Bukti korespondensi untuk artikel dengan judul "Addition Rice Husk on the Density and Impact Strength of Non-Asbestos Brake Pad Composites Prepared by The Hand Layup Method" di jurnal REKAYASA: Jurnal Penerapan Teknologi dan Pembelajaran oleh Deni Fajar Fitriyana S.T., MT. Artikel tersebut telah terbit dengan keterangan sebagai berikut :

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Identitas jurnal REKAYASA: Jurnal Penerapan Teknologi dan Pembelajaran adalah sebagai berikut:

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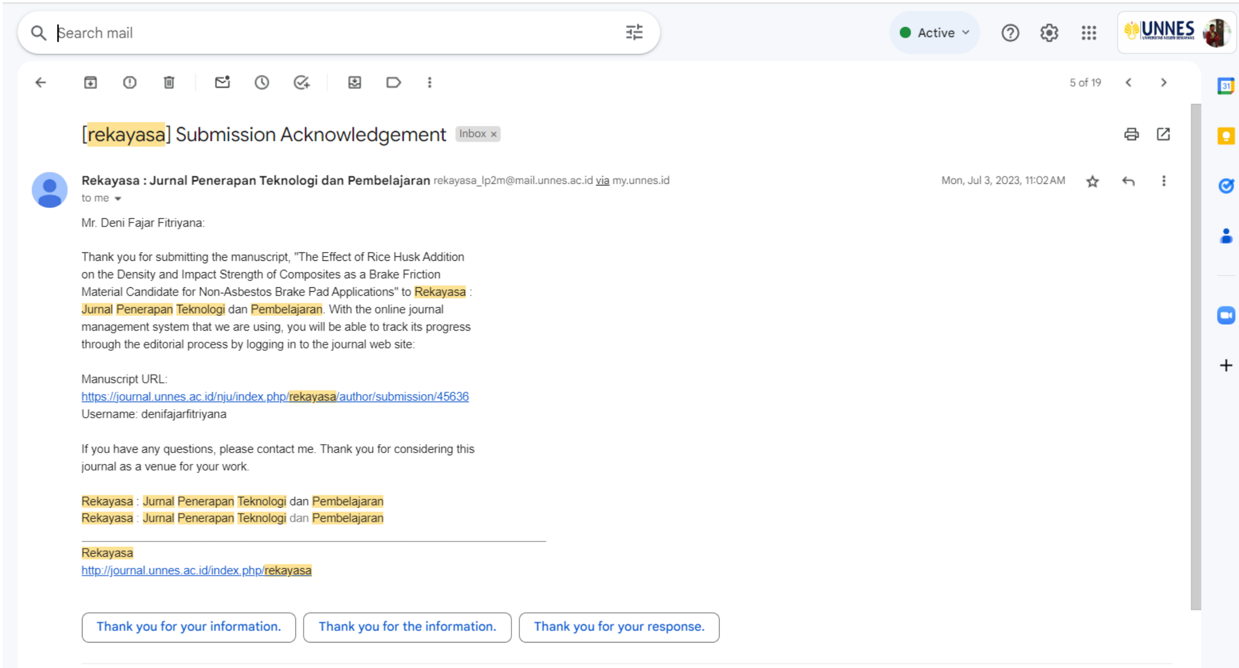
Secara ringkas, proses submit hingga terbit untuk manuskrip ini adalah sebagai berikut:

No	Tanggal	Aktvitas
1	3 Juli 2023	Submit Artikel ke jurnal Rekayasa : Jurnal Penerapan Teknologi dan Pembelajaran
2	10 Agustus 2023	First Decision (revision)
3	19 Agustus 2023	Submit revisi
4	5 September 2023	Manuscript accepted
5	6 September 2023	Manuscript published

Berikut ini, saya sampaikan detail proses korespondensi untuk manuskrip yang berjudul **Addition Rice Husk on the Density and Impact Strength of Non-Asbestos Brake Pad Composites Prepared by The Hand Layup Method** di jurnal REKAYASA: Jurnal Penerapan Teknologi dan Pembelajaran.

1. Melakukan submit artikel ke Jurnal Rekayasa : Jurnal Penerapan Teknologi dan Pembelajaran pada tanggal 19 Juni 2023


[rekayasa] Submission Acknowledgement Inbox

Rekayasa : Jurnal Penerapan Teknologi dan Pembelajaran rekayasa_lp2m@mail.unnes.ac.id via my.unnes.id Mon, Jul 3, 2023, 11:02 AM
to me

Mr. Deni Fajar Fitriyana:

Thank you for submitting the manuscript, "The Effect of Rice Husk Addition on the Density and Impact Strength of Composites as a Brake Friction Material Candidate for Non-Asbestos Brake Pad Applications" to Rekayasa : Jurnal Penerapan Teknologi dan Pembelajaran. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

Manuscript URL:
https://journal.unnes.ac.id/nju/index.php/rekayasa/author/submission/45636
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If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

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Kelengkapan berkas yang disubmit adalah sebagai berikut :

A. Cover letter
B. Draft artikel atau manuskrip

A. Cover letter

Dear Editor in-Chief,

On behalf of the authors, I would like to submit our manuscript entitled "Addition Rice Husk on the Density and Impact Strength of Non-Asbestos Brake Pad Composites Prepared by The Hand Layup Method" for publication on the Journal of Rekayasa : Jurnal Penerapan Teknologi dan Pembelajaran. We believe this research article would be a special of interest to the reader of the Journal of Rekayasa : Jurnal Penerapan Teknologi dan Pembelajaran.

This study reports on the effect of the addition rice husk on the density and impact strength of non-asbestos brake pad composites prepared by the hand layup method. In train operations, brakes are an important component that concerns passenger safety and must be replaced periodically according to their useful life. Currently, the most widely used train brake pad material is composite, unfortunately, the majority of train brake pads in Indonesia are imported products. This study aims to manufacture and characterize composite materials for friction material for train brake pads that meet quality standards to substitute imported products. It needs to reduce dependence on imported products while at the same time encouraging the strengthening of the structure of the domestic manufacturing industry. In addition, agricultural waste in rice husks will be used to produce more environmentally friendly products. The composition of the types of composite materials, which include binder, reinforcement, abrasive, and filler materials, will be examined. Making composite materials in this study will use the hand layup method. Material characterization carried out includes impact testing and density. The characterization results show that using rice husk as a filler greatly influences the density of the resulting composite material. Specimen made from epoxy, rice husk, iron filings, and Al2O3 (wt.%) at 50%, 20%, 15%, and 15%, respectively, was able to produce a higher density compared to the composite without rice husk and epoxy material. The density test supports the results of the impact tests that have been carried out. The higher the rice husk content, the higher the density produced. Adding rice husk can increase the mechanical properties of the resulting composite material. On this letter, we would like to declare that this research paper has never been published, and not under consideration for publication in elsewhere. We hope you will consider our article for publication on your esteemed Journal. We are looking forward to hearing your kind reply.

Thank you.

Best wishes and regards,

Deni Fajar Fitriyana

B. Draft artikel yang disubmit ke Jurnal Rekayasa : Jurnal Penerapan Teknologi dan Pembelajaran

The Effect of Rice Husk Addition on the Density and Impact Strength of Composites as a Brake Friction Material Candidate for Non-Asbestos Brake Pad Applications

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Abstract

In train operation, brakes are an important component because they involve the safety of passengers. Therefore, brake pads must be replaced periodically according to their lifespan. Currently, the most widely used train brake pads material is composite. Unfortunately, most train brake pads in Indonesia still use imported products because there is no industry capable of producing train brake pads of the desired quality. This study aims to manufacture and characterize composite materials for friction material for train brake pads that meet quality standards to substitute imported products. This needs to be done to reduce dependence on imported products while at the same time encouraging the strengthening of the structure of the domestic manufacturing industry. In addition, agricultural waste in the form of rice husks will be used to produce more environmentally friendly products. In this study, the composition of the types of composite materials, which include binder, reinforcement, abrasive, and filler materials, will be examined. Making composite materials in this study will use the hand lay-up method. Material characterization carried out includes impact testing and density. The characterization results show that the use of rice husk as a filler greatly influences the density of the resulting composite material. Specimen 5 made from epoxy, rice husk, iron filings, and Al2O3 (wt.%) at 50%, 20%, 15%, and 15%, respectively, was able to produce a higher density compared to the composite without rice husk (specimen 1) and epoxy material (specimen 6). The results of this density test support the results of the impact tests that have been carried out. The higher the rice husk content, the higher the density produced. This will result in an increase in the mechanical properties of the resulting composite material.

Keywords: composite, matrix, filler, reinforcement, abrasive.

Introduction

Currently, automotive engines have been able to produce enormous power to meet human needs for high-speed transportation facilities. A good braking system is certainly needed to support high engine performance. The consumption of friction material on brake pads ranks second after petroleum and gas fuels. Brake pads are one of the spare parts that function to slow down or stop vehicles, especially land vehicles. Friction material serves to transform kinetic energy into thermal energy [1].

During high-speed vehicles, the brake pads get a load of up to 90% of the other components, so the brake pads greatly determine the safety of the driver and passengers. Brake pads are consumables that must be replaced periodically. Therefore, the need for friction material for brake pads is increasing along with the growth of the automotive industry in Indonesia [1].

Figure 1. Brake friction materials

One of the most important parts of the brake pads is the friction material, as shown in Figure 1. The friction material is made of a material that has good mechanical properties and tribological performance. Friction material is a key component of brake pads that helps to slow down or stop a moving vehicle. It works by creating friction between the brake pad and the rotor, which converts the kinetic energy of the vehicle into heat energy. This process causes the vehicle to slow down or come to a complete stop. Composite materials for friction materials generally consist of binder, reinforcement, abrasive, and filler materials. The expected mechanical properties of friction materials include hardness, tensile strength, corrosion resistance, and thermal resistance. While the desired tribological performance includes low wear and a high coefficient of friction, both in dry contact and wet contact [1].

Friction material can be used to make brake pads for motorcycles, cars, trucks, trains, and airplanes. Especially for trains, the need for friction material for train operations is very high. It is estimated that hundreds of thousands of brake friction materials are required annually. Initially, the friction material used in the braking system on trains was cast metal. For decades, Small and Medium Industries (IKM) in Indonesia have been able to meet most of these needs. However, with the development of material technology, composites are now the main choice of friction material for train braking systems.

This is inseparable from the economic value produced, where metallic friction materials have a service life of 14–19 days, while composite materials have a service life of 90–240 days [2].

PT Kereta Api Indonesia started substituting friction materials with composites around the beginning of 2010. The composite technology for friction materials for train brake pads has not been mastered by local Indonesian producers, and as a result, the volume of imports of friction materials for train brake pads is still the majority. In 2018–2019, the import value of friction material for railroads was US$ 86,640,667, or Rp. 1,238,961,538,100.00. This value is obtained from imported commodities with HS codes 68138100 and 86072100 [3]. In general, the composite friction material on the brake pads uses asbestos as reinforcement with certain resins.

Asbestos was chosen because it has good mechanical strength and is not too expensive. However, brake pads made of asbestos can experience fading at temperatures above 200° C. In addition, based on research conducted by the WHO (World Health Organization) and IARC (International Agency for Research on Cancer), asbestos is carcinogenic, so it can cause lung cancer from the dust it produces. Therefore, the application of this material is prohibited in the automotive industry and other applications. So, it is necessary to develop new materials to replace asbestos as a friction material while still maintaining its mechanical properties [4–7].

Biomass produced from agricultural activities such as bamboo, palm trees, bagasse, corn stalks, cashew shells, bananas, coir (coconut shells), pineapples, rice straw, plants (stems, leaves, seeds, fruit, stems, grass, sedge-alang), and rice husk are materials that are widely used as a commercially acceptable and environmentally friendly brake pad reinforcement material [8]. Agricultural waste contains a high concentration of natural fibers, so it can be used as a reinforcing material for polymer composites. Agricultural waste has a lot of potential in composites because of its high strength, environmental friendliness, affordability, easy availability, and availability in very large quantities [9–10].

This research needs to be carried out to produce friction material used in brake pads on trains that meets the standards so that they can substitute imported commodities in the future. On the other hand, the use of environmentally friendly materials is also needed to produce friction materials that are safe for the environment and human health. In previous studies, the research team has successfully utilized various agricultural wastes for composite applications [11–15]. In addition, the research team has also conducted research on the application of agricultural waste for the application of friction material to brake pads [1].

In this study, rice husk as reinforcement was combined with resin, filler, and abrasive materials to produce a friction material that would be used to manufacture brake pads for trains.

Material and Methods

The materials used in this study were epoxy, hardener, rice husk, iron powder (Fe_2O_3), and alumina (Al_2O_3). Next, the rice husks were crushed into powder using a crusher machine. The sieving process is carried out with a mesh of 100 to produce rice husk powder. Rice husk powder is dried at 80°C for 24 hours before being mixed with other ingredients. The mixing of the materials was carried out using the composition of epoxy, hardener, rice husk, iron powder (Fe_2O_3), and alumina (Al_2O_3) with several variations as shown in **Table 1**.

Table 1. Composite specimen composition

Spesimen	Resin Epoxy (wt.%)	Sekam padi (wt.%)	Fe_2O_3 (wt.%)	Al_2O_3 (wt.%)
1	100	0	0	0
2	50	0	25	25
3	50	5	22.5	22.5
4	50	10	20	20
5	50	15	17.5	17.5
6	50	20	15	15

The ratio of epoxy and hardener used in this study was 3:1, and then a stirring process was carried out using a magnetic stirrer for 7 minutes. Rice husk, iron filings, and alumina were added according to a predetermined composition and stirred for 5 minutes. The mixture formed was placed in a vacuum oven for 5 minutes to remove air bubbles formed during the mixing process. The mixed material is put in a specimen mold that has been adjusted to ASTM for each test (impact). The formed composite was then dried for 24 hours before testing.

The composite material formed was tested for density and impact. The density testing was performed to establish the density of the composite specimens. An electronic density meter (DME 220 series) from Vibra Canada Inc. (Mississauga, ON, USA) was used to conduct density testing following ASTM 792-08. The charpy impact test was carried out according to the ASTM D6110 standard using the GT-7045-MD IZOD CHARPY Digital Impact Tester manufactured by GOTECH Testing Machines Inc., Taiwan. In this test, the pendulum weight, pendulum speed, angle α, and span used were 25 J, 3.46 m/s, 150°, and 101.6 mm, respectively.

The test results obtained the absorbed energy value of the composite specimen of brake pads friction material. Furthermore, this value is used to find the value of the impact strength by manual calculation.

Results and Discussion

The use of rice husk has a significant effect on the density of the resulting composite material. Specimens and composite density test results are shown in **Figures 2 and 3**.

Figure 2. Density test specimens

Figure 3 shows that the composite density of the brake pads friction material in specimens 1, 2, 3, 4, 5, and 6 is 1.21 g/cm^3, 1.06 g/cm^3, 1.19 g/cm^3, 1.17 g/cm^3, 1.29 g/cm^3, and 1.33 g/cm^3. The brake pads friction material composite specimen with the lowest density was found in specimen 2, which was 1.06 g/cm^3. While the highest density in specimen 6 is 1.33 g/cm^3, specimen 2 is a specimen that does not use rice husk. Whereas in specimen 6, the rice husk used was the highest compared to the other specimens, which was wt.20%.

Rice husk has a high content of amorphous silica, about 95%. Thus, increasing the rice husk used in this study significantly increased the amorphous silica content in the specimens. With a higher volume fraction of rice husk, the silica content contained in the composite specimen also increases. The silica content functions as an absorbent for water vapor, which can form bonds between the materials making up the composite specimens to blend more optimally. This is because the low water content can improve the bond density between the constituent materials in the composite specimen of the brake pads friction material. The high-water content in composite specimens can interfere with the matrix's main function as a binder material in the composite [16].

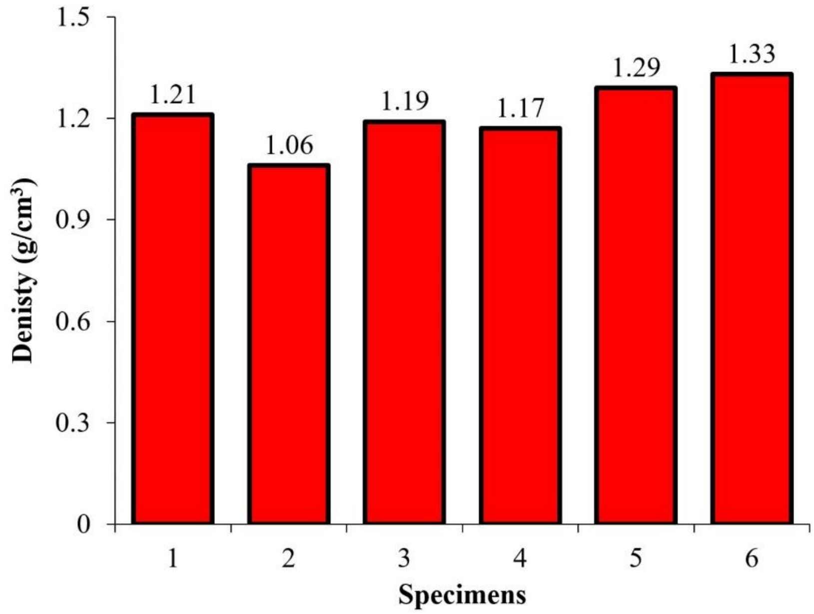

Figure 3. The effect of the composition used on the results of the density test

Research conducted by Suhot *et al.,* (2021) states that composites with rice husk reinforcement can be applied in the manufacture of brake pads. This is because rice husk has a high silica content, which can make the composite structure have a good density so that it can form composite specimens of brake pads friction material with the ability to withstand wear and tear and last a long time [17]. Other research states that composites with high silica content can increase density. This is due to the increased adhesion between the filler and the matrix, which results in a more compact structure and increased density. Research conducted by Jiang et al. showed that a 20% silica concentration with a particle size of 5 μm produced a PTFE/SiO_2 composite with a higher density than other specimens. However, the density of the composite decreases if the silica content exceeds 20%, considering that agglomerates can reduce the adhesion between the filler and the matrix [18].

The results of this study resulted in a friction material specimen with a density that met the requirements for brake friction material applications. In general, commercial brake friction materials have a density of 1,010 to 2,060 g/cm^3 [16]. However, the results of this study are not suitable for the application of brake pads on trains. This happens because the brake pads on a train must have a density in the range of 1.7 to 2.4 g/cm^3.

Specimen 1 Specimen 2 Specimen 3 Specimen 4 Specimen 5 Specimen 6

Figure 4. Charpy impact test specimens

The use of rice husk has a significant effect on the impact strength of the resulting composite material. Specimens and composite impact strength test results are shown in **Figures 4 and 5**. **Figure 5** shows that the impact strength of the brake pads friction material composite in specimens 1, 2, 3, 4, 5, and 6 was 0.0095 KJ/m^2, 0.0101 KJ/m^2, 0.0104 KJ/m^2, 0.0101 KJ/m^2, 0.0104 KJ/m^2, and 0.0107 KJ/m^2. The brake pads friction material composite specimen with the lowest impact strength was found in specimen 1, which was 0.0095 KJ/m^2. While the highest impact strength on specimen 6 is 0.0107 KJ/m^2, Specimen 1 is a specimen that uses 100 wt.% epoxy resin. Whereas in specimen 6, the rice husk used was the highest compared to the other specimens, namely 20 wt.%.

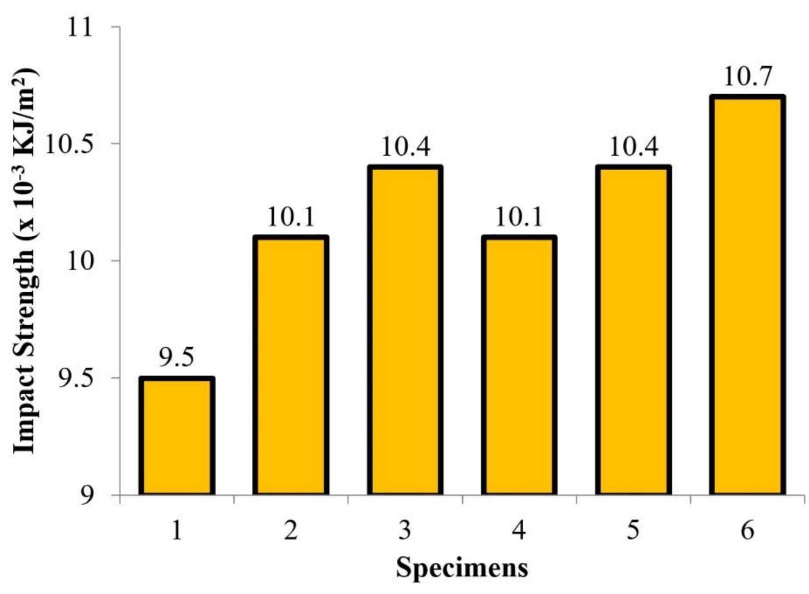

Figure 5. The effect of the composition used on the results of the impact test

The test results show that the presence of rice husk material and additional materials (Al_2O_3 and Fe_2O_3) can influence increasing the impact strength of the brake pads friction material. This was proven by the volume fraction variation in specimens 2 to 6, which showed a higher impact strength than specimen 1. In addition, the addition of rice husk volume fraction in each variation of the friction material composite specimen influenced increasing the impact strength. In general, impact strength is related to the bond between the composite materials. This makes one of the impact strength factors in the brake pads friction material composite specimen have the highest value in specimen 6 with the highest rice husk volume fraction, namely 20% rice husk.

The results of the charpy impact test on specimen 6 produced in this study were higher than the results of research conducted by Iman et al (2020). In their research, they used acacia wood charcoal with an epoxy matrix as an alternative to non-asbestos brake pads, with the highest impact strength of 0.0080 J/mm^2 [18].

Conclusions

- Friction material for railroad brake pads made from composites reinforced with rice husks has been successfully produced.
- The use of rice husk greatly affects the density of the resulting composite material. Specimen 6 made from Epoxy, Rice Husk, Iron Powder, and Al_2O_3 of (wt.%) 50%, 20%, 15%, and 15%, respectively, produced higher density and impact strength compared to other specimens.
- The higher the content of rice husk used, the greater the density and impact strength produced in the specimen.

Acknowledgement

The author would like to thank the Faculty of Engineering, UNNES, for the support provided for the implementation of this research through a Dosen Pemula research scheme with Research Contract Number 1.13.4/UN37/PPK.05/2022.

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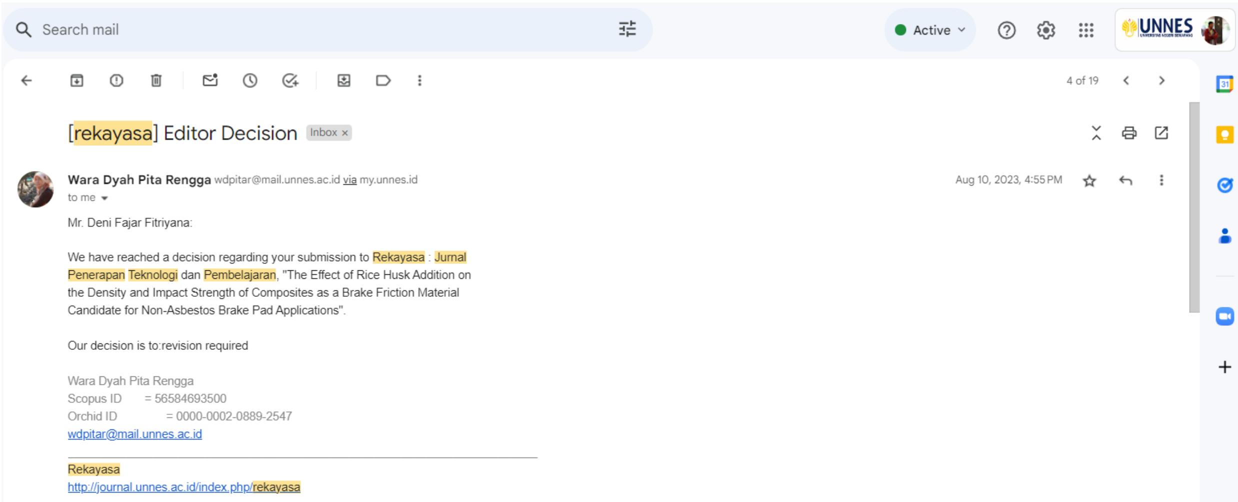
2. Terdapat notifikasi dari Editor yang menyatakan bahwa artikel telah selesai di review pada tanggal 10 Agustus 2023. Pada tahap ini, Submission telah direview dan perlu dilakukan perbaikan.



[rekayasa] Editor Decision

Wara Dyah Pita Rengga wdpitar@mail.unnes.ac.id via my.unnes.id

to me

Aug 10, 2023, 4:55 PM

Mr. Deni Fajar Fitriyana:

We have reached a decision regarding your submission to Rekayasa : Jurnal Penerapan Teknologi dan Pembelajaran, "The Effect of Rice Husk Addition on the Density and Impact Strength of Composites as a Brake Friction Material Candidate for Non-Asbestos Brake Pad Applications".

Our decision is to:revision required

Wara Dyah Pita Rengga
Scopus ID = 56584693500
Orchid ID = 0000-0002-0889-2547
wdpitar@mail.unnes.ac.id

Rekayasa
http://journal.unnes.ac.id/index.php/rekayasa

Komen atau koreksi dari reviewer adalah sebagai berikut :

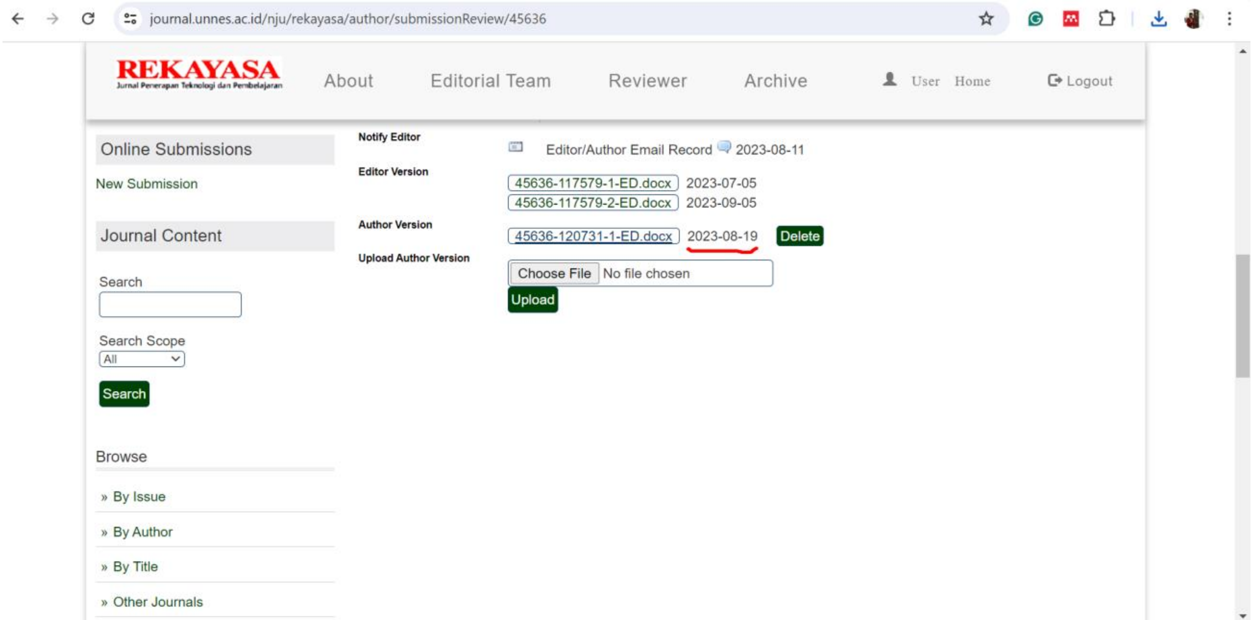
This research is in the form of making the material and its characterization of the readiness of the tool as a brake pad application (the word effect in front of the title should be replaced).

Previous title: The Effect of Rice Husk Addition on the Density and Impact Strength of Composites as a Brake Friction Material Candidate for Non-Asbestos Brake Pad Applications

1. Title: please consider changing the title to engineering methods as engineering research (applied)

2. It is better if you repeat citations (1) and only take the important ones or use other similar articles
3. One of the most important parts of the brake pads is the friction material, as shown in Figure 1. The sentence is clarified if this product is the result of research that can be displayed in the results and discussion. If it is only for information, it should be deleted..
4. Citations use APA, not [number].
5. the previous research gap has not been seen, the novelty has not been seen either. It is expected that the characteristics and uses of the material in composite form and its function as a brake and the material has been applied.
6. Comparisons can also be made on the basic material of rice husk in previous studies related to its characteristics as a material
7. the relationship between the flow of the research description from the introduction to the method is not yet a sequential story.
8. Result and discussion
9. Explanations for figures 4 and 5 should be separated if the discussion is different.
10. The conclusion is made into 1 paragraph
11. References in APA style and a minimum of 20 article citations. Please take everything from the article, nothing in the form of a policy or news.
12. The citation year has been good for the last 10 years, but the 2008 discussion article is still found

3. Mengirimkan response letter dan artikel yang telah diperbaiki pada tanggal 19 Agustus 2023.



Berkas yang diikirmkan pada tahap ini adalah:

A. Response letter untuk reviewer 1

D. Manuskrip yang diperbaiki dengan track change

E. Manuskrip yang diperbaiki tanpa track change (Clean versions)

A. Response letter untuk reviewer 1

Response to reviewer's comments

We thank the reviewer for the comments and suggestions. We have now addressed them as discussed below. All changes have been shown in a marked version of the manuscript (in 'red font'), which is attached with this submission. Also, all responses are indicated in blue font under each comment while the reviewer's comments remain in black font.

Reviewer 1

1. Title: please consider changing the title to engineering methods as engineering research (applied)

Thank you for the suggestions and corrections from the reviewer. The author has corrected the title of the manuscript according to the reviewer's suggestion.

2. It is better if you repeat citations (1) and only take the important ones or use other similar articles

Thank you for the suggestions and corrections from the reviewer. The authors have improved this section.

3. One of the most important parts of the brake pads is the friction material, as shown in Figure 1. The sentence is clarified if this product is the result of research that can be displayed in the results and discussion. If it is only for information, it should be deleted.

Thank you for the suggestions and corrections from the reviewer. The authors have improved this section.

4. Citations use APA, not [number].

Thank you for the suggestions and corrections from the reviewer. The authors have improved this section.

5. the previous research gap has not been seen, the novelty has not been seen either. It is expected that the characteristics and uses of the material in composite form and its function as a brake and the material has been applied.

Thank you for the reviewer's suggestions and corrections. The authors have improved this section. An explanation of the reviewer's question has been added at the end of the paragraph in the introduction section.

6. Comparisons can also be made on the basic material of rice husk in previous studies related to its characteristics as a material

Thank you for the reviewer's suggestions and corrections. The authors have improved this section. The authors have provided an explanation of this in the introduction.

7. the relationship between the flow of the research description from the introduction to the method is not yet a sequential story.

Thank you for the reviewer's suggestions and corrections. Already fixed.

8. Result and discussion. Explanations for figures 4 and 5 should be separated if the discussion is different.

Thank you for the reviewer's suggestions and corrections. Already fixed.

9. The conclusion is made into 1 paragraph

Thank you for the reviewer's suggestions and corrections. Already fixed.

10. References in APA style and a minimum of 20 article citations. Please take everything from the article, nothing in the form of a policy or news.

Thank you for the reviewer's suggestions and corrections. The authors have improved this section. The authors have updated the references used.

11. The citation year has been good for the last 10 years, but the 2008 discussion article is still found

Thank you for the reviewer's suggestions and corrections. Already fixed.

B. Manuskrip yang diperbaiki dengan track change

The Influence of Rice Husk Addition on the Density and Impact Strength of Non-Asbestos Brake Pad Composites Prepared by The Hand Lay-Up Method

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Abstract

In train operation, brakes are an important component because they involve the safety of passengers. Therefore, brake pads must be replaced periodically according to their lifespan. Currently, the most widely used train brake pads material is composite. Unfortunately, most train brake pads in Indonesia still use imported products because there is no industry capable of producing train brake pads of the desired quality. This study aims to manufacture and characterize composite materials for friction material for train brake pads that meet quality standards to substitute imported products. This needs to be done to reduce dependence on imported products while at the same time encouraging the strengthening of the structure of the domestic manufacturing industry. In addition, agricultural waste in the form of rice husks will be used to produce more environmentally friendly products. In this study, the composition of the types of composite materials, which include binder, reinforcement, abrasive, and filler materials, will be examined. Making composite materials in this study will use the hand lay-up method. Material characterization carried out includes impact testing and density. The characterization results show that the use of rice husk as a filler greatly influences the density of the resulting composite material. Specimen 5 made from epoxy, rice husk, iron filings, and Al2O3 (wt.%) at 50%, 20%, 15%, and 15%, respectively, was able to produce a higher density compared to the composite without rice husk (specimen 1) and epoxy material (specimen 6). The results of this density test support the results of the impact tests that have been carried out. The higher the rice husk content, the higher the density produced. This will result in an increase in the mechanical properties of the resulting composite material.

Keywords: composite, matrix, filler, reinforcement, abrasive.

Introduction

Currently, automotive engines have been able to produce enormous power to meet human needs for high-speed transportation facilities. A good braking system is certainly needed to support high engine performance. The consumption of friction material on brake pads ranks second after petroleum and gas fuels. Brake pads are one of the spare parts that function to slow down or stop vehicles, especially land vehicles. Friction material serves to transform kinetic energy into thermal energy (Irawan et al., 2022).

During high-speed vehicles, the brake pads get a load of up to 90% of the other components, so the brake pads greatly determine the safety of the driver and passengers. Brake pads are consumables that must be replaced periodically. Therefore, the need for friction material for brake pads is increasing along with the growth of the automotive industry in Indonesia (Irawan et al., 2023).

One of the most important parts of the brake pads is the friction material. The friction material is made of a material that has good mechanical properties and tribological performance. Friction material is a key component of brake pads that helps to slow down or stop a moving vehicle. It works by creating friction between the brake pad and the rotor, which converts the kinetic energy of the vehicle into heat energy. This process causes the vehicle to slow down or come to a complete stop. Composite materials for friction materials generally consist of binder, reinforcement, abrasive, and filler materials. The expected mechanical properties of friction materials include hardness, tensile strength, corrosion resistance, and thermal resistance. While the desired tribological performance includes low wear and a high coefficient of friction, both in dry contact and wet contact (Abutu, Lawal, Ndaliman, & Araga, 2018; Irawan et al., 2022, 2023).

Friction material can be used to make brake pads for motorcycles, cars, trucks, trains, and airplanes. Especially for trains, the need for friction material for train operations is very high. It is estimated that hundreds of thousands of brake friction materials are required annually. Initially, the friction material used in the braking system on trains was cast metal. For decades, Small and Medium Industries (IKM) in Indonesia have been able to meet most of these needs. However, with the development of material technology, composites are now the main choice of friction material for train braking systems. This is inseparable from the economic value produced, where metallic friction materials have a service life of 14–19 days, while composite materials have a service life of 90–240 days (Kemenperin, 2016).

PT Kereta Api Indonesia started substituting friction materials with composites around the beginning of 2010. The composite technology for friction materials for train brake pads has not been mastered by local Indonesian producers, and as a result, the volume of imports of friction materials for train brake pads is still the majority. In 2018–2019, the import value of friction material for railroads was US$ 86,640,667, or Rp. 1,238,961,538,100.00. This value is obtained from imported commodities with HS codes 68138100 and 86072100 (Badan Pusat Statistik (BPS), 2023). In general, the composite friction material on the brake pads uses asbestos as reinforcement with certain resins.

Asbestos was chosen because it has good mechanical strength and is not too expensive. However, brake pads made of asbestos can experience fading at temperatures above 200° C. In addition, based on research conducted by the WHO (World Health Organization) and IARC (International Agency for Research on Cancer), asbestos is carcinogenic, so it can cause lung cancer from the dust it produces. Therefore, the application of this material is prohibited in the automotive industry and other applications. So, it is necessary to develop new materials to replace asbestos as a friction material while still maintaining its mechanical properties (Abutu, Lawal, Ndaliman, Lafia-Araga, et al., 2018; Amirjan, 2019; Arman et al., 2018; Lawal et al., 2019; Singaravelu et al., 2019).

Biomass produced from agricultural activities such as bamboo, palm trees, bagasse, corn stalks, cashew shells, bananas, coir (coconut shells), pineapples, rice straw, plants (stems, leaves, seeds, fruit, stems, grass, sedge-alang), and rice husk are materials that are widely used as a commercially acceptable and environmentally friendly brake pad reinforcement material (Iman & Widjanarko, 2020; Lawal et al., 2019; Nawangsari et al., 2019). Agricultural waste contains a high concentration of natural fibers, so it can be used as a reinforcing material for polymer composites. Agricultural waste has a lot of potential in composites because of its high strength, environmental friendliness, affordability, easy availability, and availability in very large quantities (Nguyen et al., 2017; OGAH & Timothy, 2018).

This research needs to be carried out to produce friction material used in brake pads on trains that meets the standards so that they can substitute imported commodities in the future. On the other hand, the use of environmentally friendly materials is also needed to produce friction materials that are safe for the environment and human health. In previous studies, the research team has successfully utilized various agricultural wastes for composite applications (Cionita et al., 2022; Hadi, Hamdan, et al., 2021; Hadi, Tezara, et al., 2021; Rihayat et al., 2021; Tezara et al., 2021). In addition, the research team has also conducted research on the application of agricultural waste for the application of friction material to brake pads (Irawan et al., 2022). However, to our knowledge, the utilization of epoxy resin, rice husk, Al_2O_3, and Fe_2O_3 in the fabrication of non-asbestos brake pad composites has not been widely explored. Furthermore, in this research, rice husk will be combined with epoxy resin, Al_2O_3, and Fe_2O_3 to produce friction materials that will be used to produce brake pads for trains. The purpose of this study is to determine the effect of the addition of rice husk on the density and impact strength of the Non-Asbestos Brake Pad Composites produced.

Material and Methods

The materials used in this study were epoxy, hardener, rice husk, iron powder (Fe_2O_3), and alumina (Al_2O_3). Next, the rice husks were crushed into powder using a crusher machine. The sieving process is carried out with a mesh of 100 to produce rice husk powder. Rice husk powder is dried at 80°C for 24 hours before being mixed with other ingredients. The mixing of the materials was carried out using the composition of epoxy, hardener, rice husk, iron powder (Fe_2O_3), and alumina (Al_2O_3) with several variations as shown in **Table 1**.

Table 1. Composite specimen composition

Spesimen	Resin Epoxy (wt.%)	Sekam padi (wt.%)	Fe_2O_3 (wt.%)	Al_2O_3 (wt.%)
1	100	0	0	0
2	50	0	25	25
3	50	5	22.5	22.5
4	50	10	20	20
5	50	15	17.5	17.5
6	50	20	15	15

The ratio of epoxy and hardener used in this study was 3:1, and then a stirring process was carried out using a magnetic stirrer for 7 minutes. Rice husk, iron, and alumina powders were added according to a predetermined composition and stirred for 5 minutes. The mixture formed was placed in a vacuum oven for 5 minutes to remove air bubbles formed during the mixing process. The mixed material is put into a specimen mould that has been adjusted to an impact specimen according to ASTM D6110. The formed composite was then dried for 24 hours before testing.

The composite material formed was tested for density and impact. The density testing was performed to establish the density of the composite specimens. An electronic density meter (DME 220 series) from Vibra Canada Inc. (Mississauga, ON, USA) was used to conduct density testing following ASTM 792-08. The charpy impact test was carried out according to the ASTM D6110 standard using the GT-7045-MD IZOD CHARPY Digital Impact Tester manufactured by GOTECH Testing Machines Inc., Taiwan. In this test, the pendulum weight, pendulum speed, angle α, and span used were 25 J, 3.46 m/s, 150^o, and 101.6 mm, respectively. The test results obtained the absorbed energy value of the composite specimen of brake pads friction material. Furthermore, this value is used to find the value of the impact strength by manual calculation.

Results and Discussion

The use of rice husk has a significant effect on the density of the resulting composite material. The composite specimen for density testing is shown in **Figures 1**.

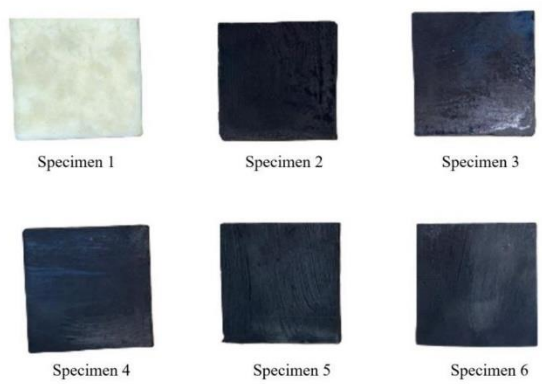

Figure 1. Density test specimens

Figure 2 shows that the composite density of the brake pads friction material in specimens 1, 2, 3, 4, 5, and 6 is 1.21 g/cm^3, 1.06 g/cm^3, 1.19 g/cm^3, 1.17 g/cm^3, 1.29 g/cm^3, and 1.33 g/cm^3. The brake pads friction material composite specimen with the lowest density was found in specimen 2, which was 1.06 g/cm^3. While the highest density in specimen 6 is 1.33 g/cm^3, specimen 2 is a specimen that does not use rice husk. Whereas in specimen 6, the rice husk used was the highest compared to the other specimens, which was wt.20%.

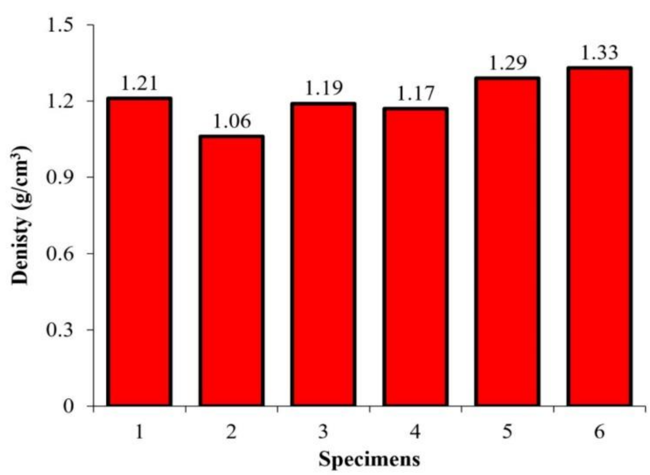

Figure 2. The effect of the composition used on the results of the density test

Rice husk has a high content of amorphous silica, about 95%. Thus, increasing the rice husk used in this study significantly increased the amorphous silica content in the specimens.

With a higher volume fraction of rice husk, the silica content contained in the composite specimen also increases. The silica content functions as an absorbent for water vapor, which can form bonds between the materials making up the composite specimens to blend more optimally. This is because the low water content can improve the bond density between the constituent materials in the composite specimen of the brake pads friction material. The high-water content in composite specimens can interfere with the matrix's main function as a binder material in the composite (Irawan et al., 2023).

Research conducted by Suhot *et al.,* (2021) states that composites with rice husk reinforcement can be applied in the manufacture of brake pads. This is because rice husk has a high silica content, which can make the composite structure have a good density so that it can form composite specimens of brake pads friction material with the ability to withstand wear and tear and last a long time (Suhot et al., 2021). Other research states that composites with high silica content can increase density. This is due to the increased adhesion between the filler and the matrix, which results in a more compact structure and increased density. Research conducted by Jiang et al. showed that a 20% silica concentration with a particle size of 5 μm produced a PTFE/SiO_2 composite with a higher density than other specimens. However, the density of the composite decreases if the silica content exceeds 20%, considering that agglomerates can reduce the adhesion between the filler and the matrix (Jiang & Yuan, 2018).

The results of this study resulted in a friction material specimen with a density that met the requirements for brake friction material applications. In general, commercial brake friction materials have a density of 1,010 to 2,060 g/cm^3 (Irawan et al., 2023). However, the results of this study are not suitable for the application of brake pads on trains. This happens because the brake pads on a train must have a density in the range of 1.7 to 2.4 g/cm^3.

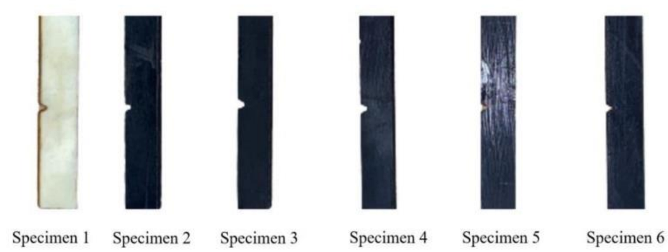

Figure 4. Charpy impact test specimens

The use of rice husk has a significant effect on the impact strength of the resulting composite material. The composite specimen for impact strength testing is shown in **Figures 4**.

Figure 5 shows that the impact strength of the brake pads friction material composite in specimens 1, 2, 3, 4, 5, and 6 was 0.0095 KJ/m^2, 0.0101 KJ/m^2, 0.0104 KJ/m^2, 0.0101 KJ/m^2, 0.0104 KJ/m^2, and 0.0107 KJ/m^2. The brake pads friction material composite specimen with the lowest impact strength was found in specimen 1, which was 0.0095 KJ/m^2. While the highest impact strength on specimen 6 is 0.0107 KJ/m^2, Specimen 1 is a specimen that uses 100 wt.% epoxy resin. Whereas in specimen 6, the rice husk used was the highest compared to the other specimens, namely 20 wt.%.

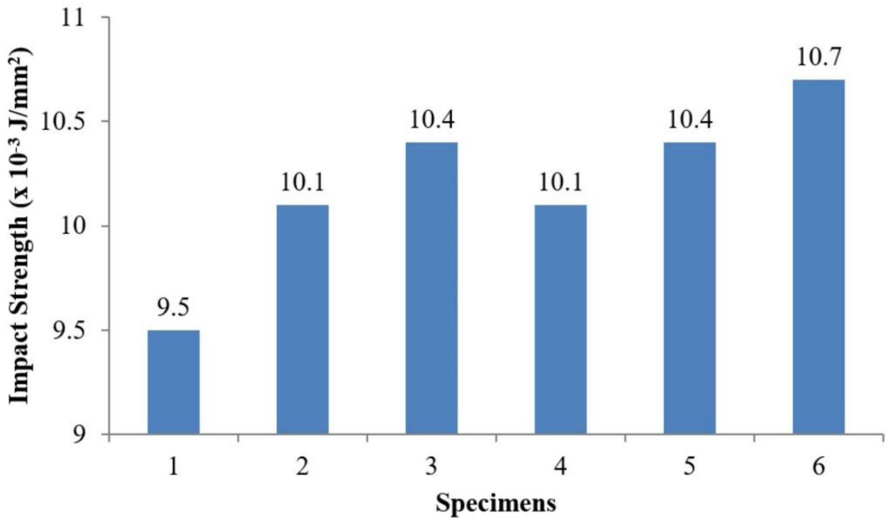

Figure 5. The effect of the composition used on the results of the impact test

The test results show that the presence of rice husk material and additional materials (Al_2O_3 and Fe_2O_3) can influence increasing the impact strength of the brake pads friction material. This was proven by the volume fraction variation in specimens 2 to 6, which showed a higher impact strength than specimen 1. In addition, the addition of rice husk volume fraction in each variation of the friction material composite specimen influenced increasing the impact strength. In general, impact strength is related to the bond between the composite materials. This makes one of the impact strength factors in the brake pads friction material composite specimen have the highest value in specimen 6 with the highest rice husk volume fraction, namely 20% rice husk.

The results of the Charpy impact test on specimen 6 produced in this study were higher than the results of research conducted by Iman et al (2020). In their research, they used acacia wood charcoal with an epoxy matrix as an alternative to non-asbestos brake pads, with the highest impact strength of 0.0080 J/mm^2 (Iman & Widjanarko, 2020). Compared to the research conducted by Suriadi et al (2019) and Wijaya et al (2016), the results of this study produced higher impact strength. The best impact test result on the hybrid composite brake lining obtained in Suriadi et al (2019) study was 0.000339547 J/mm². The hybrid composite brake lining consists of basalt, clamshell, alumina, and resin with a composition of 40%, 10%, 10%, and 40% respectively. This composite showed a stronger and more complete bond between the matrix and basalt than other hybrid composites, resulting in higher impact strength values (Suriadi & Atmika, 2019). Wijaya et al (2016) have conducted Charpy impact tests on hybrid composite brake linings made of phenolic resin matrix reinforced with basalt, alumina, and clamshell particles. The results showed that the HK2 variation hybrid composite showed the highest impact strength, at 0.000339547 J/mm2. This is due to the stronger and more perfect bond between the matrix and basalt particles compared to the other hybrid composite variations. Overall, the Charpy impact test proved to be effective in evaluating the impact resistance of hybrid composite brake pads (Suma Wijaya et al., 2016).

Conclusions

Friction material for railroad brake pads made from composites reinforced with rice husks has been successfully produced. The use of rice husk significantly affects the density of the resulting composite material. Specimen 6, made from epoxy, rice husk, iron powder, and Al_2O_3 of (wt.%) 50%, 20%, 15%, and 15%, produced higher density and impact strength than other specimens. The higher the content of rice husk used, the greater the density and impact strength produced in the specimen.

Acknowledgement

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C. Manuskrip yang diperbaiki tanpa track change (Clean versions)

The Influence of Rice Husk Addition on the Density and Impact Strength of Non-Asbestos Brake Pad Composites Prepared by The Hand Lay-Up Method

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Abstract

In train operation, brakes are an important component because they involve the safety of passengers. Therefore, brake pads must be replaced periodically according to their lifespan. Currently, the most widely used train brake pads material is composite. Unfortunately, most train brake pads in Indonesia still use imported products because there is no industry capable of producing train brake pads of the desired quality. This study aims to manufacture and characterize composite materials for friction material for train brake pads that meet quality standards to substitute imported products. This needs to be done to reduce dependence on imported products while at the same time encouraging the strengthening of the structure of the domestic manufacturing industry. In addition, agricultural waste in the form of rice husks will be used to produce more environmentally friendly products. In this study, the composition of the types of composite materials, which include binder, reinforcement, abrasive, and filler materials, will be examined. Making composite materials in this study will use the hand lay-up method. Material characterization carried out includes impact testing and density. The characterization results show that the use of rice husk as a filler greatly influences the density of the resulting composite material. Specimen 5 made from epoxy, rice husk, iron filings, and Al2O3 (wt.%) at 50%, 20%, 15%, and 15%, respectively, was able to produce a higher density compared to the composite without rice husk (specimen 1) and epoxy material (specimen 6). The results of this density test support the results of the impact tests that have been carried out. The higher the rice husk content, the higher the density produced. This will result in an increase in the mechanical properties of the resulting composite material.

Keywords: composite, matrix, filler, reinforcement, abrasive.

Introduction

Currently, automotive engines have been able to produce enormous power to meet human needs for high-speed transportation facilities. A good braking system is certainly needed to support high engine performance. The consumption of friction material on brake pads ranks second after petroleum and gas fuels. Brake pads are one of the spare parts that function to slow down or stop vehicles, especially land vehicles. Friction material serves to transform kinetic energy into thermal energy (Irawan et al., 2022).

During high-speed vehicles, the brake pads get a load of up to 90% of the other components, so the brake pads greatly determine the safety of the driver and passengers. Brake pads are consumables that must be replaced periodically. Therefore, the need for friction material for brake pads is increasing along with the growth of the automotive industry in Indonesia (Irawan et al., 2023).

One of the most important parts of the brake pads is the friction material. The friction material is made of a material that has good mechanical properties and tribological performance. Friction material is a key component of brake pads that helps to slow down or stop a moving vehicle. It works by creating friction between the brake pad and the rotor, which converts the kinetic energy of the vehicle into heat energy. This process causes the vehicle to slow down or come to a complete stop. Composite materials for friction materials generally consist of binder, reinforcement, abrasive, and filler materials. The expected mechanical properties of friction materials include hardness, tensile strength, corrosion resistance, and thermal resistance. While the desired tribological performance includes low wear and a high coefficient of friction, both in dry contact and wet contact (Abutu, Lawal, Ndaliman, & Araga, 2018; Irawan et al., 2022, 2023).

Friction material can be used to make brake pads for motorcycles, cars, trucks, trains, and airplanes. Especially for trains, the need for friction material for train operations is very high. It is estimated that hundreds of thousands of brake friction materials are required annually. Initially, the friction material used in the braking system on trains was cast metal. For decades, Small and Medium Industries (IKM) in Indonesia have been able to meet most of these needs. However, with the development of material technology, composites are now the main choice of friction material for train braking systems. This is inseparable from the economic value produced, where metallic friction materials have a service life of 14–19 days, while composite materials have a service life of 90–240 days (Kemenperin, 2016).

PT Kereta Api Indonesia started substituting friction materials with composites around the beginning of 2010. The composite technology for friction materials for train brake pads has not been mastered by local Indonesian producers, and as a result, the volume of imports of friction materials for train brake pads is still the majority. In 2018–2019, the import value of friction material for railroads was US$ 86,640,667, or Rp. 1,238,961,538,100.00. This value is obtained from imported commodities with HS codes 68138100 and 86072100 (Badan Pusat Statistik (BPS), 2023). In general, the composite friction material on the brake pads uses asbestos as reinforcement with certain resins.

Asbestos was chosen because it has good mechanical strength and is not too expensive. However, brake pads made of asbestos can experience fading at temperatures above 200° C. In addition, based on research conducted by the WHO (World Health Organization) and IARC (International Agency for Research on Cancer), asbestos is carcinogenic, so it can cause lung cancer from the dust it produces. Therefore, the application of this material is prohibited in the automotive industry and other applications. So, it is necessary to develop new materials to replace asbestos as a friction material while still maintaining its mechanical properties (Abutu, Lawal, Ndaliman, Lafia-Araga, et al., 2018; Amirjan, 2019; Arman et al., 2018; Lawal et al., 2019; Singaravelu et al., 2019).

Biomass produced from agricultural activities such as bamboo, palm trees, bagasse, corn stalks, cashew shells, bananas, coir (coconut shells), pineapples, rice straw, plants (stems, leaves, seeds, fruit, stems, grass, sedge-alang), and rice husk are materials that are widely used as a commercially acceptable and environmentally friendly brake pad reinforcement material (Iman & Widjanarko, 2020; Lawal et al., 2019; Nawangsari et al., 2019). Agricultural waste contains a high concentration of natural fibers, so it can be used as a reinforcing material for polymer composites. Agricultural waste has a lot of potential in composites because of its high strength, environmental friendliness, affordability, easy availability, and availability in very large quantities (Nguyen et al., 2017; OGAH & Timothy, 2018).

This research needs to be carried out to produce friction material used in brake pads on trains that meets the standards so that they can substitute imported commodities in the future. On the other hand, the use of environmentally friendly materials is also needed to produce friction materials that are safe for the environment and human health. In previous studies, the research team has successfully utilized various agricultural wastes for composite applications (Cionita et al., 2022; Hadi, Hamdan, et al., 2021; Hadi, Tezara, et al., 2021; Rihayat et al., 2021; Tezara et al., 2021). In addition, the research team has also conducted research on the application of agricultural waste for the application of friction material to brake pads (Irawan et al., 2022). However, to our knowledge, the utilization of epoxy resin, rice husk, Al_2O_3, and Fe_2O_3 in the fabrication of non-asbestos brake pad composites has not been widely explored. Furthermore, in this research, rice husk will be combined with epoxy resin, Al_2O_3, and Fe_2O_3 to produce friction materials that will be used to produce brake pads for trains. The purpose of this study is to determine the effect of the addition of rice husk on the density and impact strength of the Non-Asbestos Brake Pad Composites produced.

Material and Methods

The materials used in this study were epoxy, hardener, rice husk, iron powder (Fe_2O_3), and alumina (Al_2O_3). Next, the rice husks were crushed into powder using a crusher machine. The sieving process is carried out with a mesh of 100 to produce rice husk powder. Rice husk powder is dried at 80°C for 24 hours before being mixed with other ingredients. The mixing of the materials was carried out using the composition of epoxy, hardener, rice husk, iron powder (Fe_2O_3), and alumina (Al_2O_3) with several variations as shown in **Table 1**.

Table 1. Composite specimen composition

Spesimen	Resin Epoxy (wt.%)	Sekam padi (wt.%)	Fe_2O_3 (wt.%)	Al_2O_3 (wt.%)
1	100	0	0	0
2	50	0	25	25
3	50	5	22.5	22.5
4	50	10	20	20
5	50	15	17.5	17.5
6	50	20	15	15

The ratio of epoxy and hardener used in this study was 3:1, and then a stirring process was carried out using a magnetic stirrer for 7 minutes. Rice husk, iron, and alumina powders were added according to a predetermined composition and stirred for 5 minutes. The mixture formed was placed in a vacuum oven for 5 minutes to remove air bubbles formed during the mixing process. The mixed material is put into a specimen mould that has been adjusted to an impact specimen according to ASTM D6110. The formed composite was then dried for 24 hours before testing.

The composite material formed was tested for density and impact. The density testing was performed to establish the density of the composite specimens. An electronic density meter (DME 220 series) from Vibra Canada Inc. (Mississauga, ON, USA) was used to conduct density testing following ASTM 792-08. The charpy impact test was carried out according to the ASTM D6110 standard using the GT-7045-MD IZOD CHARPY Digital Impact Tester manufactured by GOTECH Testing Machines Inc., Taiwan. In this test, the pendulum weight, pendulum speed, angle α, and span used were 25 J, 3.46 m/s, 150°, and 101.6 mm, respectively. The test results obtained the absorbed energy value of the composite specimen of brake pads friction material. Furthermore, this value is used to find the value of the impact strength by manual calculation.

Results and Discussion

The use of rice husk has a significant effect on the density of the resulting composite material. The composite specimen for density testing is shown in **Figures 1**.

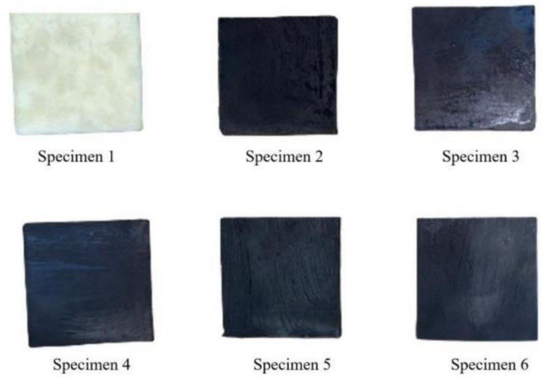

Figure 1. Density test specimens

Figure 2 shows that the composite density of the brake pads friction material in specimens 1, 2, 3, 4, 5, and 6 is 1.21 g/cm^3, 1.06 g/cm^3, 1.19 g/cm^3, 1.17 g/cm^3, 1.29 g/cm^3, and 1.33 g/cm^3. The brake pads friction material composite specimen with the lowest density was found in specimen 2, which was 1.06 g/cm^3. While the highest density in specimen 6 is 1.33 g/cm^3, specimen 2 is a specimen that does not use rice husk. Whereas in specimen 6, the rice husk used was the highest compared to the other specimens, which was wt.20%.

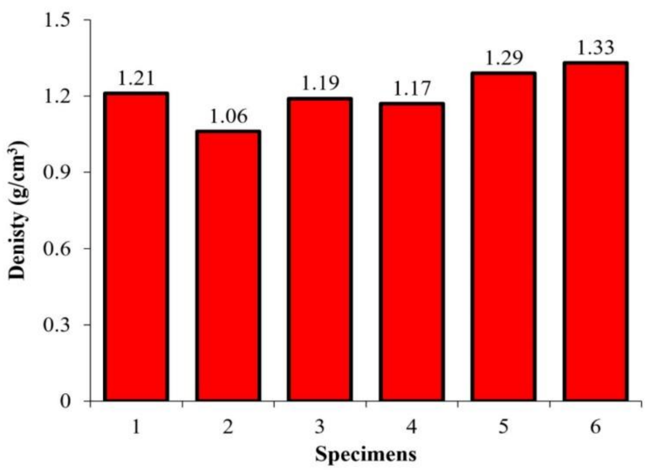

Figure 2. The effect of the composition used on the results of the density test

Rice husk has a high content of amorphous silica, about 95%. Thus, increasing the rice husk used in this study significantly increased the amorphous silica content in the specimens.

With a higher volume fraction of rice husk, the silica content contained in the composite specimen also increases. The silica content functions as an absorbent for water vapor, which can form bonds between the materials making up the composite specimens to blend more optimally. This is because the low water content can improve the bond density between the constituent materials in the composite specimen of the brake pads friction material. The high-water content in composite specimens can interfere with the matrix's main function as a binder material in the composite (Irawan et al., 2023).

Research conducted by Suhot *et al.,* (2021) states that composites with rice husk reinforcement can be applied in the manufacture of brake pads. This is because rice husk has a high silica content, which can make the composite structure have a good density so that it can form composite specimens of brake pads friction material with the ability to withstand wear and tear and last a long time (Suhot et al., 2021). Other research states that composites with high silica content can increase density. This is due to the increased adhesion between the filler and the matrix, which results in a more compact structure and increased density. Research conducted by Jiang et al. showed that a 20% silica concentration with a particle size of 5 μm produced a PTFE/SiO_2 composite with a higher density than other specimens. However, the density of the composite decreases if the silica content exceeds 20%, considering that agglomerates can reduce the adhesion between the filler and the matrix (Jiang & Yuan, 2018).

The results of this study resulted in a friction material specimen with a density that met the requirements for brake friction material applications. In general, commercial brake friction materials have a density of 1,010 to 2,060 g/cm^3 (Irawan et al., 2023). However, the results of this study are not suitable for the application of brake pads on trains. This happens because the brake pads on a train must have a density in the range of 1.7 to 2.4 g/cm^3.

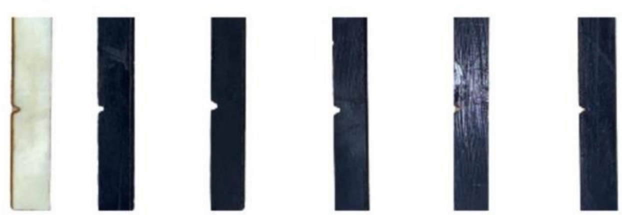

Figure 4. Charpy impact test specimens

The use of rice husk has a significant effect on the impact strength of the resulting composite material. The composite specimen for impact strength testing is shown in **Figures 4**.

Figure 5 shows that the impact strength of the brake pads friction material composite in specimens 1, 2, 3, 4, 5, and 6 was 0.0095 KJ/m^2, 0.0101 KJ/m^2, 0.0104 KJ/m^2, 0.0101 KJ/m^2, 0.0104 KJ/m^2, and 0.0107 KJ/m^2. The brake pads friction material composite specimen with the lowest impact strength was found in specimen 1, which was 0.0095 KJ/m^2. While the highest impact strength on specimen 6 is 0.0107 KJ/m^2, Specimen 1 is a specimen that uses 100 wt.% epoxy resin. Whereas in specimen 6, the rice husk used was the highest compared to the other specimens, namely 20 wt.%.

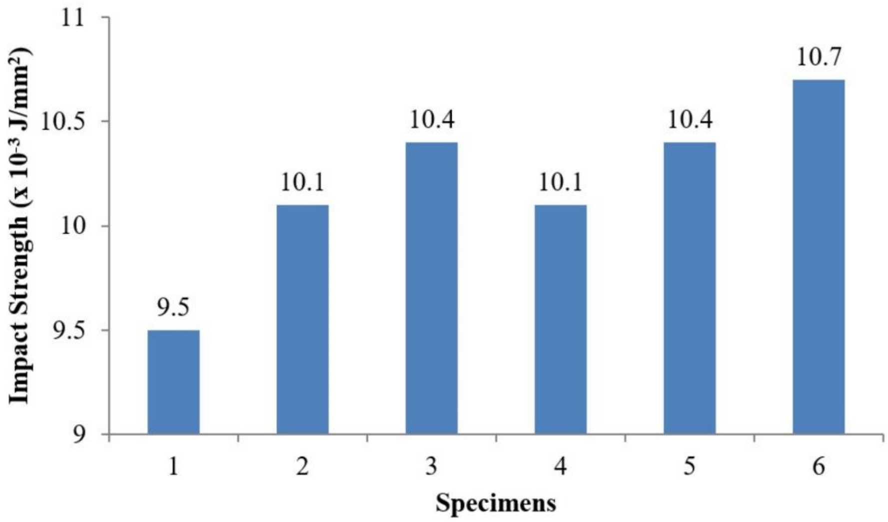

Figure 5. The effect of the composition used on the results of the impact test

The test results show that the presence of rice husk material and additional materials (Al_2O_3 and Fe_2O_3) can influence increasing the impact strength of the brake pads friction material. This was proven by the volume fraction variation in specimens 2 to 6, which showed a higher impact strength than specimen 1. In addition, the addition of rice husk volume fraction in each variation of the friction material composite specimen influenced increasing the impact strength. In general, impact strength is related to the bond between the composite materials. This makes one of the impact strength factors in the brake pads friction material composite specimen have the highest value in specimen 6 with the highest rice husk volume fraction, namely 20% rice husk.

The results of the Charpy impact test on specimen 6 produced in this study were higher than the results of research conducted by Iman et al (2020). In their research, they used acacia wood charcoal with an epoxy matrix as an alternative to non-asbestos brake pads, with the highest impact strength of 0.0080 J/mm^2 (Iman & Widjanarko, 2020). Compared to the research conducted by Suriadi et al (2019) and Wijaya et al (2016), the results of this study produced higher impact strength. The best impact test result on the hybrid composite brake lining obtained in Suriadi et al (2019) study was 0.000339547 J/mm². The hybrid composite brake lining consists of basalt, clamshell, alumina, and resin with a composition of 40%, 10%, 10%, and 40% respectively. This composite showed a stronger and more complete bond between the matrix and basalt than other hybrid composites, resulting in higher impact strength values (Suriadi & Atmika, 2019). Wijaya et al (2016) have conducted Charpy impact tests on hybrid composite brake linings made of phenolic resin matrix reinforced with basalt, alumina, and clamshell particles. The results showed that the HK2 variation hybrid composite showed the highest impact strength, at 0.000339547 J/mm2. This is due to the stronger and more perfect bond between the matrix and basalt particles compared to the other hybrid composite variations. Overall, the Charpy impact test proved to be effective in evaluating the impact resistance of hybrid composite brake pads (Suma Wijaya et al., 2016).

Conclusions

Friction material for railroad brake pads made from composites reinforced with rice husks has been successfully produced. The use of rice husk significantly affects the density of the resulting composite material. Specimen 6, made from epoxy, rice husk, iron powder, and Al_2O_3 of (wt.%) 50%, 20%, 15%, and 15%, produced higher density and impact strength than other specimens. The higher the content of rice husk used, the greater the density and impact strength produced in the specimen.

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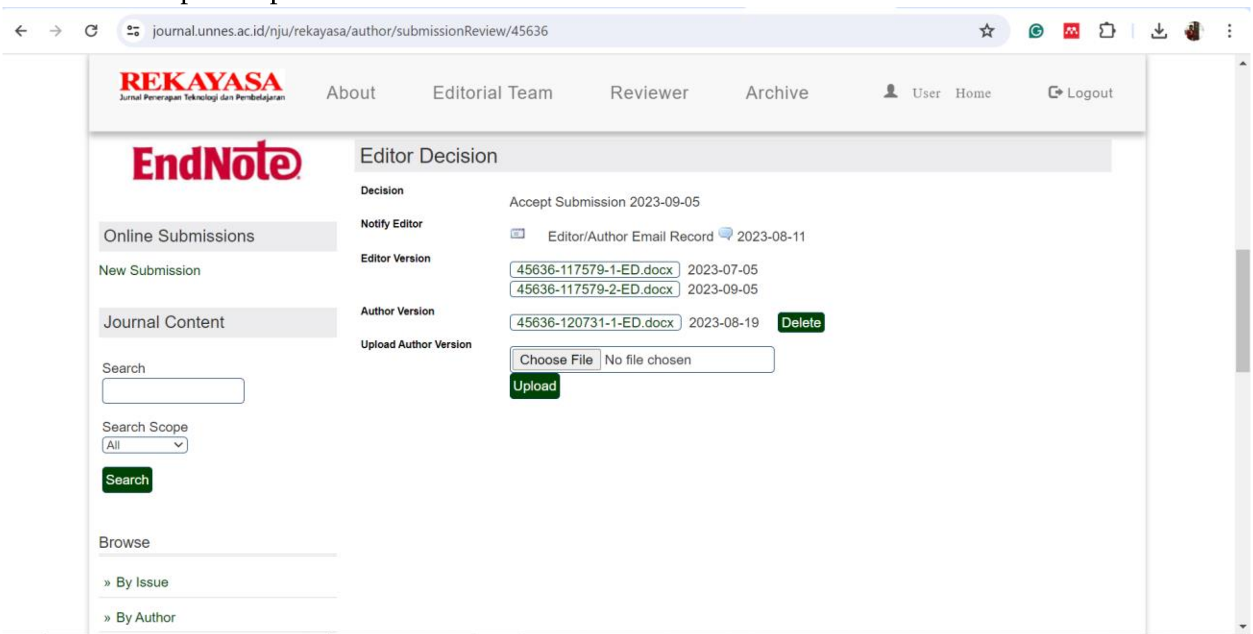

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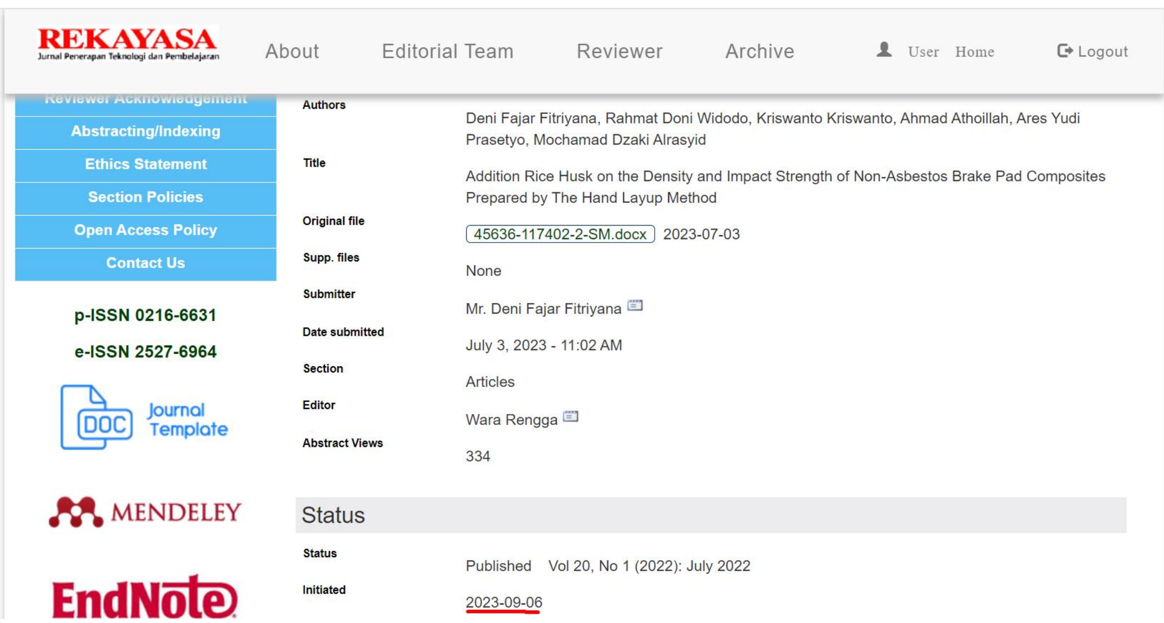

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Abstract

In train operations, brakes are an important component that concerns passenger safety and must be replaced periodically according to their useful life. Currently, the most widely used train brake pad material is composite, unfortunately, the majority of train brake pads in Indonesia are imported products. This study aims to manufacture and characterize composite materials for friction material for train brake pads that meet quality standards to substitute imported products. It needs to reduce dependence on imported products while at the same time encouraging the strengthening of the structure of the domestic manufacturing industry. In addition, agricultural waste in rice husks will be used to produce more environmentally friendly products. The composition of the types of composite materials, which include binder, reinforcement, abrasive, and filler materials, will be examined. Making composite materials in this study will use the hand layup method. Material characterization carried out includes impact testing and density. The characterization results show that using rice husk as a filler greatly influences the density of the resulting composite material. Specimen made from epoxy, rice husk, iron filings, and Al_2O_3 (wt.%) at 50%, 20%, 15%, and 15%, respectively, was able to produce a higher density compared to the composite without rice husk and epoxy material. The density test support the results of the impact tests that have been carried out. The higher the rice husk content, the higher the density produced. Adding rice husk can increase the mechanical properties of the resulting composite material.

Keywords: brakes, composite, hand layup, mechanical properties, agricultural waste

INTRODUCTION

Automotive engines have produced enormous power to meet human needs for high-speed transportation facilities. A good braking system is certainly needed to support high engine performance. The consumption of friction material on brake pads ranks second after petroleum and gas fuels. Brake pads are a spare part that slows down or stops vehicles, especially land vehicles. Friction material transforms kinetic energy into thermal energy (Irawan et al., 2022).

During high-speed vehicles, the brake pads get a load of up to 90% of the other components, so the brake pads greatly determine the safety of the driver and passengers. Brake pads are consumables that must be replaced periodically. Therefore, the need for friction material for brake pads is increasing along with the growth of the automotive industry in Indonesia (Irawanirawa.

The friction material is one of the most essential parts of the brake pads. The friction material is made of a material that has good mechanical properties and tribological performance. The friction material is a critical component of brake pads that helps to slow down or stop a moving vehicle. It creates friction between the brake pad and the rotor, which converts the vehicle's kinetic energy into heat energy. This process causes the vehicle to slow down or come to a complete stop. Composite materials for friction materials generally consist of binder, reinforcement, abrasive, and filler materials. The expected mechanical properties of friction materials include hardness, tensile strength, corrosion resistance, and thermal resistance. At the same time, the desired tribological performance includes low wear and a high coefficient of friction, both in dry contact and wet contact (Abutu et al., 2018A; Irawan et al., 2022).

Friction material can make brake pads for motorcycles, cars, trucks, trains, and aeroplanes. Especially for trains, the need for friction material for train operations is very high. It is estimated that hundreds of thousands of brake friction materials are required annually. Initially, the friction material used in the braking system on trains was cast metal. For decades, Small and Medium Industries in Indonesia have been able to meet most of these needs. However, with the development of material technology, composites are now the primary choice of friction material for train braking systems. It is inseparable from the economic value produced, where metallic friction materials have a service life of 14–19 days, while composite materials have a service life of 90–240 days.

PT. Kereta Api Indonesia started substituting friction materials with composites around the beginning of 2010. Local Indonesian producers have not mastered the composite technology for friction materials for train brake pads. As a result, the volume of imports of friction materials for train brake pads is still the majority. In 2018–2019, the import value of friction material for railroads was US$ 86,640,667, or IDR 1,238,961,538,100.00. This value is obtained from imported commodities with HS codes 68138100 and 86072100, according to the data released by Badan Pusat Statistik, 2023. Generally, the composite friction material on the brake pads uses asbestos as reinforcement with certain resins.

Asbestos was chosen because it has good mechanical strength and is not too expensive. However, brake pads made of asbestos can experience fading at temperatures above 200°C. In addition, based on research conducted by the World Health Organization and International Agency for Research on Cancer, asbestos is carcinogenic, so it can cause lung cancer from the dust it produces. Therefore, the application of this material is prohibited in the automotive industry and other applications. So, it is necessary to develop new materials to replace asbestos as a friction material while still maintaining its mechanical properties (Abutu et al., 2018B; Amirjan, 2019; Arman et al., 2018; Lawal et al., 2019; Singaravelu et al., 2019).

Biomass produced from agricultural activities such as bamboo, palm trees, bagasse, corn stalks, cashew shells, bananas, coconut shells), pineapples, rice straw, grass, and rice husk are materials that are widely used as commercially acceptable and environmentally friendly brake pad reinforcement material (Iman & Widjanarko, 2020; Lawal et al., 2019; Nawangsari et al., 2019). Agricultural waste contains a high concentration of natural fibres for polymer composites to be used as reinforcing material. Agricultural waste has much potential in composites because of its high strength, environmental friendliness, affordability, easy availability, and availability in substantial quantities (Nguyen et al., 2017; Ogah & Timothy, 2018).

This research needs to be carried out to produce friction material used in brake pads on trains that meets the standards so that they can substitute imported commodities in the future. On the other hand, using environmentally friendly materials is also needed to produce safe friction materials for the environment and human health. In previous studies, the research team has successfully utilized various agricultural wastes for composite applications (Cionita et al., 2022; Hadi et al., 2021; Hadi, Tezara, et al., 2021; Rihayat et al., 2021; Tezara et al., 2021). In addition, the research team has also researched the application of agricultural waste for applying friction material to brake pads (Irawan et al., 2022). However, to our knowledge, using epoxy resin, rice husk, Al_2O_3, and Fe_2O_3 in fabricating non-asbestos brake pad composites has yet to be widely explored. Furthermore, in this research, rice husk will be combined with epoxy resin, Al_2O_3, and Fe_2O_3 to produce friction materials that will be used to produce brake pads for trains. This study aims to determine the effect of adding rice husk on the density and impact strength of the Non-Asbestos Brake Pad Composites produced.

METHOD

The materials used in this study were epoxy, hardener, rice husk, iron powder Fe_2O_3, and alumina Al_2O_3. Next, the rice husks were crushed into powder using a crusher machine. The sieving process is carried out with a mesh 100 to produce rice husk powder. Rice husk powder is dried at 80°C for 24 hours before mixed with other ingredients. The materials were mixed using the composition of epoxy, hardener, rice husk, iron powder (Fe_2O_3), and alumina (Al_2O_3) with several variations, as shown in **Table .1**

Table 1. Composite specimen composition

Specimen	Epoxy Resin (wt.%)	Rice husk (wt.%)	Fe_2O_3 (wt.%)	Al_2O_3 (wt.%)
1	100	0	0	0
2	50	0	25	25
3	50	5	22.5	22.5
4	50	10	20	20
5	50	15	17.5	17.5
6	50	20	15	15

The ratio of epoxy and hardener used in this study was 3:1, and then a stirring process was carried out using a magnetic stirrer for 7 minutes. Rice husk, iron, and alumina powders were added according to a predetermined composition and stirred for 5 minutes. The mixture formed was placed in a vacuum oven for 5 minutes to remove air bubbles formed during the mixing process. The mixed material is put into a specimen mould that has been adjusted to an impact specimen according to ASTM D6110. The formed composite was then dried for 24 hours before testing.

The composite material formed was tested for density and impact. The density testing was performed to establish the density of the composite specimens. An electronic density meter (DME 220 series) from Vibra Canada Inc. (Mississauga, ON, USA) was used to conduct density testing following ASTM 792-08. The Charpy impact test was carried out according to the ASTM D6110 standard using the GT-7045-MD IZOD CHARPY Digital Impact Tester manufactured by GOTECH Testing Machines Inc., Taiwan. In this test, the pendulum weight, speed, angle α, and span used were 25 J, 3.46 m/s, 150°, and 101.6 mm, respectively. The test results obtained the absorbed energy value of the brake pad friction material composite specimen. Furthermore, this value is used to find the value of the impact strength by manual calculation.

RESULT AND DISCUSSION

The use of rice husk significantly affects the density of the resulting composite material. The composite specimen for density testing is shown in Figure 1. The composite density of the brake pads friction material in specimens 1, 2, 3, 4, 5, and 6 is 1.21 g/cm^3, 1.06 g/cm^3, 1.19 g/cm^3, 1.17 g/cm^3, 1.29 g/cm^3, and 1.33 g/cm^3 are shown in Figure 2. The brake pads friction material composite specimen with the lowest density was found in specimen 2, which was 1.06 g/cm^3. While the highest density in specimen 6 is 1.33 g/cm^3, specimen 2 is a specimen that does not use rice husk. Whereas in specimen 6, the rice husk used was the highest compared to the other specimens, which was 20%wt.

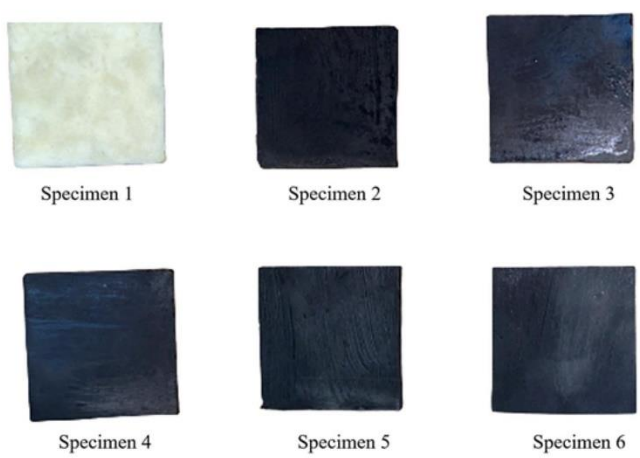

Figure 1. Density test specimens

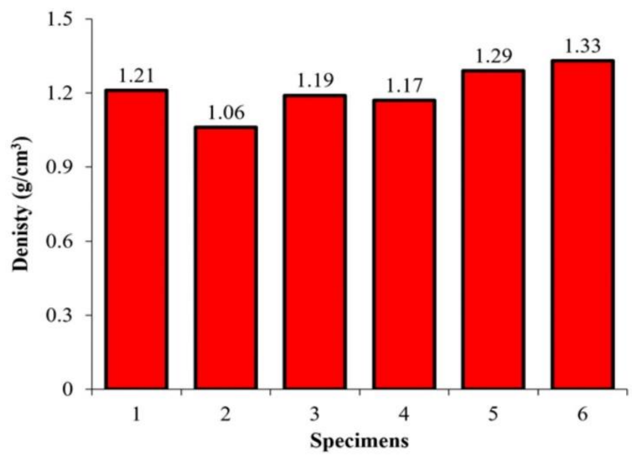

Figure 2. The effect of the composition used on the results of the density test

Rice husk has a high content of amorphous silica, about 95%. Thus, increasing the rice husk used in this study significantly increased the amorphous silica content in the specimens. With a higher volume fraction of rice husk, the silica content contained in the composite specimen also increases. Silica functions as an adsorbent for water vapour by forming bonds between the constituent materials of the composite specimens to combine to form a more optimal unit. Because the low water content can improve the bond density between the constituent materials in the composite specimen of the brake pad friction material, the high water content in composite specimens can interfere with the matrix's primary function as a binder material in the composite (Irawan et al., 2023).

The composites with rice husk reinforcement can be applied to manufacture brake pads. Because rice husk has a high silica content, the composite structure has a good density to form composite specimens of brake pad friction material that can withstand wear and tear and last a long time (Suhot et al., 2021). Other research states that composites with high silica content can increase density due to the increased adhesion between the filler and the matrix, which results in a more compact structure and increased density. A 20% silica concentration with a particle size of 5 μm produced a PTFE/SiO2 composite with a higher density than other specimens. However, the density of the composite decreases if the silica content exceeds 20%, considering that agglomerates can reduce the adhesion between the filler and the matrix (Jiang & Yuan, 2018).

This study resulted in a friction material specimen with a density that met the requirements for brake friction material applications. Commercial brake friction materials generally have a density of 1,010 to 2,060 g/cm^3 (Irawan et al., 2023). However, the results of this study are not suitable for the application of brake pads on trains. It happens because the brake pads on a train must have a density of 1.7 to 2.4 g/cm^3.

The use of rice husk significantly affects the impact strength of the resulting composite material. The composite specimen for impact strength testing is shown in **Figure 4. Figure 5** shows that the impact strength of the brake pads friction material composite in specimens 1, 2, 3, 4, 5, and 6 was 0.0095 kJ/m², 0.0101 kJ/m², 0.0104 J/m², 0.0101 kJ/m², 0.0104 kJ/m², and 0.0107 J/m². The brake pads friction material composite specimen with the lowest impact strength was found in specimen 1, which was 0.0095kJ/m². While the highest impact strength on specimen 6 is 0.0107 kJ/m², Specimen 1 is a specimen that uses 100 wt.% epoxy resin. Whereas in specimen 6, the rice husk used was the highest compared to the other specimens, namely 20 wt.%.

The test results show that the presence of rice husk material and additional materials (Al_2O_3 and Fe_2O_3) can influence increasing the impact strength of the brake pad friction material. It was proven by the volume fraction variation in specimens 2 to 6, which showed a higher impact strength than specimen 1. In addition, the addition of rice husk volume fraction in each variation of the friction material composite specimen influenced increasing the impact strength. In general, impact strength is related to the bond between the composite materials. It makes one of the impact strength factors in the brake pads friction material composite specimen have the highest value in specimen 6 with the highest rice husk volume fraction, namely 20% rice husk.

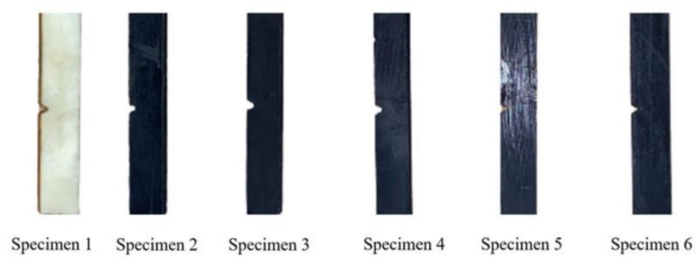

Figure 4. Charpy impact test specimens

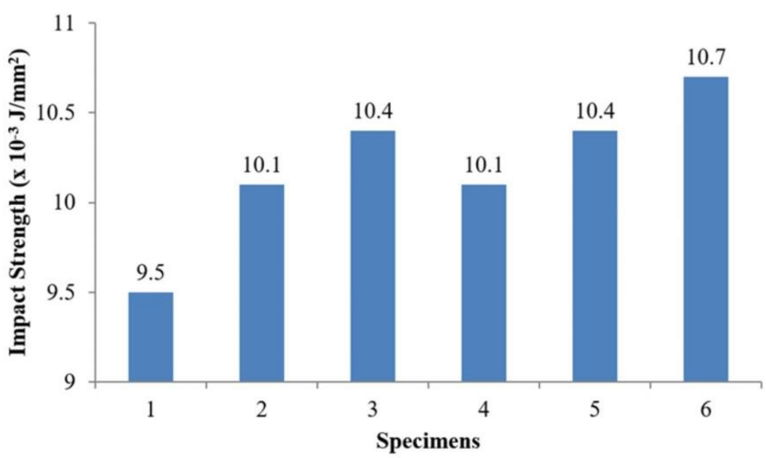

Figure 5. The effect of the composition used on the results of the impact test

The results of the Charpy impact test on specimen six produced in this study were high that acacia wood charcoal with an epoxy matrix as an alternative to non-asbestos brake pads, with the highest impact strength of 0.0080 J/mm^2 (Iman & Widjanarko, 2020). Compared to study that have the best impact test result on the hybrid composite brake lining was 0.000339547 J/mm^2. The hybrid composite brake lining consists of basalt, clamshell, alumina, and resin with a composition of 40%, 10%, 10%, and 40%, respectively. This composite showed a stronger and more complete bond between the matrix and basalt than other hybrid composites, resulting in higher impact strength values (Suriadi & Atmika, 2019).

Wijaya. S et al. (2016) have conducted Charpy impact tests on hybrid composite brake pads made of phenolic resin matrix reinforced with basalt, alumina, and clamshell particles. The results showed that the variation hybrid composite showed the highest impact strength, at 0.000339547 J/mm^2, due to the stronger and more perfect bond between the matrix and basalt particles compared to the other hybrid composite variations. Overall, the Charpy impact test proved effective in evaluating the impact resistance of hybrid composite brake pads (Suma Wijaya et al., 2016).

CONCLUSION

Friction material for railroad brake pads made from composites reinforced with rice husks has been successfully produced. The use of rice husk significantly affects the density of the resulting composite material. Specimen 6, made from epoxy, rice husk, iron powder, and Al_2O_3 of (wt.%) 50%, 20%, 15%, and 15%, produced higher density and impact strength than other specimens. The higher the content of rice husk used, the greater the density and impact strength produced in the specimen.

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