 120 seconds time, and 20 psi pressure. The data analysis technique uses the factorial anova method because it is to determine the effect of the interaction between particle size and composite composition on brake lining. Data analysis was carried out twice, namely hardness test data and wear rate tests. After that, the data obtained was processed using the Minitab application. The results showed that particle size and composite composition affect the hardness and wear of brake lining. Smaller particle size increases hardness, especially in specimens using Fe composition. The use of iron powder resulted in higher hardness. Iron powders with better mechanical properties showed lower wear rates. The interaction effect of particle size and composite composition on brake lining performance is that the interaction of the two independent variables has a significant effect on brake lining performance.

Keywords : brake pads, hardness, non asbestos, wear

1. INTRODUCTION

The braking system is an important component in a vehicle because it functions to slow down or stop the speed of the vehicle. Most vehicles today use disc brakes because they are better at conducting heat than drum brakes [1]. Brake systems that do not function properly can be caused by several factors, one of which is due to wear on the disc and brake lining due to friction. So that the construction of brake linings is made of materials that have good and effective abilities to achieve optimal braking performance [2].

In the last two decades, the use of asbestos materials has been popular for making brake linings due to its strength, heat resistance and fire resistance. However, the impact of asbestos materials has been known to be carcinogenic or a dangerous substance that causes lung cancer and other health problems, so it should not be used as a material for making brake linings [3]. According to a report from the Ministry of Environment and Forestry, deaths from asbestos globally reached 255,000 people per year. Seeing the impact of the use of asbestos which is so dangerous, the government made a regulation regarding the use of asbestos, the regulation is stated in PP No. 18 of 1999 that asbestos is included in the category of B3 (Hazardous and Toxic Material) waste, and stated in PP No. 74 of 2001 that the use of asbestos must be supervised.Therefore, new asbestos-free alternative friction materials as brake pads have been developed. Thus, many studies have been conducted and are still ongoing for the development of not only asbestos-free brakes but also those with less impact on human health and better technical efficiency. Natural fibers that can be utilized in the manufacture of non-asbestos brake linings are bamboo, jute, coconut powder, corn cob, teak wood powder, rice husk ash and many more [4].

Several studies have been conducted in the field of asbestos-free brake pad development. The use of bagasse [5], glugu wood sawdust waste charcoal [6], banana peel [7] teak wood powder [8] etc. has been investigated. Various studies around the world are focusing on how to utilize industrial or agricultural waste as a source of industrial raw materials. The utilization of this waste is not only economical, but it can also maintain a better nature. One of the agricultural wastes that are widely available in Indonesia is sengon wood waste, sengon wood is a production wood that is widely produced and produces powder that becomes waste, and incidentally in my environment there is a lot of sengon wood waste that has not been utilized properly, so this raises the idea of using the powder as one of the research materials in making brake lining. Zincon wood powder is combined with iron ore or aluminum powder as reinforment to produce brake linings that have good mechanical strength and wear resistance. In this case, for a disc brake system, no single material meets the desired performance-related criteria, such as safety and durability under different braking conditions. Friction materials are required to provide a stable coefficient of friction and low wear rates over a wide range of operating speeds, pressures, temperatures and environmental conditions. In addition, they must also be compatible with the brake rotor or disc material to reduce severe wear, vibration, and noise during braking [4]. Therefore, based on previous studies [7] and [8], the reason for choosing the particle size and composition of its components is the novelty of this study and this is what distinguishes it from previous research specially in material Sengon wood. In addition to considering practical matters for the purpose of ease in the brake pad moulding process. Because with a smaller particle size and the selection of composition using sengon wood will help facilitate the brake pad moulding process.

From the description above that by mixing sengon wood powder, iron ore and aluminum powder with a resin to form a composite is expected to have good mechanical strength. In this study biocomposites from sengon wood powder with variations in particle size and composite composition as an application of brake lining by testing hardness and wear as a non-asbestos brake lining material. Therefore the objectives of this research are: 1) Knowing the effect of variations in particle size and composite composition on the hardness of brake lining; 2) Knowing the effect of variations in particle size and composition of composites used on the wear rate of brake linings; and 3) Knowing the interaction of variations in particle size and composition of composites on performance in non-asbestos brake linings.

2. METHODS

2.1 Material

Since the target of this study is to compare the results of previous similar studies with different materials used in this study, the criteria for selecting particle size and the composition of the mixture are made the same as the previous study. The only difference lies in the use of sengon wood material. The sengon wood material was obtained from around the house because it so happened that the area (Banyuwangi Regency) is one of the producers of sengon wood. The materials used during this work were polyester resin, sengon wood powder, iron powder and aluminum powder as shown in Figure 1 with the material composition shown in Table 1 below.

Figure 1. Ingredients

2.2 Specimen Making Method

The materials were prepared and mixed in the container and the mixing of the materials was done properly so as to achieve a homogeneous state and then transferred into the mold. The mixtures were added according to their respective compositions as shown in Table 1 in terms of specimen weight:

Table 1. Material Composition

Specimen Number	Specimen Code	Unit Composition Presentation (%)				Particle Size (Meh)
		Sengon Wood Powder	iron powder	Aluminum Powder	Polyester Resin	
1	A1	50	0	10	40	40
2	A2	50	0	10	40	60
3	A3	50	0	10	40	80
4	A4	50	0	10	40	100
5	B1	50	10	0	40	40
6	B2	50	10	0	40	60
7	B3	50	10	0	40	80
8	B4	50	10	0	40	100
9	G	(Comparison Sample)				

The specimens are produced using a compression machine with a press molding technique. This stage is called the compaction stage which aims to compact the powder. In this compaction process, marking the hardness of the material also affects the length of time for molding and the amount of pressure applied during the compaction process given in the process of making brake lining. The longer the time required and the greater the compaction pressure applied, the harder the brake lining specimen. In this process, the compressive force applied was 3ton for 5 minutes. Furthermore, the specimen is removed from the mold to carry out the sintering process so that the bond between the materials becomes heavier. Sintering is done at 80°C for 30 minutes. The brake lining was dried at room temperature for 2 hours to ensure the material was dry. The brake disc lining specimens are then glued to the brake lining mounting plate with the application of an adhesive layer, the brake lining mounting plate is made of mild steel, which must be prepared by cleaning the plate behind the brake lining and applying an adhesive layer. The strength of the adhesive bond between the material and the friction and lightness of the steel is very important to avoid debonding during use. The following photos of the resulting brake lining are shown in Figure 2.

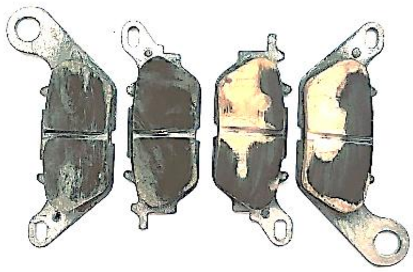

Figure 2. Brake lining results

2.3 Specimen Testing

Hardness values of the specimens were obtained using a durometer hardness tester. A 63 mm high sample was used to conduct the test on a wide variety of different material compositions. The test was conducted using a shore D type durometer tester with testing standards according to ASTM D2240.

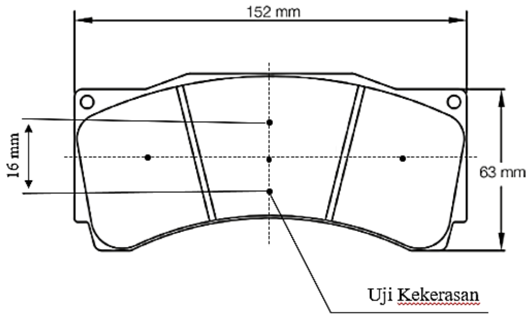

Figure 3. Hardness test equipment

Wear Rate Testing is done with a disc brake simulator. Before the brake lining is installed on the simulator, it needs to be weighed to determine the initial weight of the brake lining. The compressive force acting on the brake lining is generated by the brake lever and the amount of pressure generated is controlled using a pressure gauge and for the rotation speed of the brake disc is measured using a tachometer. After the brake disc stops, the weight of the brake lining is weighed after friction. Before testing, the surface of the specimen is heated at a temperature of 10°C to 35°C to determine the effect of heat treatment of the specimen on the wear rate. During the test, it must be placed on a smooth and flat surface free of oxide scale, foreign objects, and free of lubricants so that no displacement occurs during the test. Wear rate testing is carried out for 60 seconds with a rotation speed of 800 rpm. The weight difference measured before and after the test gives the sample wear. The formula used to convert weight loss into wear rate is:

$$M = \frac{W0-W1}{A.t} \quad (1)$$

M = wear rate (gram/mm^2.second)

W0 = weight before wear rate (gr)

W1 = weight after wear rate(gr)

t =time testing (second)

A = cross sectional area (mm)

3. RESULTS AND DISCUSSION

3.1 Hardness Test Results

In the process of collecting data in this study using a shore D Teclock GS-702 durometer hardness tester at the Mechanical Engineering Material Testing Laboratory of Malang State Polytechnic and obtained the results of research on the hardness of zincon wood powder brake materials, aluminum, iron powder as follows:

Table 2. Hardness test results

Specimen No	Specimen Code	Hardness Value (HD)					Average
		1 st Tes	2 st Tes	3 st Tes	4 st Tes	5 st Tes	
1	A1	64	66	68	67	65	66
2	A2	70	68	69	70	69	69
3	A3	75	76	76	74	75	75
4	A4	78	78	79	78	79	78
5	B1	69	68	67	69	68	68
6	B2	75	76	74	76	75	75
7	B3	76	76	79	78	76	77
8	B4	81	82	80	82	80	81
9	G	74	75	74	75	73	75

Data collection that has been carried out, then processed using statistical software. The following are the results of the analysis that has been carried out. Analysis of Variance (anova) is used to determine the relationship between the dependent variable and the independent variable. In this case the method used is factorial anova.

Table 3. Anova and Model Summary

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	1002,58	143,225	133,23	0,000
Linear	4	974,70	243,675	226,67	0,000
Uk Partikel (Mesh)	3	875,48	291,825	271,47	0,000
Kom Komposit (1=Al ; 2=Fe)	1	99,23	99,225	92,30	0,000
2-Way Interactions	3	27,88	9,292	8,64	0,000
Uk Partikel (Mesh)*Kom Komposit (1=Al ; 2=Fe)	3	27,88	9,292	8,64	0,000
Error	32	34,40	1,075		
Total	39	1036,98			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1,03682	96,68%	95,96%	94,82%

This study uses alpha (α) of 5% or 0.05. From the table above, it is known that the particle size and composite composition variables have a significant effect on the hardness value (response) because the P-value is less than the specified alpha (α) (p-value < alpha (α), so the null hypothesis (H0) is rejected and the alternative hypothesis (H1) is accepted. And the interaction of the two variables has a significant effect because the P-value is less than the specified alpha (α) (p-value < alpha (α), so the null hypothesis (H0) is rejected and the alternative hypothesis (H1) is accepted. From (R-square) of 96.68%, the remaining 3.32% is an error caused by other variables not in the study.

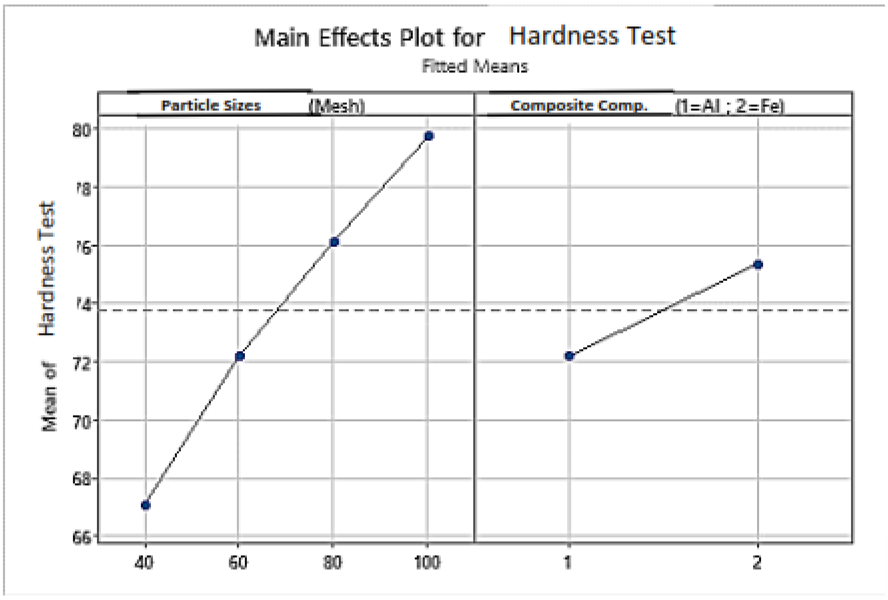

Figure 4. Factorial Plot

Based on Figure 4. there are two main lines, namely horizontal which shows the independent variable and vertical which shows the dependent variable. The graph shows that the smaller the particle size or the larger the mesh size used during testing causes the higher or increase in the resulting hardness value. The composite composition graph shows that the use of iron powder material produces a better hardness value than aluminum powder.

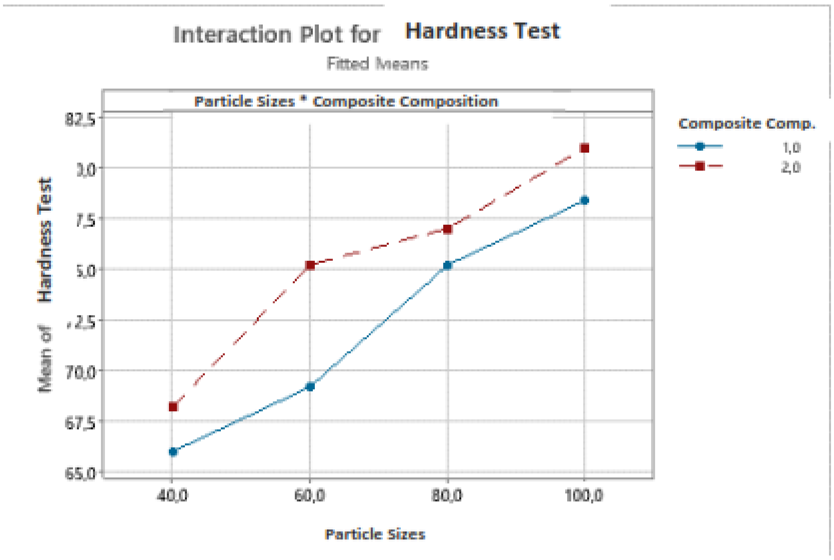

Figure 5 . Factorial interaction plots

Figure 5. is an interaction graph between particle size and composite composition which aims to determine the effect of interaction between independent variables on the dependent variable, where in this study describes the relationship between particle size and composite composition on hardness value. In graph 2 the line shows the independent variable composite composition with different colors according to the material used from the specimen, namely blue shows the specimen with aluminum material while orange shows the specimen with iron powder material. In the graph, it can be seen that the level of hardness of the specimen is getting bigger along with the use of smaller particle sizes or the larger the mesh size used, while in the composite composition the use of iron powder has a higher hardness than the use of aluminum powder in the specimen.

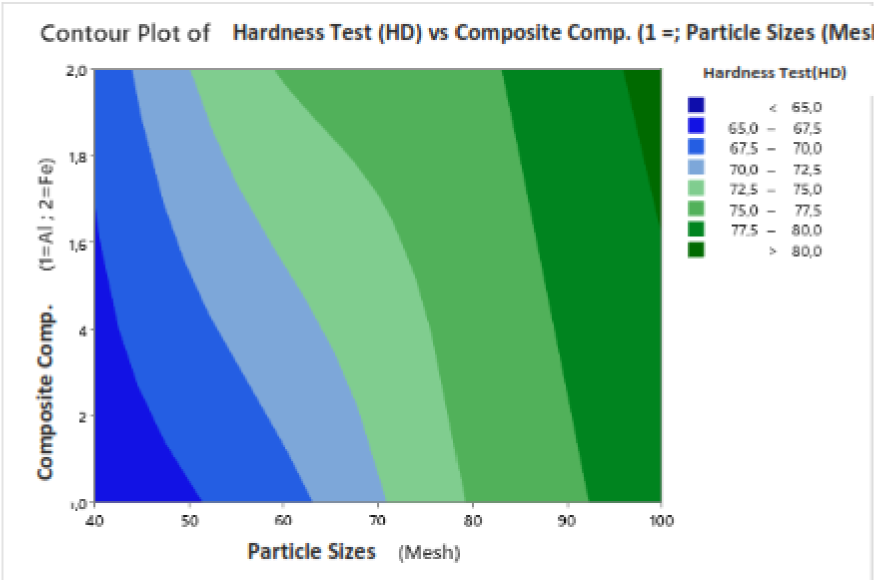

Figure 6. Countour plot graph

Figure 6 is a contour plot graph of the effect of particle size and composite composition on the hardness value of the specimen, showing that the horizontal line on the graph is the variation of particle size and the vertical line on the graph is the composite composition. The dark green color number 2 from the right shows the hardness level area of 77.5 - 80 HD, with a particle size of 100 mesh in composite composition number 1 and 2. The light green color shows the hardness level area of 75 - 77.5 HD with a particle size of 80 mesh in composite composition number 1 and 2, and at a particle size of 60 mesh in composite composition number 2. Tosca green color or the middle part which means the hardness level of 72.5 - 75 HD with a particle size of 80 mesh in composite composition number 1, and at a particle size of 60 mesh in composite composition number 2. In sky blue or the middle part which means the hardness level of 70 - 72.5 HD with a particle size of 60 mesh in composite composition number 1, and at a particle size of 50 mesh in composite composition number 2. The light blue color shows the hardness level area of

67.5 - 70 HD with a size of 60 mesh in composite composition number 1, and at a particle size of 40 mesh in composite composition number 2. While the azure blue color or the leftmost part of the graph shows the hardness level area of 65 - 67.5 HD with a particle size of 40 mesh in composite composition number 1. And the sapphire blue color shows the hardness level less than < 65HD in composite composition number 1.

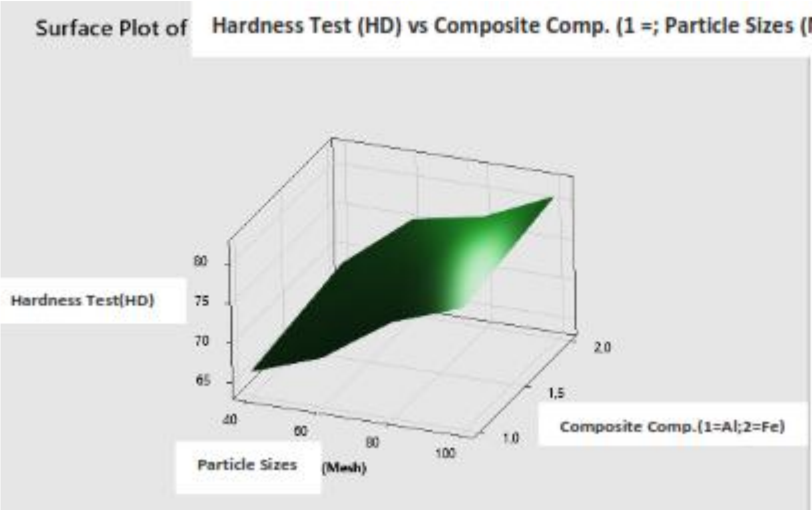

Figure 7. Surface plot graph

Figure 7 is a surface plot graph of the results of the study of the effect of particle size and composite composition on specimen hardness. In the graph, the x-axis shows the particle size, the y-axis shows the composite composition, and the z-axis shows the hardness level. From the graph it can be concluded that, the effect of particle size on hardness is the smaller the particle size or the larger the mesh size, the greater the level of hardness produced. In the effect of composite composition on the level of hardness, it can be concluded that the use of composition number 2 or iron powder has better hardness than the use of composition number 1 or aluminum powder.

3.2 Wear Test Results

In the process of taking data in this study using formula 1.1 the results of the wear test are as follows:

Table 4. Wear Test Results

No	Kode	Wear Rate (gram/ mm^2 .sec)					Average
		1 st Tes	2 st Tes	3 st Tes	4 st Tes	5 st Tes	
1	A1	0,000000336	0,000000318	0,000000309	0,000000315	0,000000326	0,000000321
2	A2	0,000000316	0,000000328	0,000000323	0,000000316	0,000000324	0,000000321
3	A3	0,000000272	0,000000265	0,000000257	0,000000280	0,000000272	0,000000269
4	A4	0,000000252	0,000000253	0,000000249	0,000000253	0,000000246	0,000000251
5	B1	0,000000319	0,000000330	0,000000335	0,000000325	0,000000327	0,000000327
6	B2	0,000000272	0,000000268	0,000000277	0,000000265	0,000000268	0,000000270
7	B3	0,000000258	0,000000261	0,000000241	0,000000246	0,000000249	0,000000251
8	B4	0,000000234	0,000000242	0,000000251	0,000000241	0,000000258	0,000000245
9	G	0,000000354	0,000000360	0,000000327	0,000000309	0,000000363	0,000000343

Analysis of Variance (anova) is used to determine the relationship between the dependent variable and the independent variable. In this case the method used is factorial anova..:

Table 5 Anova dan model summary

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	0,000000	0,000000	114,31	0,000
Linear	4	0,000000	0,000000	178,60	0,000
U Partikel(Mesh)	3	0,000000	0,000000	220,12	0,000
Kom Komposit(1=Al ; 2=Fe)	1	0,000000	0,000000	54,04	0,000
2-Way Interactions	3	0,000000	0,000000	28,58	0,000
U Partikel(Mesh)*Kom Komposit(1=Al ; 2=Fe)	3	0,000000	0,000000	28,58	0,000
Error	32	0,000000	0,000000		
Total	39	0,000000			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0,0000000	96,15%	95,31%	93,99%

This study uses alpha (α) of 5% or 0.05. From the table above, it is known that the particle size and composite composition variables have a significant effect on the wear value (response) because the P-value is less than the specified alpha (α) (p-value < alpha (α), so the null hypothesis (H0) is rejected and the alternative hypothesis (H1) is accepted. And the interaction of the two variables has a significant effect because the P-value is less than the specified alpha (α) (p-value < alpha (α) then the null hypothesis (H0) is rejected and the alternative hypothesis (H1) is accepted. From (R-square) of 96.15%, the remaining 3.85% is an error caused by other variables not in the study.

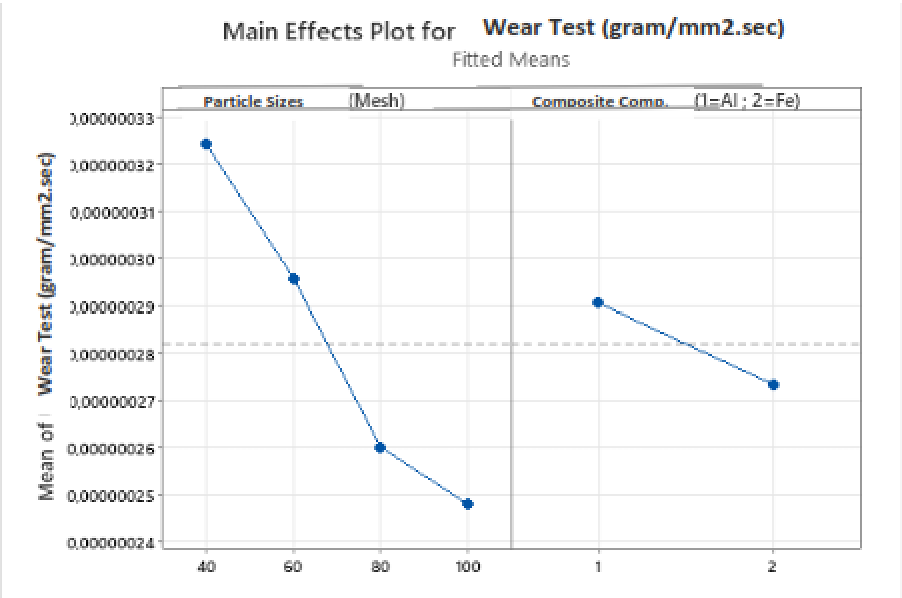

Figure 8 Factorial Plot

Based on Figure 8. there are 2 main lines, namely horizontal which shows the independent variable and vertical which shows the dependent variable. The graph shows that the smaller the particle size or the larger the mesh size, the lower or lower the wear rate produced. In the composite composition shows the use of iron powder material the wear rate is lower or decreases than aluminum powder.

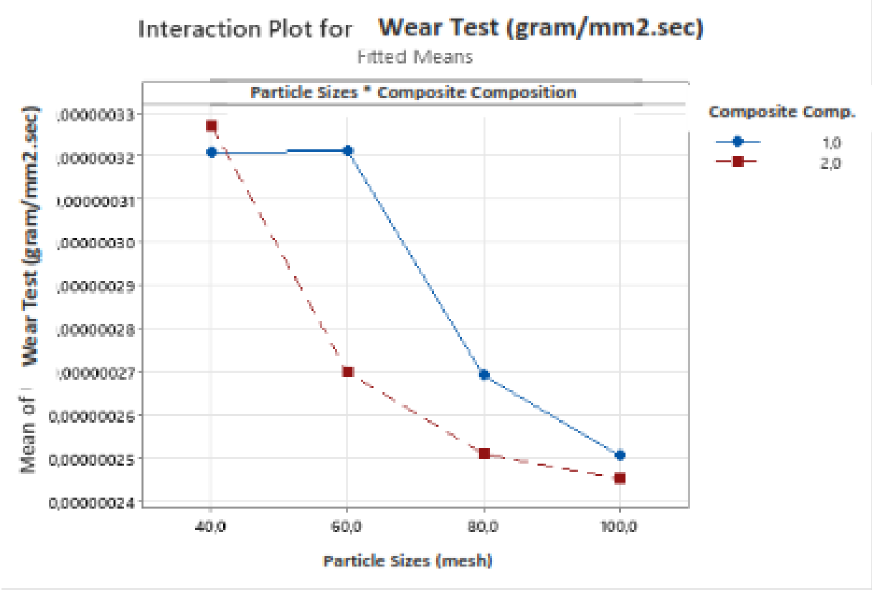

Figure 9. Factorial interaction plots

Figure 9. is a graph of the interaction between particle size and composite composition which aims to determine the effect of the interaction between the independent variable on the dependent variable, where in this study describes the relationship between particle size and composite composition on wear rate. In the graph there are 2 lines showing the independent variable composite composition with different colors according to the material used from the specimen, namely blue and orange. In the graph, it can be seen that the wear rate of the specimen is getting smaller along with the smaller the particle size or the larger the mesh size used, while in the composite composition the use of iron powder has a smaller wear rate than the use of aluminum powder in the specimen.

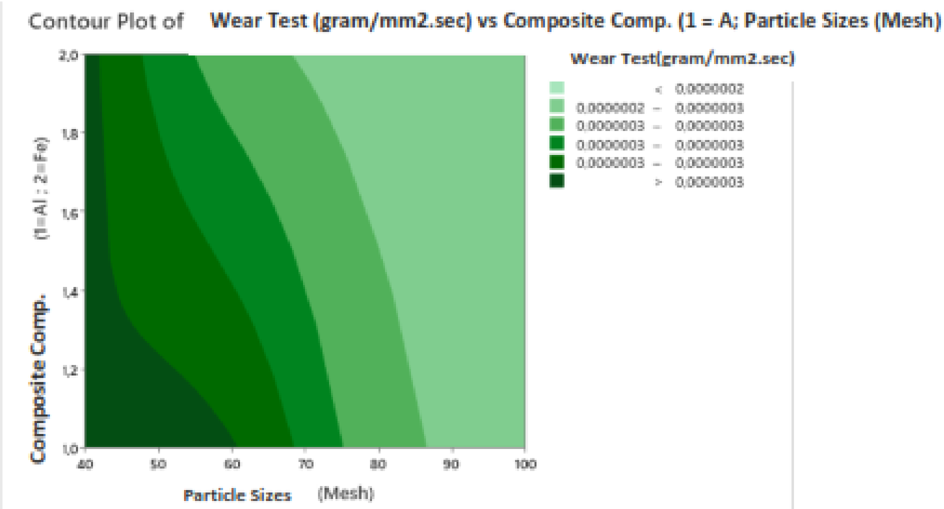

Figure 10. Countour plot graph

In Figure 10. above is a contour plot graph of the effect of particle size and composite composition on the wear rate value of the specimen, showing that the horizontal line on the graph is the variation of particle size and the vertical line on the graph is the composite composition. In the figure above, the tosca green color or the rightmost part of the graph shows the smallest wear rate area of 0.0000002 g/mm^2.second with a particle size of 90 - 100 mesh in composite compositions 1 and 2 and at a particle size of 80 mesh in composite composition number 2. The jade green color or the right part shows the wear rate area of 0.0000002 - 0.0000003 g/mm^2. seconds with a particle size of 80 mesh in composite composition number 1, at a particle size of 60 mesh in composite composition number 2. In the middle part of the figure above shows Emerald green color shows the wear rate area of 0.0000003 g/mm^2.seconds with a particle size of 80 mesh in composite composition number 1, and at a particle size of 60 mesh in composite composition number 2. The dark green color shows the wear rate area of 0.0000003 g/mm^2.second with a particle size of 60 mesh in composite composition number 1, and at a particle size of 50 mesh in composite composition number 2. The dark green color or the leftmost part of the graph shows the area of the greatest wear rate of >0.0000003 g/mm^2.second with a particle size of 60 mesh in composite composition number 1 and at a particle size of 40 mesh with composite compositions number 1 and 2.

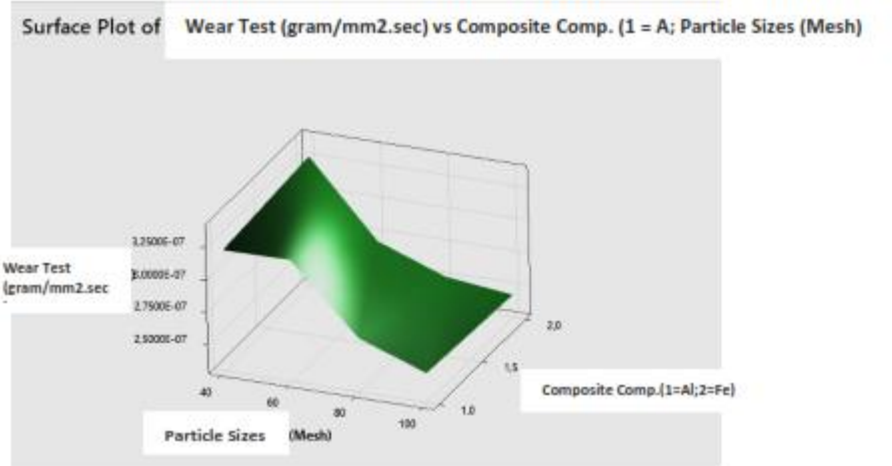

Figure 11. Surface plot graph

Figure 11 is a surface plot graph of the results of the study of the effect of particle size and composite composition on specimen wear. In the graph, the x-axis shows the particle size, the y-axis shows the composite composition, and the z-axis shows the wear rate. From the graph it can be concluded that, the effect of particle size on wear is the larger the mesh size or the smaller the particle size, the smaller the wear rate produced will be. This can be caused by the level of hardness which also increases against the particle size as the previous research variables did. The greater the level of hardness, the smaller the wear rate produced. On the effect of composite composition on wear rate, it can be concluded that the use of composition number 2 or iron powder has a relatively lower wear rate compared to the use of composition number 1 or aluminum powder.

3.3 Discussion

Effect of Particle Size and Composite Composition on Hardness Level

Based on the processing of hardness test data above is a significant effect. The hardness level of the particle size is known to be higher at a larger mesh size, this is because the small particle size has smaller pores so that more material bonds will create a smaller space, with small pores, the performance of the brake lining will be good. While the hardness value of the composite composition using iron powder has increased the hardness value, because iron powder has a higher density value of 7.87 gr/cm^3 while the density value of aluminum powder is 2.7 gr/cm^3. The highest hardness value is found in specimen B4 with an average of 81 HD using a mesh of 100 and a composite composition of iron powder, from this study it was found that specimens A4, B3, B4 have an average hardness value that is higher than the comparison sample on the market. Particle size variations produce good hardness values supported by research conducted by Purboputro (2020) entitled "Making Brake Pads Using Variations of Grain Mesh Aluminum Silicon (Al-Si) 50, 60, 100 With Teak Wood Powder Against Hardness Level Values, Wear and Coefficient of Friction" states that the value of the finished wood powder brake lining with Mesh 100 variation is 81.60 HD and the lowest is at Mesh 50 variation which is 75.45 HD, so it is concluded that the smaller the grain of Aluminum Silicon can affect the increase in hardness value on the natural-based brake lining teak wood powder.

While in the composition of the material it can be concluded that the higher the density value of a material, this will cause the hardness value to increase. This is in accordance with previous research entitled "Experimental Study of the Effect of Bamboo Powder Particle Size on Composite Mechanical Properties for Motorcycle Brake Pad Applications" which states that the higher the mark density value of a material can cause the mark hardness to increase as well.

Effect of Particle Size and Composite Composition on Wear Rate

In the wear test, it is known that there is a significant effect of the particle size of the non-asbestos brake lining composite. The use of smaller particle sizes or larger mesh sizes results in smaller wear rates of brake lining specimens. This indicates that the wear rate of brake lining with a mesh size of 100 is better than that of mesh sizes 40, 60, and 80. This is due to the extent of particle-matrix interface interactions at smaller particle sizes allowing small particles on the surface of the brake lining to be difficult to escape, and vice versa.

Meanwhile, the effect of composite composition on wear. Composite compositions that use iron powder materials have higher hardness compared to aluminum. This is because the mechanical characteristics of the two materials are different. From this study it can be seen that specimens with codes A1, A2, A3, A4, B1, B2, B3, B4 have a wear rate that is close to the comparison sample.

Interaction Effect of Particle Size and Composite Composition on Hardness and Wear

The interaction of the two independent variables has a significant effect on hardness and wear. This is because composite composition and particle size are closely interconnected in determining the properties and performance of brake linings. Composite composition affects the basic characteristics of the material, while particle size affects the mechanical properties of the brake lining, smaller particle size, higher strength and stiffness due to better load distribution. So the interaction of the two results in high hardness and low wear.

Knowledge gap and contribution of this study

From the results of this study, information was obtained regarding the current knowledge gap related to brake pads made of non-asbestos fibers and natural fibers used from Sengon wood. This is an innovative idea to expand the alternative use of natural fibers other than the widely used natural fibers such as bamboo, teak wood, and coconut shells. In addition, it turns out that Sengon wood also has a significant impact on the performance of non-asbestos brake pads. East Java Province is a Sengon wood producing area so it will be useful in utilizing the potential of natural resources.

4. CONCLUSION

The following conclusions can be obtained from the research on the effect of particle size and composite composition on the performance of non-asbestos brake linings:

1. The effect of particle size and composite composition on the hardness level of non-asbestos brake linings can be concluded that:
   a. Particle size affects the hardness value received. The larger the mesh size used, the higher the hardness value obtained, namely in specimen B4 with an average of 81 HD using mesh 100 and iron powder composite composition.
   b. The composite composition affects the hardness value of non-asbestos brake linings, namely with different types of materials used, the characteristics of these materials are also different. In this study, the highest hardness value was obtained in specimens using iron powder.
2. Effect of Particle Size and Composite Composition on Wear Rate
   a. Particle size variation has an influence on the wear rate, namely the larger the mesh size, the smaller the wear rate value will be obtained. This is because the particle-matrix interface interaction at a smaller particle size allows small particles on the surface of the brake lining to be difficult to escape
   b. Composite composition has an effect on the effect on canvas wear rate because the higher the mechanical properties of the type of material produced, the more the material produced is also good.
3. The interaction of the two independent variables has a significant effect on hardness and wear. This is because composite composition and particle size are closely interconnected in determining the properties and performance of brake linings. Composite composition affects the basic characteristics of the material, while particle size affects the mechanical properties of the brake lining, smaller particle size, higher strength and stiffness due to better load distribution. So, the interaction of the two results in high hardness and low wear.

5. ACKNOWLEDGMENT

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6. REFERENCES

[1] P. Blau and J. McLaughlin, “Effect of water films and sliding speed on the frictional behavior of truck disc brake materials,” Wear, vol. 36, no. 10, pp. 709–715, 2003.
[2] L. Mulyani, F. Setiawan, and E. Sofyan, “Analisis karakteristik keausan material dengan matriks resin menggunakan filler serat bambu dan pasir besi untuk aplikasi kampas rem,” Teknika STTKD: J. Tek. Elektron. Eng., vol. 8, no. 1, pp. 103–111, 2022, doi: 10.56521/teknika.v8i1.549.
[3] S. Kumar and S. K. Ghosh, “Particle emission of organic brake pad material: A review,” Proc. Inst. Mech. Eng. D J. Automob. Eng., vol. 234, no. 5, pp. 1213–1223, 2020, doi: 10.1177/0954407019879839.
[4] Suhardiman and M. Syaputra, “Wear analysis of non-asbestos brake linings made from polymer composites of rice dust and coconut shells,” Inovtek Polbeng, pp. 210–214, 2017.
[5] N. A. Ademoh and A. I. J. D. Olabisi, “Development and evaluation of maize husks (asbestos-free) based brake pad,” J. Dev., vol. 5, no. 2, pp. 67–80, 2015.
[6] I. Puja, “Studi sifat impak ketahanan aus dan koefisien gesek bahan komposit arang limbah serbuk gergaji kayu glugu dengan matrik epoxy,” J. Energi Manuf., vol. 4, no. 2, pp. 2–6, 2010.

[7] Rina, "Experimental study of the effect of bamboo powder particle size on the mechanical properties of composites for motorcycle brake lining applications," Unpublished manuscript, 2016.
[8] M. L. I. Sholihin, "Pengaruh komposisi dan temperatur material biokomposit terhadap kinerja kampas rem non-asbestos," J. Energi Teknol. Manuf., vol. 5, no. 1, pp. 29–34, 2022, doi: 10.33795/jetm.v5i01.117.