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Research Paper

A Study on Characteristics of Brake Pad Composite Materials by Varying the Composition of Epoxy, Rice Husk, Al_2O_3 and Fe_2O_3

Muhammad Khafidh[1]✉, Finny Pratama Putera[1], Rahmadi Yotenka[2], Deni Fajar Fitriyana[3], Rahmat Doni Widodo[3], Rifky Ismail[4], Agustinus Purna Irawan[5], Tezara Cionita[6], Januar Parlaungan Siregar[7], Nur Hidayah Ismail[8]

[1]Department of Mechanical Engineering, Universitas Islam Indonesia, Sleman 55584, Indonesia
[2]Department of Statistics, Universitas Islam Indonesia, Sleman 55584, Indonesia
[3]Department of Mechanical Engineering, Universitas Negeri Semarang, Semarang 50229, Indonesia
[4]Department of Mechanical Engineering, Universitas Diponegoro, Semarang 50275, Indonesia
[5]Faculty of Engineering, Universitas Tarumanagara, Jakarta Barat 11440, Indonesia
[6]Faculty of Engineering and Quantity Surveying, INTI International University, 71800, Negeri Sembilan, Malaysia
[7]Faculty of Mechanical & Automotive Engineering Technology, Universiti Malaysia Pahang, 26600, Malaysia
[8]Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya 76100, Melaka, Malaysia

✉ khafidh@uii.ac.id

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Abstract

The use of composite materials in brake pads is becoming increasingly popular due to their high-performance characteristics, including good thermal stability, high wear resistance, and low noise generation. However, the development of new composite materials that offer even better performance is still an ongoing research area. In this study, the composite was made by hand layup method using epoxy resin as matrix material, with rice husk, Al_2O_3, and Fe_2O_3 as reinforcing materials. The composition of the composites was varied by changing the percentage of the reinforcement materials. The composites were then subjected to several characterization tests, including density, hardness, flexural strength, thermal analysis, Scanning Electron Microscopy (SEM), TGA/DSC, and wear testing. The test results showed that additional reinforcement materials to the epoxy resin matrix improved the mechanical properties of the composites. Overall, the study demonstrates that a hand layup method is a viable approach for preparing brake pad composite materials and that the addition of rice husk, Al_2O_3, and Fe_2O_3 can improve the mechanical properties of the composites. The best properties produced in this research were found in one of the specimens which used epoxy, rice husk, Al_2O_3, and Fe_2O_3 with a composition of 50 wt.%, 20 wt.%, 15 wt.%, and 15 wt.%. However, the addition of rice husk also provides wear resistance and thermal stability. This study contributes to the Sustainable Development Goals (SDGs) by advancing innovation, promoting sustainability, and reducing emissions in automotive industry applications.

Keywords: Composites; Brake pad; Epoxy; Rice husk; Al_2O_3, and Fe_2O_3

1. Introduction

Along with the times, technology is having rapid growth and development, especially in the automotive field. Therefore, the need for friction material for brake pads is increasing along with the growth in the number of motorcycles in Indonesia. Brake pads are consumables that must be replaced periodically. The consumption of friction material in brake pads ranks second only to fuel. In general, brake pads are one of the parts that function to slow or stop the speed of the vehicle. Friction material in brake pads transforms kinetic energy into thermal energy. When the vehicle is at high speed, brake pads get a load of up to 90% of other components, so brake pads determine the safety of drivers and passengers [1].

Brake pads generally use asbestos as reinforcement because it is cheap and has good mechanical properties and tribological properties [2]. However, International Agency for Research on Cancer (IARC) and World Health Organization (WHO) state that asbestos can cause lung cancer from the dust produced [1], [3], [4]. In addition to that, asbestos brake pads can experience fading at temperatures above 200 °C [5]. Therefore, it is necessary to develop non-asbestos brake pads as a substitute for asbestos materials while maintaining their tribological properties and mechanical properties. Non-asbestos brake linings can work normally at temperatures above 300 °C [6]. Composite materials that use organic waste materials from agricultural products can replace asbestos materials in brake pads [7]–[10].

Composite brake pads are generally composed of binder/matrix, reinforcement, abrasives, and fillers. The expected mechanical properties of brake pads include hardness, tensile strength, corrosion resistance, and heat resistance. While the desired tribological performance includes small wear and high coefficient of friction, both during dry contact and wet contact [1]. Current research developments around the world have focused on ways to utilize industrial and agricultural wastes to replace asbestos-based brake pads and inorganic resins. Organic materials produced from agriculture such as bamboo, palm trees, bagasse, corn stalks, bananas, coconut shells, pineapples, rice straw, and rice husks are among the materials often used as reinforcing materials in brake pads that are commercially acceptable and environmentally friendly [8], [11]. Agricultural waste has great potential as a composite material because of its high strength, environmentally friendly, affordable price, easy to find, and available in very large quantities [8], [12], [13].

Various studies have been conducted in order to obtain an environmentally friendly composite brake pads material. The results of research conducted by Suhot et al. show that the potential for using rice husk as a composite material for brake pads is very large, and can be used as an alternative material for sustainable development. Rice husk has a high silica and low lignin content, which can produce materials with a wear resistance similar to ceramic materials. The high silica content on the rice husk can also produce brake pad materials with good hardness, making it scratch-resistant and durable [14].

The utilization of rice husk and rice straw in the manufacture of non-asbestos brake pads has been investigated by Kapoor et al. Their results showed that high silica content and low lignin in rice husk and rice straw can produce brake pads with mechanical properties and wear resistance like ceramic materials [15]. The use of banana fiber, coconut fiber, and rice husk powder in the manufacture of brake pads with epoxy resin as the matrix has been studied by Paramasivam et al. The manufacturing process uses additional aluminum oxide and graphite materials to improve mechanical properties using the hand lay-up method. The results of their research concluded that the use of natural materials such as banana fiber, coconut fiber, and rice husk with the addition of aluminum oxide and graphite in epoxy resin can increase the strength of the resulting brake pads material [16]. Zhang [17] claim that the use of Al_2O_3 fibers in copper-based brake pads can improve braking performance at high speeds and heavy loads. The addition of Al_2O_3 fibers contributes to an increase in the coefficient of friction at relatively low speeds and braking pressure and helps to stabilize the coefficient of friction at high braking speeds and heavy loads. The addition of Al_2O_3 fibers can also greatly reduce the loss of brake pad wear. In addition, samples with Al_2O_3 fibers exhibit lower maximum temperatures during braking.

The addition of Fe_2O_3 (iron oxide) to brake pad composite materials can help to improve their frictional and wear properties. Fe_2O_3 is a naturally occurring material that is commonly used as filler or reinforcing agent in composites. It has been found to improve the mechanical properties of brake pad composites, such as increasing the hardness and reducing wear rate, leading to longer service life and reduced maintenance requirements. Additionally, the use of Fe_2O_3 as a filler material can also help to reduce costs and make the brake pads more affordable. Research conducted by Talib et al showed that brake pads with iron oxide powder of 15% produced the highest coefficient of friction (COF).

In addition, thickness losses in this specimen have the lowest value. In addition, the sample with iron oxide powder (15%) in the T2 specimen is the best formulation which produces optimal tribological and mechanical properties [18]. Composites with higher iron oxide content will have higher strength, so the friction traces left on the surface are shallower. However, an excessive amount of iron oxide (>15%) can cause the composite to peel, especially when working at high speeds [18], [19]. Although rice husk, Al_2O_3, Fe_2O_3, and epoxy composites have been explored for various applications, there is still a research gap in investigating their potential as brake pad composites.

Previous studies have shown that the addition of various reinforcement materials can improve the mechanical and tribological properties of brake pad composites. However, the effect of adding rice husk, Al_2O_3, Fe_2O_3 to epoxy on the physical, mechanical, thermal, and tribological properties of the composite for brake pad applications has not been extensively studied. Moreover, the optimal ratios of rice husk, Al_2O_3, Fe_2O_3, and epoxy for obtaining the desired performance of the brake pad composite are yet to be determined. Furthermore, this research is required to investigate the influence of adding rice husk, Al_2O_3, Fe_2O_3 to epoxy on the properties of the brake pad composite, including wear resistance, thermal stability, hardness, density, morphology, and flexural strength.

2. Methods

2.1. Materials

The materials used in the research are epoxy, hardener, rice husk, aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3). Bisphenol, an epichlorohydrin epoxy resin and polyaminoamide hardener were obtained from PT Justus Kimiaraya, Indonesia. In general, epoxy has a density, tensile strength, and flexural strength of 1.18 g/cm^3, 63.7 MPa, and 81.3 MPa [20]. The rice husk used in this study was obtained from a rice mill close to the campus. The composition of rice husk consists of moisture (10%-15%), lignin (25%-30%), silica (15%-20%), and cellulose (50%) [21]. In addition, rice husk has a bulk density of 331.59 - 380.54 kg/m^3 [21], [22]. In this study, Al_2O_3 and Fe_2O_3 were obtained from PT Merck Tbk, Indonesia. Aluminum oxide has a density, melting point, and boiling point of 4 g/cm^3, 2040 °C, and 2980 °C [23]. While the density, melting point, and boiling point of iron oxide are 5.25 g/cm^3 at 25 °C, 1565 °C, and 3414 °C [24].

2.2. Specimen Fabrication

In this research, the manufacture of brake pads specimens was carried out using the hand lay-up method. The rice husk was crushed with a crusher machine and sieved using a 100 mesh sieve to obtain rice husk powder. Rice husk powder was dried to remove moisture content using an oven at 80 °C for 24 hours. Next, the specimens were made by mixing the materials according to the predetermined concentration (**Table 1**) using a hand mixer in a plastic cup in stages. Mixing of epoxy resin and hardener with a ratio of 1:3 was done for 7 minutes. Then rice husk powder, aluminum oxide, and iron oxide were added with an additional mixing time of 15 minutes. After all materials have been mixed homogeneously, then poured into the composite specimen mold and leveled using rollers and brushes. The formed composite was dried at room temperature for 48 hours. After that, the composite specimens were cut and characterized.

2.3. Testing and Characterization

In this study, the tests carried out were density, flexural, hardness, Thermal Gravimetric Analysis (TGA), Scanning Electron Microscopy (SEM), DSC

Table 1. Code and composition of brake pads specimens made from composites

Specimen Code	Epoxy Resin (wt%)	Rice Husk (wt%)	Iron Oxide (wt%)	Aluminum Oxide (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

(Differential Scanning Calorimetry), and wear using the Ogoshi method. Density testing was carried out according to ASTM D792 standards with the accuracy of the digital scales used of 0.01. This test was conducted to obtain the value of dry mass and mass of specimens in water. Flexural testing was conducted according to ASTM D790 standard with Universal Testing Machine. This test was conducted with a support radius, loading nose radius, and support span of 5 mm, 10 mm, and 56.0 mm. The results of this flexural test will obtain the max force and displacement values that will be used to calculate flexural strength and flexural modulus in composite specimens. Vickers hardness testing in this study follows the test method conducted by Sharma, et al. [23].

The hardness testing was carried out using a Microhardness Tester Fm-800 machine with a test load and dwell time of 25 gf, and 10 seconds.

TGA testing was conducted according to ASTM D6370 standard using STA7200-Hitachi machine. The specimen mass used in this test was 9.41 g with a test temperature of 30 °C – 700 °C. The test process was carried out with a heating rate of 10 °C/minute with a nitrogen gas flow of 20 ml/minute. The test results will obtain the temperature and weight loss values of the composite specimens. DSC testing is carried out according to ASTM D3418 standards using a PerkinElmer DSC-8500. The specimen mass used in this test is 9 g with a test temperature of 30 °C–350 °C. The test process was carried out with a heating rate of 10 °C/minute with a nitrogen gas flow of 20 ml/minute. The results of this test will get the temperature and heat flow values of the composite specimens.

SEM testing in this study was conducted to determine the morphology of composite specimens produced using Hitachi TM3030Plus. Wear testing using Oghosi High Speed Universal Wear Testing Machine (Type OAT-U). The disc width (B), disc radius (r) and disc track length during rotation (L) used in this study were 3 mm, 13.12 mm and 66.6 m. Tests were conducted with a test load (F) of 2.12 kg, and a wear distance of 15 meters rotating at a speed of 1430 rpm.

3. Results and Discussion

Figure 1 shows the density of brake pad composites specimens with various compositions of ingredient materials. The results of this study indicate that the addition of rice husk, Al_2O_3 and Fe_2O_3 greatly affects the density of the resulting composite. The lowest density is found in specimen 2 which is 1.06 g/cm^3. While the highest density value is obtained in specimen 6 which is 1.33 g/cm^3. Specimen 6 was made with a composition of epoxy, rice husk, Al_2O_3 and Fe_2O_3 with volume fractions of 50%, 20%, 15%, and 15%. The rice husk volume fraction of 20% resulted in an increase in the silica content of the composite specimens. The higher silica content results in an increase in the density of the composite due to lower water absorption [25].

Research conducted by Suhot et al. concluded that the high silica content in rice husk could produce composites with good density, so as to produce composite specimens of friction materials on brake pads with high wear resistance and longer lifetime [14].

The other research mentioned that rice husk contains a high amount of silica, which can improve the adhesion between the filler and matrix, leading to a more compact structure with a higher density [26]. Rice husk has lower water absorption than other biomass or natural fillers such as kenaf fiber, bagasse ash, wheat husk, bamboo fiber, wood fiber, and textile waste. This is because rice husk has a higher hydrophobicity than other materials [14]. The lower the water absorption, the higher the resulting density of the composite [27].

The use of Al_2O_3 and Fe_2O_3 with a volume fraction of 15% each also affects the high density value produced in specimen 6. Iron oxide and aluminum oxide powder will fill the pores in the composite specimen thereby increasing the sample density as shown in **Figure 1**. The use of iron

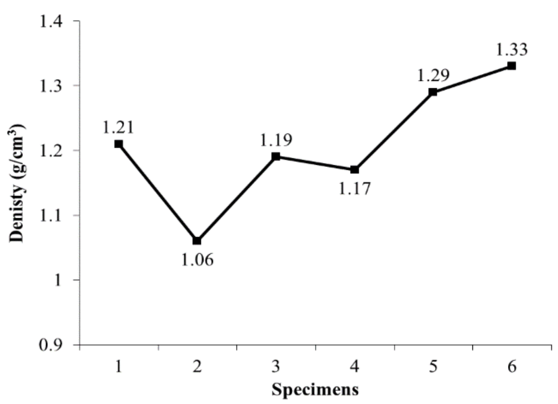

Figure 1. Density in composite specimens with various compositions

oxide and aluminum oxide in volume fractions greater than 15% resulted in a decrease in the density of the composites formed (specimen 2, 3, 4, and 5). This occurs because the use of a high volume fraction of iron oxide and aluminum oxide causes the mixture of composite materials to become increasingly inhomogeneous and agglomerations which results in an increase in porosity and a decrease in density in the composite specimen [18], [28].

With densities of 4 and 5.25 g/cm^3, respectively, Al_2O_3 and Fe_2O_3 are classified as high-density materials. A higher density of reinforcement makes achieving a uniform mixture with the matrix more difficult, as it becomes increasingly difficult to evenly disperse and distribute the reinforcing material throughout the matrix.

As a result, agglomerates and stress concentrations occur in the matrix. The presence of agglomeration in the composite can increase the number of pores, cracks, and delamination, greatly reducing interfacial bonding and density [29], [30].

This is supported by SEM images shown in **Figure 2**. SEM (Scanning Electron Microscope) testing was carried out using specimens that had been flexural tested with a magnification of X1500. Specimen 2 found more agglomeration and porosity, while specimen 6 found less agglomeration and porosity. **Figure 3** shows the results of the analysis on SEM images using the ImageJ software. Image analysis on brake pad specimens was carried out with reference to previous studies [31]. ImageJ analysis results show that the number of cracks, porosity, and agglomeration in specimen 2 is 15.8%. Whereas in specimen 6, the number of cracks, porosity, and agglomeration is 2.7%.

Specimen 2 uses a composition of epoxy, rice husk, Al_2O_3 and Fe_2O_3 with volume fractions of 50%, 0%, 25%, and 25%. Specimen 2 uses Al_2O_3 and Fe_2O_3 with the highest volume fraction compared to other specimens. The more Al_2O_3 and Fe_2O_3 used, it is difficult to obtain a homogeneous mixture during the mixing process. Al_2O_3 and Fe_2O_3 have a higher density compared to the other components (epoxy and rice husk) in the mixture. Consequently, they can settle to the bottom of the mixing vessel, causing uneven distribution and inhomogeneity. High uneven distribution and inhomogeneity can result in increased porosity and decreased density in a specimen.

This is because when the components of a mixture are not evenly dispersed, there are voids or gaps between the particles, which can lead to an increase in the overall porosity of the material. In addition, uneven distribution can result in areas of the material having different densities, which can also contribute to overall density reduction. This is what causes the density in Specimen 2 to have the smallest value compared to the other specimens [29], [30].

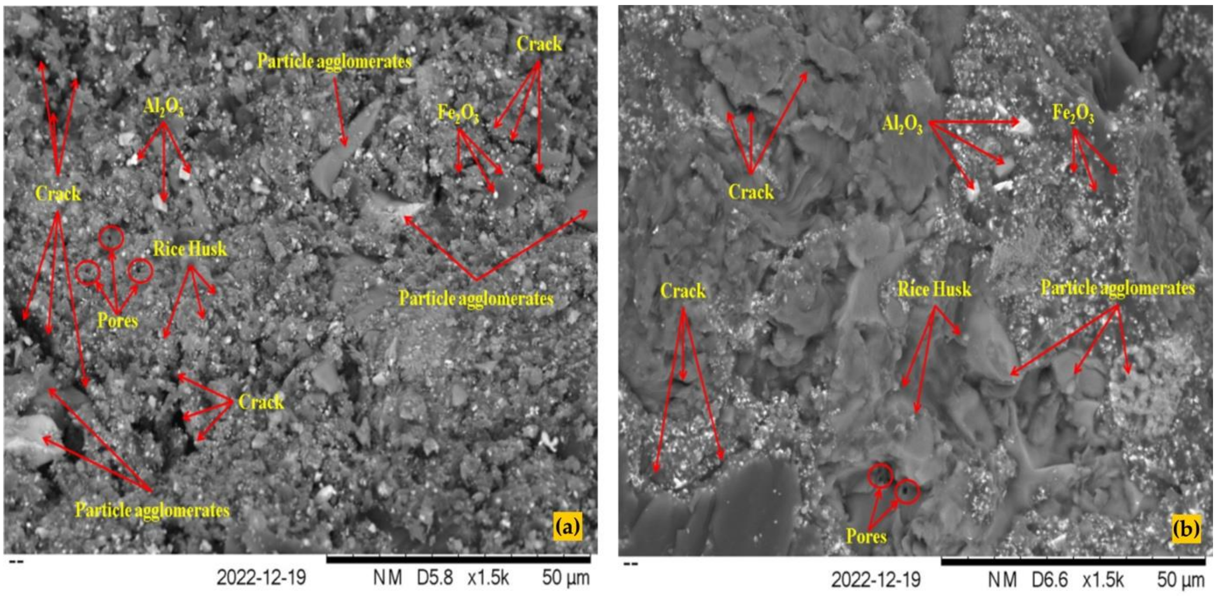

Figure 2. SEM images on the (a) specimen 2 and (b) specimen 6

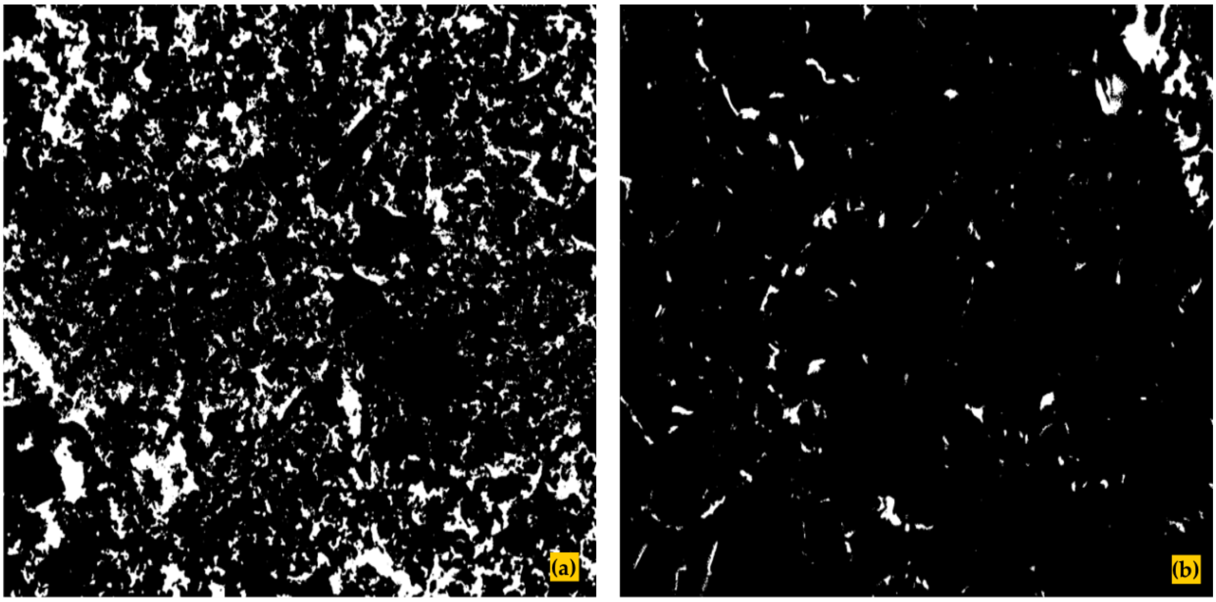

Figure 3. SEM image analysis using the ImageJ software on (a) specimen 2 and (b) specimen 6

The findings in this study are aligning with research conducted by Talib et al. According to their findings, the brake pad composites' density increased as the iron oxide volume percentage increased between 7.5% and 15%. Using iron oxide with a volume fraction of more than 15% reduces the density significantly [18]. According to the findings of Amadji et al. the mechanical characteristics of Wood Plastic Composite reduced with increased wood particle size. The existence of residual solvents that do not facilitate interfacial adhesion between constituents results in a decrease in density and an increase in porosity. The mechanical properties of Wood Plastic Composite improve as density increases [32].

This research produced composites with higher densities (especially in specimen 6) than the results of previous studies which produced densities of 1.10 g/cm³ [8] and 1.073 g/cm³ [33]. Crăciun et al. succeeded in making a friction material with a higher density than the results of this study.

In their research, composite friction materials were made using Aluminum, Hexametiltetramine, Graphite, Zirconiumoxide, Siliconcarbide, Titaniumoxide, Phenolic resin, Coconut fibre with various compositions. The density of the specimens produced in their study was 2.29 - 2.59 g/cm³ [34]. In general, the density of specimen 6 (1.33 g/cm³) produced in this study is in accordance with the recommended values of commercial brake pads, which have a density between 1.010 and 2.060 g/cm³ [33].

The effect of volume fraction of epoxy, rice husk, Al_2O_3 and Fe_2O_3 on flexural properties of composite specimens is shown in **Figure 4**. The lowest flexural strength value is found in specimen 2 with a flexural strength value of 21.99 MPa. In general, the density of a material is a measure of its mass per unit volume, and flexural strength is a measure of a material's ability to resist bending and breaking under stress [35]. In some cases, a higher density may indicate a stronger material. Higher densities have higher atomic densities and are often more resistant to deformation [36], [37].

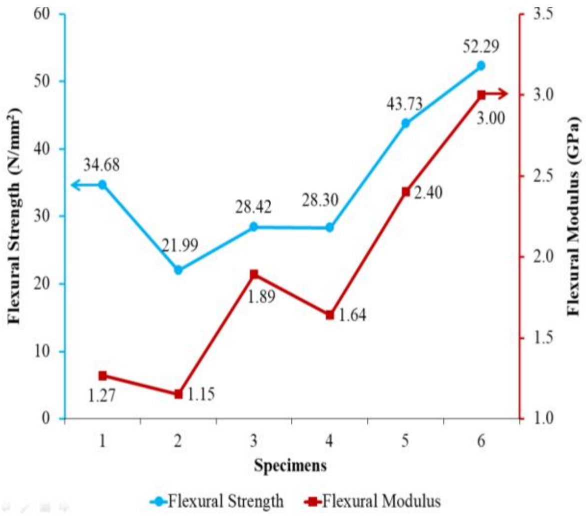

Figure 4. Flexural strength and flexural modulus of composite specimens

This study showed that increasing the composite density of sample 6 increased the flexural strength due to better load transfer between the rice husk, alumina, iron oxide, and matrix. Dense brake pads generally have higher flexural strength due dense packing of rice husks, aluminum oxide, iron oxide, and epoxy. The findings in this study are similar to the research conducted by Shivakumar et al. Their research concluded that the higher density of fly ash composites is directly proportional to the increase in flexural strength [36].

Kumar et al. conducted research to make non-asbestos brake pads using PAN fiber and bamboo natural fiber as reinforcement. The results of their research showed an increase in the density value of the BF-1, BF-2, BF-3, and BF-4 specimens, which used fiber by 3%, 6%, 9%, and 12%. The higher the density produced, the value of the resulting flexural strength is also high. The density (g/cm^3) of the BF-1, BF-2, BF-3, and BF-4 specimens were 2.60, 2.50, 2.40, and 2.30. Meanwhile, the flexural strength (MPa) on the specimens BF-1, BF-2, BF-3, and BF-4 were 65.76, 60.87, 57.97, and 53.67 [38]. The results of research conducted by Fitriyana et al. concluded that increasing the hydroxyapatite content resulted in increased density in the composite specimens. Furthermore, the increase in density resulted in increased flexural strength in the composite specimens. This happens because the particles which are well-dispersed lengthen the crack propagation path, improve the plastic deformation, and absorb more energy. They improve the surface fracture energy and composite strength [39].

Flexural strength is a measure of the maximum stress that a material can withstand when it is subjected to bending, while flexural modulus is a measure of a material's resistance to bending deformation [40]. In general, materials with higher flexural modulus tend to have higher flexural strengths, as the material is better able to resist deformation and stress [40]. The results of this study indicate that flexural strength and flexural modulus have the same trend. The findings in this study are in accordance with research conducted by Hossain et al. Their results show that flexural strength in carbon fiber/epoxy composites material has the same trend as the flexural modulus [41]. The same results were also obtained in research conducted by Islam et al [42] and Fitriyana et al [43].

Specimen 6 with volume fraction variations in epoxy, rice husk, aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3) of 50%, 20%, 15%, and 15% has produced a higher flexural strength than the other specimens, which is 52.29 MPa. The flexural strength results in this study are higher than in previous studies that produced brake pads specimens with flexural strength of 0.238 MPa [8], ± 30 MPa [44], and ± 40 MPa [43].

The effect of using epoxy, rice husk, Al_2O_3, and Fe_2O_3 with various volume fractions on the hardness of the composite material is shown in **Figure 5**.

Composite friction material on brake pads with the lowest Vickers hardness value is found in specimen 2 which is 39.2 HV. While the highest Vickers hardness value was found in specimen 6 which amounted to 83.4 HV.

The hardness of the composite specimens produced in this study is related to the density value of each composite specimen variation, so the trend shown by the hardness value is the same as the trend shown by the density value. The higher the density value, the higher the hardness of the resulting composite specimens [45]–[48]. Hardness is the resistance of a material to deformation, such as scratching or indentation [49]. As the density of a composite material increases, the particles within the material become more tightly packed. This enhanced packing can minimize the amount of space between particles (porosity), improve particle adhesion, improve load transfer, and make the material more resistant to deformation. The result is an increase in the composite material's hardness [45]–[48].

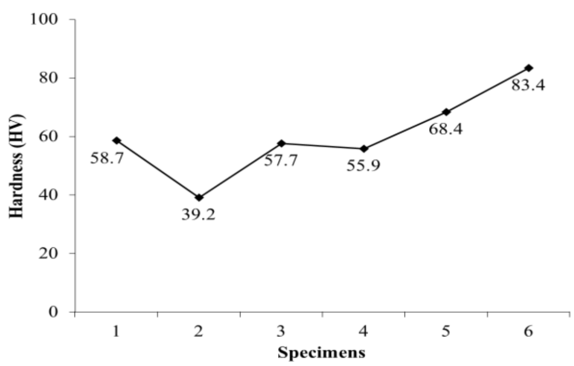

Figure 5. Hardness of composite specimens with various compositions

The results of this study have similarities with previous research. Kumar et al.'s research demonstrates that as the density of BF-1, BF-2, BF-3, and BF-4 specimens decreased, the resulting hardness decreased as well [38]. Crăciun et al. studied the effect of different percentages of coconut fiber reinforcement (0, 5, 10, and 15%) in an aluminum matrix. The findings of their study revealed that as the amount of fiber increased (5% to 15%), the density decreased due to an increase in porosity. This leads to a decrease in the brake pad specimen's hardness [34].

According to research by Sugozu et al. brake pad samples with a high density also have a high degree of hardness. Their analysis revealed that the CB-20 specimen showed the maximum density, at 2.203 g/cm^3. This specimen also has the highest hardness, 33.3 HB (approximately 40 HV) [50]. Kasim et al. investigated the relationship between hardness and density in polypropylene composites reinforced with alkaline-treated pineapple leaf fibres. Their findings show that the density of the composite increases proportionally to the fibre content, as the fibres tightly pack together. Furthermore, the study found that increasing the loading of pineapple leaf fibres improves the composite's ability to withstand indentations, increasing its hardness. This phenomenon can be attributed to the fibrous material's inherent rigidity and strength, which exceeds that of the polypropylene matrix. The composite gains overall rigidity and strength as the fibre content increases, resulting in increased density and hardness. Furthermore, the close clustering of fibres within the composite contributes to the observed density increase [51].

The results of data analysis from hardness testing show that the composite specimen of brake pads friction material in specimen 6 with a volume fraction variation of 50% resin, 20% rice husk, 15% aluminum oxide, and 15% iron oxide produces the highest hardness value of 83.4 HV. The hardness produced in this study is higher when compared to the hardness produced in previous research, which amounted to 5.821 HV [52] and 26.55 HV [53]. In addition, the hardness produced in this study is higher than the hardness of asbestos brake pads which has a hardness of 24.75 HV [53].

In this study, wear testing was only carried out on specimen 6 and specimen 2. This occurred because specimen 6 had the highest density, flexural strength, flexural modulus, and hardness compared to the other samples. Specimen 2 was selected because it had the lowest physical and mechanical properties compared to the other specimens. **Figure 6** depicts the results of the wear test conducted for this investigation. Specific wear rates on specimen 2 and specimen 6 were 7.6 x 10^{-7} mm^2/Kg and 10.8 x 10^{-7} mm^2/Kg, respectively. The specific wear rate is a measure used to calculate how much material is worn or removed from the surface of a material in a certain period of time and under certain conditions, such as frictional force or pressure [54]. The smaller the specific wear rate, meaning that less material is worn or removed from the surface of the material in the same amount of time, indicates that the material is more wear-resistant. Therefore, the smaller the specific wear rate, the higher the wear resistance of the material [55]–[57].

In general, resistance to wear increases as hardness increases [31], [58], [59]. Research by Liao et al. shows that increasing the hardness of the material results in a decrease in the wear rate. Materials that have hard properties will be more difficult to abrade, so that the test specimens have good wear resistance. This is because the specific wear value obtained in Ogoshi wear testing is inversely proportional to its wear resistance properties. The lower the specific wear value, the better the wear resistance properties of a material [60]. Research conducted by Fitriyana et al. showed the same results. Testing using the pin on disc method shows that increasing the hardness of the coating layer results in a decrease in the wear rate [31], [59].

However, different results were found in this study. Specimen 2 produces lower specific wear

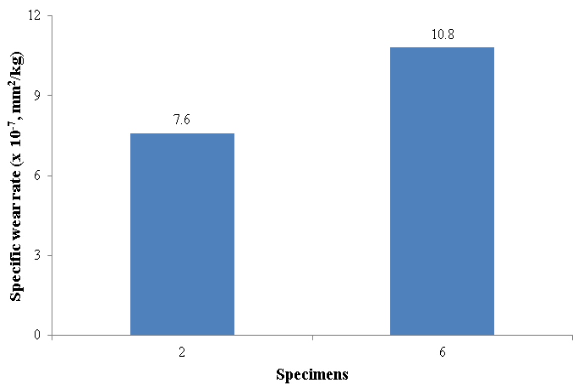

Figure 6. Comparison of specific wear rates on specimen 2 and specimen 6

rates than the specific wear rates produced in specimen 6. Even though specimen 2 has a much lower density and hardness than specimen 6. This is possible because specimen 2 contains more aluminum oxide and iron oxide. Specimen 2 was added with 25% aluminum oxide and 25% iron oxide. A decrease in specific wear rates and an improvement in wear resistance can be achieved by utilizing abrasive materials like aluminum oxide or iron oxide [61]. Compared to specimen 2, specimen 6 with compositions of 50% epoxy, 20% rice husk, 15% aluminum oxide, and 15% iron oxide, exhibited lower specific wear rates. According to Mohapatra, the incorporation of rice husks significantly decreased the thermal conductivity of the composite [62].

Low-thermal-conductivity brake pads may dissipate heat less efficiently, increasing the risk of thermal damage and glazing. This reduces the adhesion of the material used to create the brake pads, resulting in increased wear. In their investigation, Mahale et al. also discovered the same result. Their research revealed that during wear experiments, the surface temperature of Cu pads was always lower than that of SS pads because the thermal conductivity of SS pads was lower than that of Cu pads. Consequently, Cu particulates remain firmly adhered to the matrix, resulting in less wear [63]. The findings in this study are supported by findings from other studies that show an increase in surface hardness is not always accompanied by an increase in the wear resistance of the brake pad material [56], [63]–[65].

In this study, the specific wear rates produced on specimens 2 and 6 were 7.6 x 10^{-7} mm²/Kg and 10.8 x 10^{-7} mm²/Kg, respectively. The specific wear rate produced in this study is greater than the previous study, which amounted to 6.4 x 10^{-7} mm²/Kg [56]. The specific area rate was obtained in specimens using cocopeat and brass powder by 90%, and epoxy resin by 10% [56]. Furthermore, Pramono et al. were also able to produce brake pads with a smaller specific wear rate than the results obtained in this study. Pramono et al. made brake pads using mangifera indica cultivar manalagi seed powder, brass powder, magnesium oxide, and epoxy resins with various compositions. In the specimen 45%: 25%: 20%:10% (Mangifera indica cultivar manalagi seed powder, brass powder, magnesium oxide, and epoxy resins) produced brake pads with a specific wear rate of 2.52 x 10^{-7} mm²/Kg [66]. However, the specific wear rate produced in specimens 2 and 6 are smaller than the specific wear rate of brake pads on the market, which is 6.85 x 10^{-6} mm²/Kg [56].

TGA and DSC tests to determine the thermal properties of the composites produced in this study were carried out on specimens 2 and 6. This was done because specimen 6 produced the highest density, flexural strength, flexural modulus, and hardness compared to other specimens. While specimen 2 produced the lowest density, flexural strength, flexural modulus, and hardness compared to other specimens. **Figure 7** shows that the brake pad friction material composite has several temperature variations when experiencing thermal decomposition which generally occurs between temperatures of 30 °C–700 °C. At 30 °C–150 °C, specimens 6 and 2 lost 1.84% and 0.71% of their initial weight, respectively. At this stage, the composite specimen loses weight due to the evaporation of its water content [67], [68].

Rice husk contributes to a higher weight loss in specimen 6 than in specimen 2. At temperatures between 150 °C and 500 °C, specimens 6 and 2 lost 45.60% and 37.29% of their weight, respectively. The greater weight loss that occurs in specimen 6 at this stage was caused by the decomposition of the three main constituents of rice husk, namely lignin (250–500 °C), cellulose (275–350 °C), and hemicellulose (150– 350 °C) [67], [68]. At 500 °C – 700 °C, the weight loss that occurs in specimen 6 is 56.87%, with a total residue of 43.13%. Furthermore, the weight loss that occurred in specimen 2 at this stage was 53.03%, with a total residue of 46.97%.

The TGA results of this investigation revealed that specimen 2 decomposed at a slower rate, with the highest residue degradation occurring at 700 °C. This demonstrates that specimen 2 has superior thermal resistance properties compared to specimen 6. The addition of rice husks significantly decreases the thermal stability of the composite brake pad material. Research conducted by Suhot et al. showed that the addition of rice husk to composites with polypropylene as a matrix lowered the decomposition temperature of the resulting composites.

This is because rice husk is less thermally stable than polypropylene. In addition, the lower thermal degradation properties of rice husks also contribute to a decrease in the thermal degradation temperature [14]. In addition, superior thermal stability on specimen 2 is also influenced by a high content of alumina oxide and iron oxide, which are compounds that have a high melting point, so they have high heat resistance properties [24], [69], [70].

Tmax is a degradation temperature that shows the maximum weight loss in the test specimen which can make the most important indicator to determine the thermal stability of a material [68]. The results of the DTG (Derivative Thermal Gravimetry) test show that the Tmax in specimen 6 and 2 are 365.39 °C and 365.23 °C (**Figure 8**). The results obtained in this study produce a Tmax that is greater than the results obtained in previous studies which produced Tmax of 358 °C and 359 °C [71]. In previous research, Islam et al conducted a study on Thermal analysis on hybrid composites reinforced with Al_2O_3 and SiO_2 filler particles. When the composite is reinforced with Al_2O_3 and SiO_2 of 5 grams each (Composite-2) and Al_2O_3 and SiO_2 of 15 grams each (Composite-3), the resulting Tmax is 358 °C and 359 °C [71]. However, when the composite is reinforced with Al_2O_3 and SiO_2 of 0 grams each (Composite-1), the resulting Tmax is 382 °C [71]. Research conducted by Ghosh et al. was able to produce a higher Tmax than the results obtained in this study. Their research uses penolic resin as a matrix in the manufacture of composite friction materials and produces Tmax of 430 °C and 475 °C [72].

Figure 9 shows the results of DSC (Differential Scanning Calorimetry) testing performed on specimens 6 and 2. Endothermic peaks in specimen 6 are seen at temperatures of 161.55 °C and 163.91 °C. Furthermore, endothermic peaks in specimen 2 are seen at temperatures of 144.19 °C and 220.66 °C. These temperatures indicate the presence of water molecules in the composite specimen of brake friction material. According to research by Cionita et al., the thermal decomposition of the constituent materials in the composite starts at a temperature of about 180 °C and ends at about 350 °C. Thermal decomposition is the process of changing complex chemical compounds into simpler chemical compounds due to heating [68]. In this study, thermal decomposition occurred between 225 °C and 350 °C.

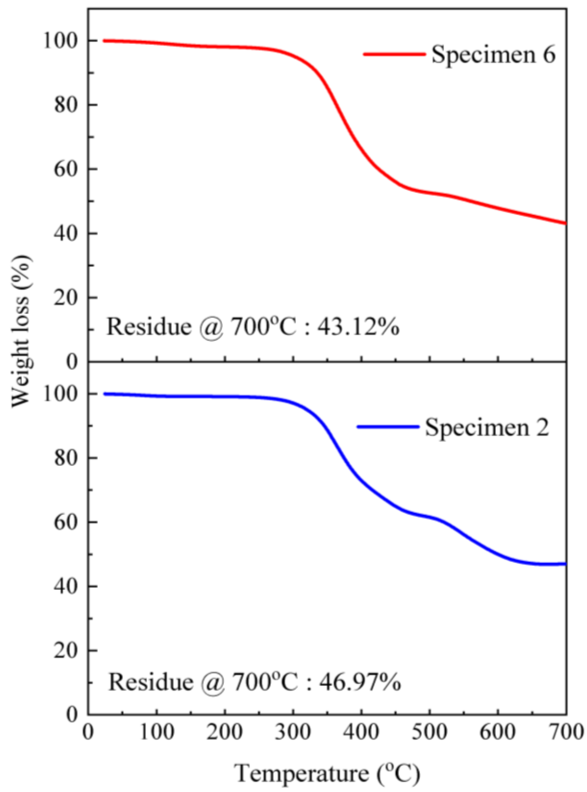

Figure 7. TG curves on specimens 6 and 2

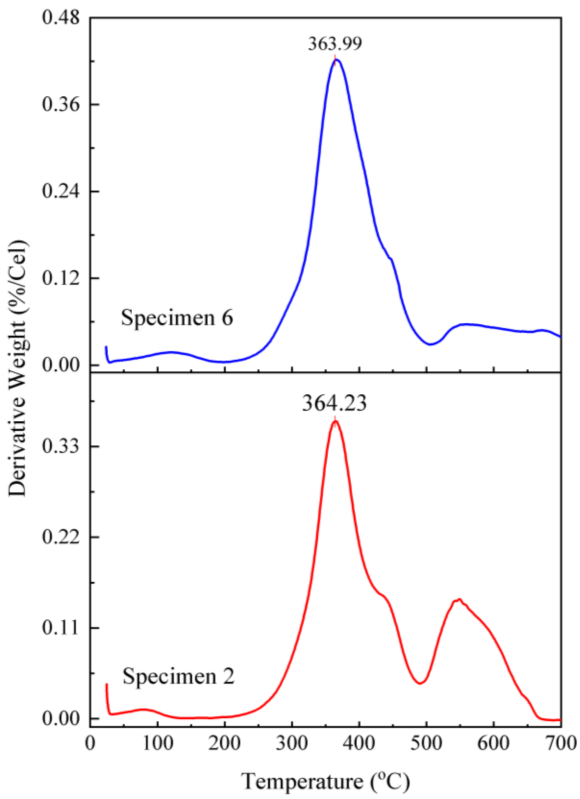

Figure 8. DTG curves on specimens 6 and 2

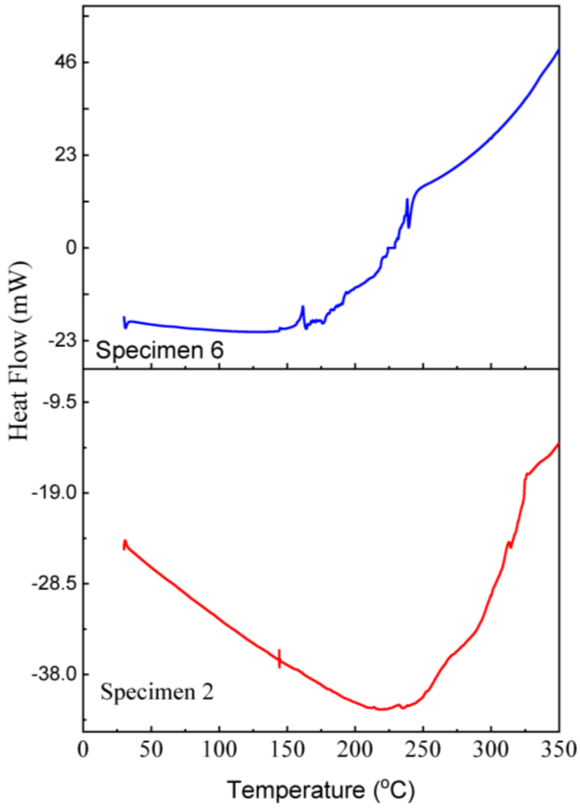

Figure 9. DSC curve on specimens 6 and 2

The temperatures at which specimens 6 and 2 decomposed thermally were 245.88 °C and 332.20 °C, respectively. The thermal decomposition temperatures produced in this study are higher than the results of previous studies. Carlevaris et al. made brake pads using benzoxazine with the resulting thermal decomposition occurring between 164.4 °C and 246.5 °C [73].

Overall, the results of this study are consistent with Sustainable Development Goal 9 - Industry, Innovation, and Infrastructure, as it prioritizes advancing the industry and fostering innovation in material science. By investigating and implementing innovative composite materials, this study contributes to the development of sustainable and efficient brake pads, thereby contributing to the achievement of Sustainable Development Goal 12 - Responsible Consumption and Production. This research aims to improve the efficacy and efficiency of brake pads, which could result in less material waste and more sustainable consumption and production methods in the automotive industry. In addition, by utilizing rice husk as a resource in composite materials, the research addresses responsible consumption and production procedures promotes a circular economy, and contributes to Sustainable Development Goal 12. In addition, the enhanced wear resistance and thermal stability of the brake pads indirectly contribute to Sustainable Development Goal 13 - Climate Action by reducing carbon emissions and promoting vehicle energy efficiency. This study emphasizes the potential for the automotive industry, innovation, and responsible consumption and production practices to generate positive environmental and economic impacts [74].

4. Conclusion

This study explores the feasibility of using a hand layup method to fabricate brake pad composite materials with the addition of rice husk, Al_2O_3, and Fe_2O_3 to the epoxy resin as a matrix material. The study investigates the impact of varying fraction volumes of these materials on the physical and mechanical properties of the composite. The findings showed that adding rice husk, Al_2O_3, and Fe_2O_3 to the epoxy had a significant impact on the composite properties such as density, hardness, flexural strength and flexural modulus. When the amounts of Al_2O_3, and Fe_2O_3 increase, the material mixture becomes less homogenous, resulting in the inhomogeneity of the composite constituent material. As a result, the porosity of the material increases while the density decreases.

In this study, hardness, flexural strength, and flexural modulus all decrease as density decreases. This behaviour was clearly visible in Specimen 2, which used epoxy, rice husk, Al_2O_3, and Fe_2O_3 in proportions of 50%, 0%, 25%, and 25%. Specimen 2 has a lower hardness, flexural strength, and flexural modulus than the other specimens due to its low density.

Specimen 2 produced density, hardness, flexural strength, and flexural modulus of 1.06 g/cm^3, 39.2 HV, 21.99 MPa, and 1.15 GPa. Specimen 6 had the highest values for density, hardness, flexural strength, and flexural modulus, which were 1.33 g/cm^3, 83.4 HV, 52.29 MPa, and 3.00 GPa, respectively. The concentrations of epoxy, rice husk, Al_2O_3, and Fe_2O_3 in specimen 6 were 50%, 20%, 15%, and 15%, respectively. However, the addition of 20% rice husk to specimen 6 resulted in lower wear resistance and thermal stability than specimen 2. Rice husk decreased the thermal conductivity of specimen 6 so that it dissipated heat less efficiently, thereby increasing the risk of thermal damage and glazing and decreasing the adhesion of the material used to produce the brake pads. In addition, rice husk is less thermally stable, causing specimen 6's thermal resistance to be lower than that of specimen 2. This study aligns with Sustainable Development Goals (SDGs) 9, 12, and 13 by advancing innovation, fostering sustainability, and reducing emissions in automotive industry applications.

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Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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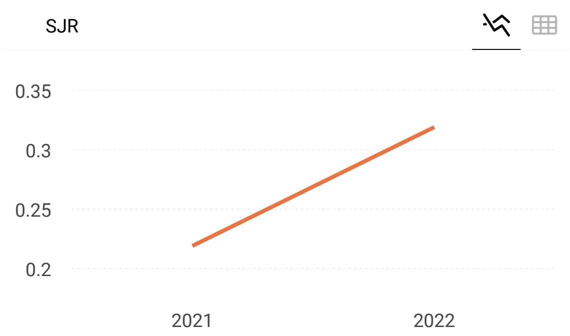

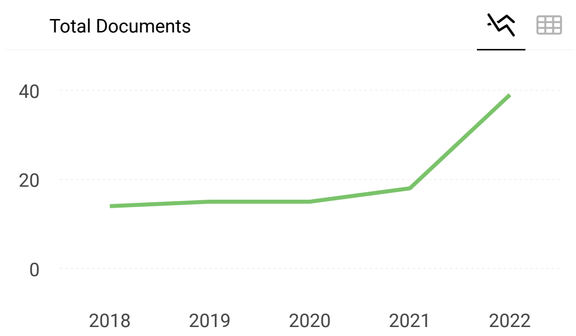

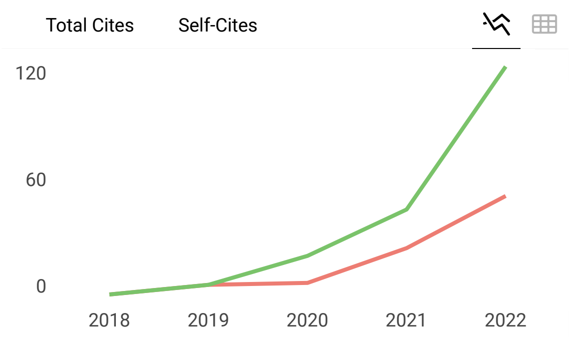

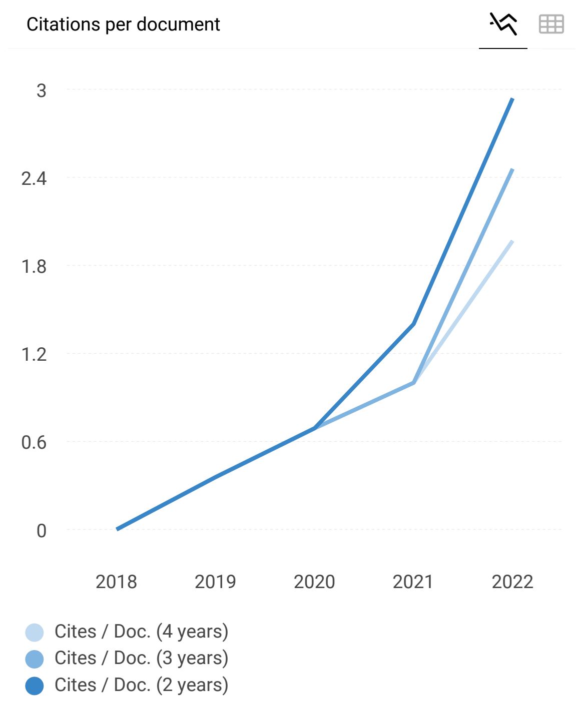

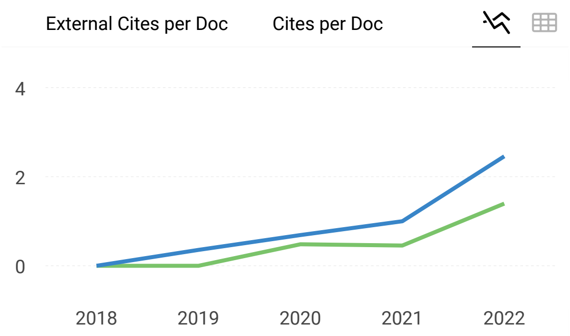

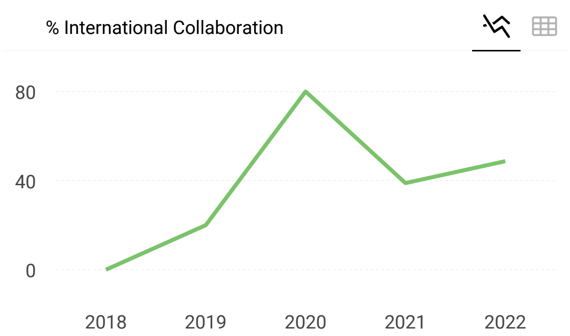

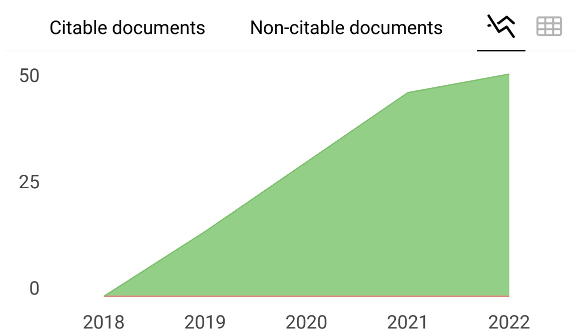

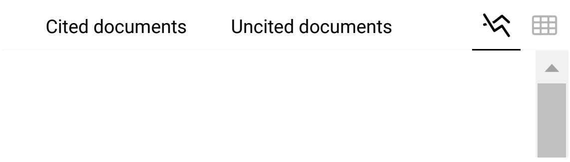

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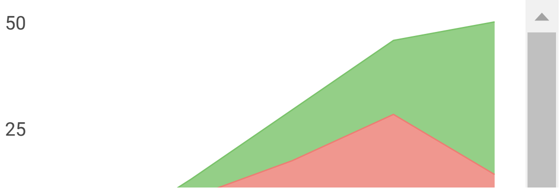

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