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Eco-friendly materials for brake pad- ANSYS overview

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ABSTRACT

Recently, the awareness of green environment has raised in huge manner with comfort for nature to protect environment in terms of wastage accumulation. Among automotive components, most of the vehicles returned as a scrap vehicle so that the wastes extracted and became harmful due to the chemical treatments of materials. The spare parts of independent components are not much disposes with proper treatment. This exhausts effects the environment under wastages. Here, the brake pad having constituents are not supposed to eco-friendly like asbestos and harmful filler materials. The influence of asbestos materials leads negative impact to environment and surrounding creatures and sustainability to ecological transition. The performance of the brakes pads are completely depends on brake pad and its frictional properties. Based on this, the current study performs about prediction on natural eco-friendly materials used as brake pads by focusing on Eco safe composite mixtures. The prediction is done by simulation in ANSYS with the different eco-friendly materials such as palm kernel fiber, Coconut coir, bamboo, banana peels and so on.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Advancements in Materials and Manufacturing.

1. Introduction

Brakes are vital part of high performance among vehicles that deserves a great deal of attention to safety only. As a combination of assembly, brake system includes fluid, lines, pedals, levers, linkages, and braking units. To design any system, it is important to select a material, which gives strength, durability, performance and other characteristics. The braking components inside a braking system are crucial for safe and efficient operation. These components include brake calipers, master cylinders, and hydraulic control systems [1–10].

Brakes uses friction materials to transform mechanical energy into thermal energy. The heat produced from the friction material transferred to atmosphere and other components of braking system. A vehicle's brake system is made up of a disc brake and a pad, which work together to slow down and speed up the vehicle. Thermal heat is produced during the braking process as a result of friction between the disc's surface and the brake pad. It should be prevented from getting the disc and pad to friction at a high temperature [11,12]. A set of metallic discs and brake pads make up an automobile brake system as fulfill rigid elements to sustain in environment. Here, the usage of brakepad is manufactured by the asbestos fiber materials which affects carcinogenic cancer [13]. In brakes operation, wear debris are released in atmosphere and pollute the environment. Brake pad is classified in to three categories namely metallic, non-metallic [14] and Non Asbestos Organic (NAO). The materials from which brake pads have significant impact on its type of frictional and wear qualities of the materials used to make brake pads should be steady and consistent. There are several types of natural fibers available that can be used in various applications, including jute, flax, hemp [15], kenaf, sisal, and cotton [16]. These fibers can be used alone or in combination with synthetic fibers to produce composites with improved properties. For example, natural fiber composites can have improved impact resistance, tensile strength, and stiffness compared to pure synthetic composites [17]. Additionally, the use of natural fibers can help reduce the environmental impact and carbon footprint of the composites industry.

Eco-friendly friction components replace expensive materials with natural fibres. The automotive industry is currently experiencing a resurgence in the use of natural fibres as reinforcements in technological applications. Natural fibres provide more sound absorption capacity, are more resistant in fracture occurrence,

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and have better physical properties for managing energy. Green House Gases (GHGs) is causing rapid climate change, which is in turn resulting in reduced crop yields and people's ability to access food. These GHG emissions are largely due to human activities, such as burning fossil fuels and agricultural practices [18].

Brake pads are typically tested to determine various properties that are important for their performance in the application. Some of the properties that may be measured during testing include abrasion resistance, hardness [19–20], friction coefficient, compressive strength, specific gravity, water and oil soaks, tensile strength, thermal conductivity, disc temperature, and stopping time [21]. These tests are designed to ensure that the brake pads are safe and reliable, and will perform as expected under a wide range of conditions. Additionally, testing may be carried out to evaluate the performance of different types of brake pads under specific conditions, such as high-speed or high-temperature operation, or in wet or humid environments. The article discusses the potential of agricultural waste [22] as a valuable resource in various industries, due to its organic nature and abundance. Agricultural waste comes from various plant components like seeds [21], shells [23], leaves [24], fruits [25], and, including materials such as oil palm shells [25–29], rice husk [30–33]corn chaff [34–36], and coconut shells [37,38]. The article highlights the economic benefits and environmental advantages of repurposing agricultural waste and utilizing it in manufacturing industries, which can help to control environmental pollution.(Fig. 1).

2. Proposed methodology

The methodology for the evaluation of finding the analytical solution for eco-friendly brakepad materials with its minimum boundary condition. Fig. 2 represents the steps proceeds for achieve the results with the absolute conditions. The model of brake pad with disc is designed using CATIA V5 and the loads applied, mesh features and applied materials achieved with ANSYS 19 simulation. Finite Element Analysis [39] is a tool that has been used to examine various solutions. Even in this project, FEA is utilised to examine the various stresses, their deformation, and forces that are present in the brake pad. Due to the lack of damping and inertial effects caused by the loads on the components, static analysis is employed to calculate the displacement strains, stresses, and forces [39]. The various loadings that can be exerted in a static analysis are steady state inertial forces such as rotational velocity, temperatures, externally applied forces and externally applied pressure. In this present work, linear static analysis is employed. In the case of application of inertial loads, mass properties such as density of the materials to be defined.

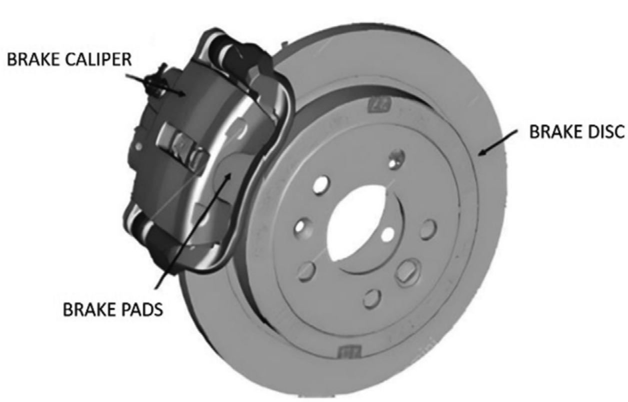


Fig. 1. Brake pad assembly.

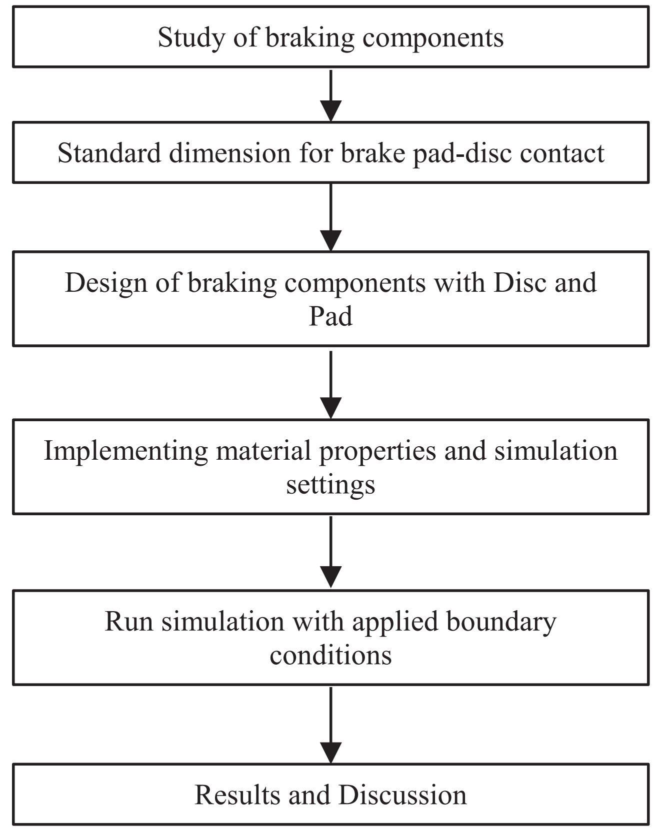


Fig. 2. Flowchart for preparing simulation for brake pad.

The fiber structure in friction material plays an important role in determining the friction and wear properties of the material. The way the fibers arranged and bonded to the matrix [40] affects the coefficient of friction, the wear rate, and the strength of the friction material. The length, diameter, and orientation of the fibers also influence how well they can absorb heat and transfer it away from the surface of the friction material. Additionally, the fiber structure of friction material can affect the porosity and permeability of the material, which can in turn affect its ability to absorb and dissipate heat. Therefore, selecting fibers with appropriate properties and optimizing their structure in the friction material is crucial for achieving effective braking performance and durability.

3. Brake pad design

The design supports to addresses the need for alternatives to traditional brake pad materials due to the phasing out of asbestos material [10]. The focus of the study is on using natural fibers as a replacement for improving performance characteristics of brake pads and conducting tribological research to support this effort to predict the best material based on analysis and simulation.

The thickness and width of the brake pad are important factors that affect its effectiveness and longevity. A thicker pad may provide better stopping power, but may also be heavier and have a shorter lifespan due to increased wear. A wider pad may distribute the pressure more evenly across the rotating surface, but may also be less effective at generating friction due to a smaller contact area. Fig. 3 shows the dimensions of brake pad, 120 mm of circular length associated with rotor also having outer radius of 136 mm and inner hole of radius 70 mm considered as a sample model. (Refer Fig. 3 for other dimensions).

4. Materials employed

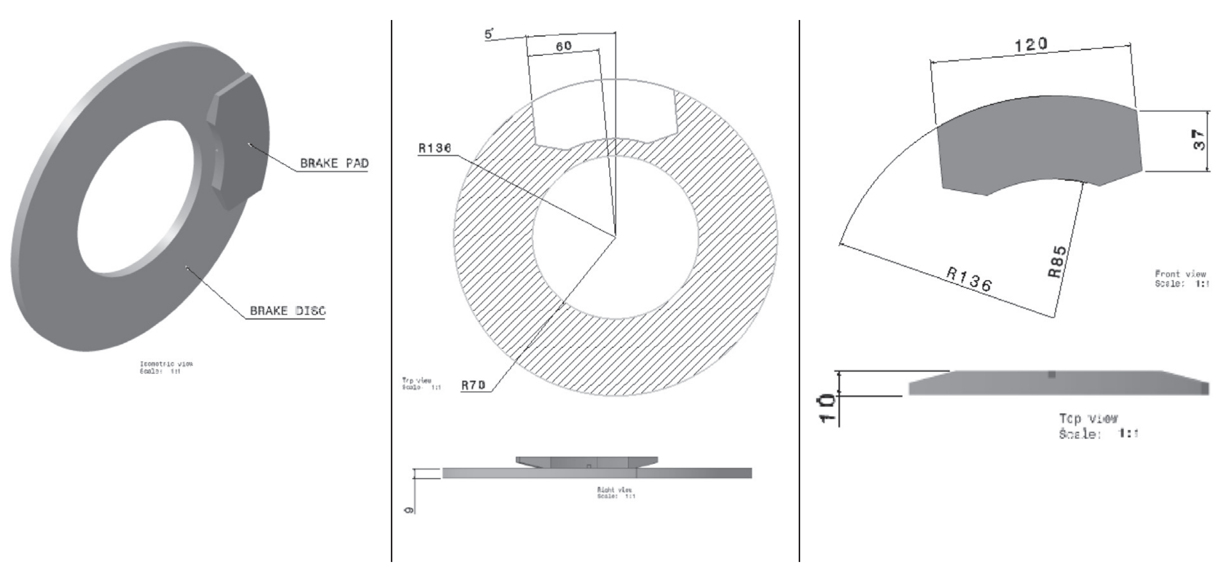
In this environment, mother nature there are number of materials are still existing without discovered much and are not much used as by products. Nowadays due to climate change, environment causes new sustainable and eco-friendly materials are used as daily usage products and other vehicle level products. To improve more environmental products as different usages, it would be most welcome to make our environment with a less pollution behaviour. Fig. 3 shows the different materials fibers are existing materials used for brake pad applications. The number of researchers worked with the numerous amount of ingredients to improve mechanical tribological properties in terms of braking applications [41].

The need for eco-friendly materials in automotive brake pads due to environmental concerns has led to research on the usage of natural fibers as reinforcement. Asbestos usage in brake pads is unsafe and thus researchers are exploring natural fibers, which are cheap and readily available, possess excellent properties, and are non-toxic [7]. The materials employed is driven by the need for an eco-friendly and sustainable solution.

The proper utilization of available natural resources and wastes is essential in developing sustainability in industry. This approach is vital in addressing environmental degradation and achieving the Sustainable Development Goals. There are several resources available to help industries achieve sustainability [42], such as the use of circular economy principles, the adoption of sustainable consumption and production practices, and the management of waste. The replacement reason of asbestos material is, the use of asbestos can cause adverse respiratory conditions, as confirmed by medical research [43]. Asbestos is a hydrated magnesium silicate. In vehicle brakes, the amount of asbestos used typically ranges from 30 to 70%. While the use of asbestos has positive characteristics, including thermal stability up to 500 °C, the ability to regenerate the friction surface during use, excellent wear resistance, strength, flexibility, and reasonable cost [44], its usage can still induce adverse respiratory conditions, as confirmed by medical research. Despite its strength and low cost, asbestos is being phased out due to the health risks it poses to the lungs. The brief suggests that the use of local materials for brake pads and brake lining can reduce cost while possessing desired mechanical and chemical properties, such as hardness, resistance to abrasion, and environmental friendliness [45].

Basalt fiber is an inorganic fiber has suitable properties of good in as follows: elasticity modulus, strength, temperature resistance, and strain to failure, and process-ability [46].Though it is less cost, eco-friendly with renewable characteristics considered 10 other ingredients to make a complete friction material [47–49]. The ingredients, he used are as follows, Basalt fiber, Glass fiber, Wollastonite, Barytes, Mineral wool, Friction dust, Graphite, Iron powder and Copper powder. An Approximate chemical analysis of basalt fiber is SiO_2 (46.2%), Al_2O_3(13%), Fe_2O_3 (12%), MgO(10%), CaO (10%), TiO_2 (2%), K_2O(1.2%), Na_2O(3.5%) and traces (<1%) [50]. These basalt fibers are used in various applications in military, defense equipments, aeronautical, civil infrastructural projects [48]. The study utilized eco-friendly raw materials, such as plant flax fiber, along with mineral basalt fiber and wollastonite, for reinforcement, as well as natural graphite, zircon, vermiculite, and baryte as fillers and a cardanol-based benzoxazine-toughened phenolic resin as the binder for brake pad composites [49,51]. The influence of hemp fibers [15] as an additive with basalt fiber, strength, stiffness, fracture toughness is well improved. From this, the selection of Basalt fibres are a suitable material in the automobile sector due to their dependable structural behaviours.

Based on a review of the literature and the authors' earlier research, formulations of the palm seed and leaf [24] added friction compositions incorporated. With the addition of palm seed powder [52] form and barium sulphate mixture with the 66 wt% has included binder (phenolic resin) 20 wt%, fibre (steel) 10 wt%, friction modifiers (cashew, alumina, graphite) 23 wt% and functional fillers (Cu and Zn) 13 wt%. All ingredients were sieved, and the average size of particles was 300 mesh (48–84 μm). Considering surface treatment of fibers, it is an important process used to improve the adhesion and interfacial bonding between the matrix and fibers, as well as other components [53]. The synthetic fibers have excellent mechanical properties and are commonly used as reinforcement in fiber-reinforced polymers, but natural fibers also have unique properties that may benefit composites in certain applications. Natural fibers have lower density, can dampen vibrations, and exhibit blunt fracture behavior [54]. One method of surface treatment is the use of saline treatment in basalt fibers, which increases the roughness and shear strength of the fiber. Another



(a) Brake pad Assembly   (b) Assembly dimensions   (c) Dimensions of brake pad

Fig. 3. Schematic drawing of Brake pad with Rotor disc [MODEL] All dimensions are in mm, Different Eco-friendly fibers.

Fig. 3 (*continued*)

method is to coat the PI matrix with a coupling agent DMF (dimethylformamide, which is a common organic solvent used in various chemical reactions) to improve the surface roughness and interfacial shear stress of aramid fibers. These treatments help to create a stronger and more durable material. [55].

Aramid pulp has carried the highest influence among them due to its unique physical properties, such as improved fibrillation with the constituents. Its ease processing aids by imparting better pre-form green strength [56]. The aramid fiber did not sufficient and higher temperature with the addition of raw content only. So if the effectiveness of the frictional properties loses its strength, the braking application would be unsuitable for aramid fiber. To overcome this, the combination of fibers and its composites enhances the frictional effect. As a result, it is used with other fibres to create effective characteristics from different but distinctive to one another.

Apart from ceramic brake pads, grey cast iron and Stainless steel SUS410 are used [57] when considered about the physical property and chemical property, but the weight of the brake pad increases that makes the disadvantages. So to control the weight of stainless steel, Aluminium alloy composite AA8081-15 wt% SiC-3 wt% is considered as the replacement of asbestos brake pad. The addition of steel wool [58] with other natural agro wastes will improve reinforcement properties and thermal stability.

Palm kernel fibers (PKFs) is extracted from a ore of palm cake and the nut shell were collected and suspended in caustic soda (sodium hydroxide) for 24 h to remove the trace of red oil. The fibers as shown in Fig. 3b washed with water to remove caustic soda and dried under sun light for nearly a week. This dried PKFs was beaten into powder form and separated as mesh size 6100 µm. When it applies to a brake pad, it shows rigidity and sustain to control the stress occurs since the mesh size is increases it may occurs less deformation [22,59,60]. To achieve palm kernel fiber as a commercial brakepad, a grain size of 100 µm hot pressing, cooling, curing and finish with surface as some ingredients like aluminium oxide, calcium carbonate and epoxy resins are added [61]. The usage of reinforcement with palm fibers to polymer composite mixture makes engineering properties in hard state [62,63]. The potential of reinforcing epoxy with short palmyra fibers (SPF) to improve its dry sliding wear resistance. Palmyra fiber is a low-cost and naturally available fiber derived from palmyra leaf stalks [64]. A parametric analysis is performed on the dry sliding wear process undergone by this new class of composite material consisting of epoxy and SPF. The purpose of the study is to explore the possibility of improving the wear resistance [65] of neat epoxy via SPF reinforcement. The oil palm fiber for the production of panel products and carbon nanomaterials. Overall, oil palm fiber appears to be a versatile and sustainable resource that has the potential to be used in a wide range of applications. [29]. The waste PCBs [66,67] are mixed with the palm ash to improve wear resistance and frictional behaviour that could potentially reduce environmental impact.

A by-product of the extraction of **palm-seed** oil is palm slag. Oil palm enterprises face a financial and environmental risk when disposing as a land-fill**. P**alm slag, phenolic resin, steel fiber, graphite, and alumina are the five ingredients added for brake pad material mixture [59]. Palm slag is used as filler in the brake pad mixtures [67]. The proportions of each component are as follows: Phenolic resin is preferred as the binding agent, graphite as the lubricant, steel fibre as the reinforcement, and alumina as the abrasive. The particle size of Palm slag is considered as 600 µm. the addition of calcium carbonate and dolomite with palm slag [68] makes comparatively strength and durability to the frictional product.

Abaca is extracted from the leaf sheath around the trunk of the abaca plant (Musa textilis), which is a species of banana tree native to the Philippines. Presently, banana fiber is a waste product of banana cultivation. Therefore, the manufacturing of fibers for industrial purposes is possible at the cost of their processing [69]. The poly vinyl ester composites are added with abaca as a single layer fiber with ramie fiber [70] makes good result in tensile property. The coupling agents of mixed composites well behaved with reinforced polypropylene make abaca fiber's properties as glass fibers. The properties are as follows as good as tensile strength and flexural strength and impact strength [71] with the additional binders as benzenediazonium chloride [69].

Jute fibre is an insulator extracted from stalks of jute plants. Once the harvest completes, fibers are sacked into water which obtained antistatic properties. Moreover, it is characterized by moderate moisture retention. It is resistant to microorganisms [72], but not to chemical and photochemical attack. Due to a low density, light weight and its stiffness, Jute fibers are used in many sectors of industry, like automotive, marine and defense and sports sector. Fig. 3f shows the jute fiber extraction with polyester and epoxy resins [73]. The use of chemical surface modifications [74,75] of jute fabrics for their potential use as reinforcing agents in composites based on a biodegradable polyester amide matrix, BAK 1095. The study analyzes the effect of different fiber surface treatments and fabric amounts on the performance of resulting composites [76]. The composites reinforced with jute fibers can exhibit the fade phenomenon at higher temperatures, where the friction coefficient decreases and wear rate increases [77].

Corn stalks are as raw material for asbestos-free fiber-cement is quite feasible, considering environmental and economic aspects. It is fiber-cement corrugated sheets [78], that indicates good thermal stability, crysltalllity, it is not deformed with climatic change conditions since it is extracted by acid-base solution. In addition, it may use as a fuel also. The extraction of corn-stalk fiber is shown in Fig. 3e. The corn fiber stalk has lower porosity which leads to lower friction coefficient which in response, leading to reduction of space between particles [31].

Natural fibers can be produced from different parts of plants like leafs, stem, bark, or seeds. This process involves harvesting, soaking, brushing, and drying. Their chemical composition, especially cellulose content and the orientation of fibrils determines mechanical properties of each fiber type. All natural fibers for industrial applications have high amounts of cellulose, but the structure of cellulose microfibrils may vary, resulting in different tensile strengths and elongations at stress. Also the diameter of single fiber is different for each fiber type. The main natural fibers applied in the plastic industry are: jute, sisal, flax, coir, abaca [88], kenaf [89], and softwood [90].

The modification on raw materials composition can be done in automotive brake pad manufacturing to ensure the benefit of mankind. Therefore, investigation on a new formulated automotive brake pad production with natural material was conducted. The potential utilization of agricultural wastes [91] as new and inexpensive materials to replace synthetic filler in the brake pad makes comfort to environment.

Fibre used were **Pineapple Leaf fiber** (filler), with epoxy resin [87,92], is distinct from what is raised for fruit. A fruit-bearing plant's leaves also produce fibre, but they don't produce fibre of high quality. The best grade pineapple leaf fibre comes from long-leaved pineapple trees that are specifically cultivated for their fibre. Also it has good thermal insulated property which shows good results in friction. With the reinforcememt with the polymer matrix. It have more adequate strength to occupy loads. Fig. 3l shows the picture of pineapple fiber. With the increase of amount of fiber, the material makes stronger and rigid.

Table 1 summarizes the mechanical and physical properties belongs to the different materials applicable to brakepad.

The possible use of **rice husk dust** as natural filler in brake pad can help to reduce the burden of agricultural wastes and automotive manufacturing cost. According to Karthikeyan[86], rice husk [32] are known to have low lignin and high silica contents which influence the automotive brake pad the ceramic like properties replaces the use of rice husk dust has also increased the frictional performance. Samples with 20 % rice husk and rice straw powder showed greater friction coefficient (µ) values than 4 %. The frictional coefficient µ value of rice husk mixed-brake pad was between 0.280 and 0.392. 0.381 revealed the µ value of friction material mixed with composite mineral fibre of Wheat and maize to make a brake pad structure as rigid behavior.

The main raw materials in this study were binder resin (phenol formaldehyde), metallic fibres (steel, magnesium oxide and copper), friction modifiers (graphite and brass), and fillers (barium sulphate and rice husk dust). The rice husk is crushed into dust in crusher to produce rice husk dust (RHD) [93]. There are different sizes of 80-mesh and 100-mesh dust size considered. It is then dried into 1 – 3 % of moisture content to be tried for a week [94]. This RHD was mixed with other raw materials under mixer for nearly 30 min. Fig. 3k shows the dried rice husk to use as brake pad mixture [86]. All other ingredients are set in as powder form with the rice husk powder. Thus, rice husk brake pad forms to simulate results.

In the past, composites of **coconut** fiber/natural rubber latex were extensively used by the automotive industry. How-ever, during the seventies and eighties, newly developed synthetic fibers due to better performance gradually substituted cellulose fibers [22]. In the fiber usage sectors, there has been some rebirth in interest of employing these fibres as reinforcement materials for environmental benefits of employing renewable and biodegradable materials may be to blame for this interest. The epoxy content coconut shell filler particle composites [42] show promise as a sustainable and environmentally friendly alternative to conventional composite materials.

Bagasse fiber induced from sugarcane that evolves lignocellulosic material made up of cellulose, hemicellulose, and lignin, and is an abundant, low-cost, and renewable resource. Due to its fibrous nature and excellent mechanical properties, sugarcane bagasse fiber has numerous potential applications in various fields such as textiles, paper, construction, and as a reinforcement material in composite materials. However, the effectiveness of bagasse fiber as a reinforcement material depends on various factors such as fiber length, diameter, and surface characteristics with the chemical composition from resins and banana fibers [95,96].

Sisal fibre is fairly rough and inappropriate. It exhibits apt strength, endurance, machinability, attraction for specific colouring materials, and ability to adapt in seawater [85]. Sisal ropes and twines are widely used for various industrial sector like as marine, agronomic, transport and general industrial use. When cotton and sisal fibers were added to polyester composites, the friction coefficient significantly increased by 46% and 50% compared to the neat polyester. This suggests that the addition of these fibers may improve the frictional performance of the composite material [97]. Fig. 3j represents the sisal fibers in dried form. With the additional of biocomposites [98] using polycaprolactone and starch as matrix, and sisal fibers as reinforcement to improve surface treatment and morphology. The influence of fiber treatment on the mechanical properties of composite materials made from unidirectional sisal fibers reinforced with epoxy matrix [99] suggests that the use of proper fiber treatment can lead to better adhesion between the fiber and the matrix, even distribution of fibers, improving the tensile strength and stiffness of the composite.

Banana fibre extracted from banana peels and its decompose during banana cultivation. Banana fibre can therefore be obtained for industrial uses without the need for any further financial input. In polyester resin, banana fibre is proven to be an effective reinforcing [100]. The length of the fibres has a significant impact on the composites' characteristics. The banana peel fibers represents in Fig. 3a. The short form of banana fibers with varying length, which enhance the mechanical properties of the composite and affects its interfacaial shear length so that it obtains low porosity [101].

5. Bamboo

The mixture of MgO and Bamboo fibers with epoxy resin, the brake mixture is formed [80]. It is classified into three different Compositions based on the different percentages of Bamboo fiber but keeping the ratio of MgO and Epoxy Resin the same. Moreover, the Composition with a 60% bamboo fibre, 20% epoxy resin, and MgO formulation has demonstrated the best performance. Bamboo fibers from 0.5 to 8.5 years old can be used for making fiber-reinforced composites due to the almost complete growth of cell walls in the fibers near the outer surface of the bamboo stem [102] to strengthen the mechanical and tensile other than natural fibers.

Coconut coir

Coir extracted from the husk of coconut fruit fiber which is dried. It has more life compared to other natural fibers due to its high lignin content [103]. It is then reinforced with thermoset and thermoplastic resins to make tight impact on strength. This matrix combination provided the adhesive property [104] within the interface. Different percentages of the obtained particles were used in the brake pad material mixture, such as 10 and 30%. These particles may have been used as a filler to improve the performance of brake pads or as a sustainable alternative to traditional fillers [105]. Coir fiber showed very high interfacial adhesion under dry conditions. The adhesive property is important when it is used for brakepad applications so it has to test for different aging solutions [106]. The coconut coir induced brake pads has a certain porosity [107] to control the effect of water and oil on the friction coefficient and by increasing porosity more than 10% minimise the brake noise [108]. Fig. 3d shows the pictured of coconut fibers. Coir fiber reinforced polymer composites developed for industrial and socio-economic and household applications such as automotive interior, paneling and roofing as building materials, storage tank, packing material, helmets and postboxes, mirror casing, paper weights, projector cover, voltage stabilizer cover [109,110]. The study found that increasing the percentage of ground coconut powder in the composite brake pad resulted in lower breaking strength, hardness, compressive strength, and impact, which in turn led to increased brittleness of the brake pad [111]. These findings suggest that the addition of too much coconut powder can negatively impact the mechanical properties of the composite material and reduce its effectiveness as a brake pad.

Flax fiber is obtained from the layer, which covers the stem of a plant [112], and flax seed grown in mild and subtropical regions of the world. It is a natural, cellulosic, multi-cellular bast fiber. It is about 10–100 cm in length. Its diameter varies from 40 to 80 μm. The fibrous form of flax seed fibers is shown in Fig. 3g. Flax fiber is extracted from the skin of the stem of flax plant. It is arranged in the form of thin filaments, around a central wooden cylinder [82]. It is soft, shiny and flexible and stronger than cotton fiber but less elastic. With the fiber content increase, the water absorption was more. The material used was that the friction samples were mainly Flax fibers, so it can be used as brake pad application.

Kapok fiber(KF) is a moisture-resistant, quick-drying, resilient, and flexible fibre. These kapok fibres acts as elastic fibre, fluffy, low density [113] is good for less wear, and it is too brittle for spinning, but it weighs only one-eighth as much as cotton. This fiber has hollow-tube structure with the size of 0.8–1.0 μm in wall thickness and 8–10 μm in diameter [114], and accordingly, It is very light in weight and low in density. Due to the presence of waxy substance on the fiber surface, KF also shows intrinsic resistance to water and high affinity to oils, Kapok fibers can be used for brakepad applications also.[83] Fig. 3h shows the Kapok fibers.

Kenaf or (Hibiscuss cannabinus L.), is one of the non-wood plant fibers used as reinforcement or fillers in the polymer matrix. The fiber is with a base diameter of 3 to 5 mm [115]. The kenaf plant can be divided into several parts including the long stem which provides the long fiber. Meanwhile, the kenaf stem consists of two types of fibers in the outer and inner layer, [116]. Besides that, a thin central pith layer known as a sponge-like tissue are non– ferrous cells. This ferrous like structure make the material property as rigid and strength, even if the stresses to pull out ratio is high compare to other properties, it make as unique. Thus, kenaf fiber can implement as brake pad material as reinforcement and fillers [84].

To improve more strength and durability to the fibers, fly ash [117] is also plays an vital role in the addition of filler materials and additives. The effect of resin content on the tribological behavior of brake pad refers to the study of friction, wear, and lubrication of interacting surfaces in relative motion. The resin content in a brake pad composite material can affect factors such as the coefficient of friction, the wear rate, and the durability of the brake pad.

Table 1
Mechanical properties of fibers.

S.No	Types of Fibre	Elongation at break (%)	Density g/cm^3	Young's modulus (Gpa)	Tensile strength (Mpa)
1	Abaca	9–11	1.42–1.65	38–45	879–980
2	Bagasse	6.20–8.2	0.31–1.25	15–18	257.3–290.5
3	Bamboo	4.0–7.0	0.6–1.1	22.2–54.2	360.5–590.3
4	Banana	1.21–3.55	0.65–1.36	3.00–3.78	51.6–55.2
5	Basalt Fibre	3.00–3.15	0.26	85–87	34–62
6	Coconut (coir)	27.21–32.32	0.67–1.15	4.0–6.0	173.5–175.0
7	Corn stalks	1.90–2.30	0.21–0.38	4.10–4.50	33.40–34.80
8	Flax	2.70–3.6	1.27–1.55	50–70	500–900
9	Jute	1.69–1.83	1.3–1.45	20–50	300–700
10	Kapok	1.20–1.75	0.68–1.47	4.56–5.12	80.3–111.5
11	Kenaf	1.56–1.78	0.15–0.55	23.1–27.1	295–955
12	Oil palm	2.13–5.00	0.7–1.55	2.7–3.2	227.5–278.4
13	Pineapple	2.78–3.34	1.25–1.60	5.51–6.76	166–175
14	Rice straw	2.11–2.25	0.86–0.87	24.67–26.33	435–450
15	Sisal	4.10–4.3	1.45–1.5	10–30	300–500

By increasing the resin content [118] above a certain threshold can lead to improved tribological performance, while excessive resin can negatively impact the performance of the brake pad. Therefore, resin content is considered as phenolic resin or epoxy are used to control and optimize for achieve the desired tribological properties

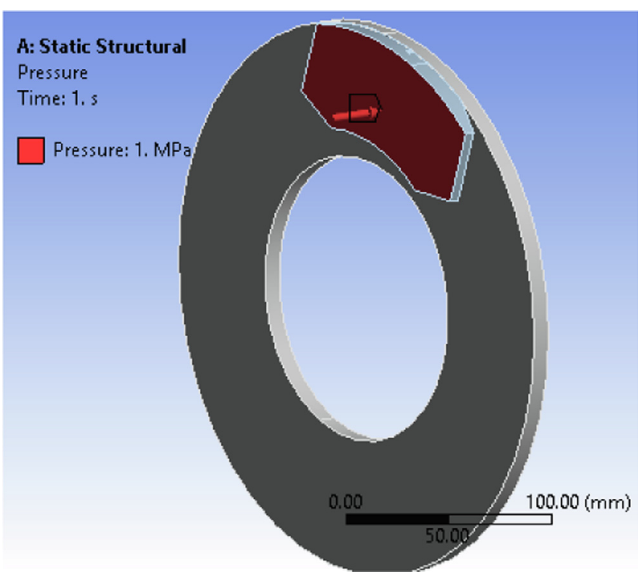


Fig. 4. Pressure applied to Brake pad as 1 MPa.

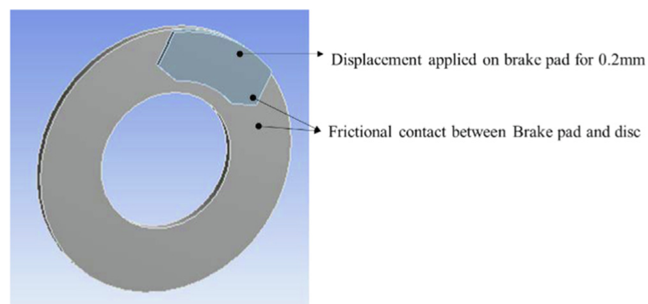


Fig. 5. Boundary conditions applied to Brake pad.

for brake pad composite materials [119]. The addition of silicon carbide particles could improve the wear resistance and frictional behavior of the composite [120]. The study provides insights that could help in the development of more efficient and durable brake systems for automobiles.

6. Brakepad modelling in ANSYS

For ATV vehicles, [121]. Assuming, pressure applied on the Brake Pad by Caliper Piston is calculated in four wheeler as 1 MPa since braking fluid is considered as pressure. Here, the analysis is based on the structural analysis under static conditions only but the transient condition with time varies also can evaluated. In this simulation method, total deformation, equivalent (Von-Mises) stress and maximum principal stresses are calculated under

Table 2
Deformation and Stress value of the Eco-friendly materials.

S.No	Types of Fibre	Deformation length, mm	Equivalent Stress,MPa	Maximum Stress, MPa
1	Abaca	0.56 [Fig. 6.1]	3690.9 [Fig. 6.2]	1118.6 [Fig. 6.3]
2	Bagasse	0.57 [Fig. 7.1]	947.1 [Fig. 7.2]	646.92 [Fig. 7.3]
3	Bamboo	0.57 [Fig. 8.1]	2285.4 [Fig. 8.2]	738.54 [Fig. 8.3]
4	Banana	0.58 [Fig. 9.1]	498.91 [Fig. 9.2]	180.02 [Fig. 9.3]
5	Basalt Fibre	0.51 [Fig. 10.1]	290.9 [Fig. 10.2]	93.76 [Fig. 10.3]
6	Coconut (coir)	0.50 [Fig. 11.1]	389.1 [Fig. 11.2]	127.6 [Fig. 11.3]
7	Corn stalks	0.52 [Fig. 12.1]	344.1 [Fig. 12.2]	109.75 [Fig. 12.3]
8	Flax	0.58 [Fig. 13.1]	878.4 [Fig. 13.2]	309.1 [Fig. 13.3]
9	Jute	0.55 [Fig. 14.1]	3930.3 [Fig. 14.2]	1197.5 [Fig. 14.3]
10	Kapok	0.58 [Fig. 15.1]	661.45 [Fig. 15.2]	236.36 [Fig. 15.3]
11	Kenaf	0.55 [Fig. 16.1]	2492.5 [Fig. 16.2]	766.5 [Fig. 16.3]
12	Oil palm	0.58 [Fig. 17.1]	426.3 [Fig. 17.2]	154.49 [Fig. 17.3]
13	Pineapple	0.58 [Fig. 18.1]	851.4 [Fig. 18.2]	300.19 [Fig. 18.3]
14	Rice straw	0.57 [Fig. 19.1]	2588.8 [Fig. 19.2]	814.88 [Fig. 19.3]
15	Sisal	0.56 [Fig. 20.1]	2837.2 [Fig. 20.2]	863.47 [Fig. 20.3]

assumptions with the constant hydraulic pressure P at 1 MPa (drag brake application) during 1 s. By applying the brake pad's and its characteristics' of different material qualities within boundary conditions. Tetrahedral pattern and tight mesh are used for this part's meshing to produce the most accurate results.

Fig. 4 depicts the boundary conditions for the current model when pressure is applied to only one side of the pad. The pads at the edges are fixed in all degrees of freedom with the exception of the normal direction, and the disc is fixed tightly in all directions. In order to make touch with the disc surface, the pad moves up and down. The setup for solid disc rotor model and the drilled disc rotor model was the same for the whole process in ANSYS 19.3 and it can be done one after another disc rotor model [122]. This is because the goal is to determine how different disc rotor surface designs affect the brake pad during frictional contact. The specified material characteristics were used. For the simulation,

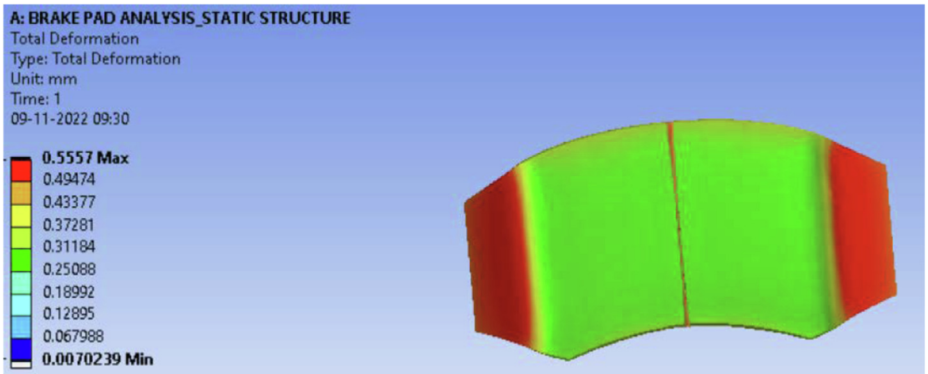


Fig. 6.1. Deformation analysis of Abaca fiber.

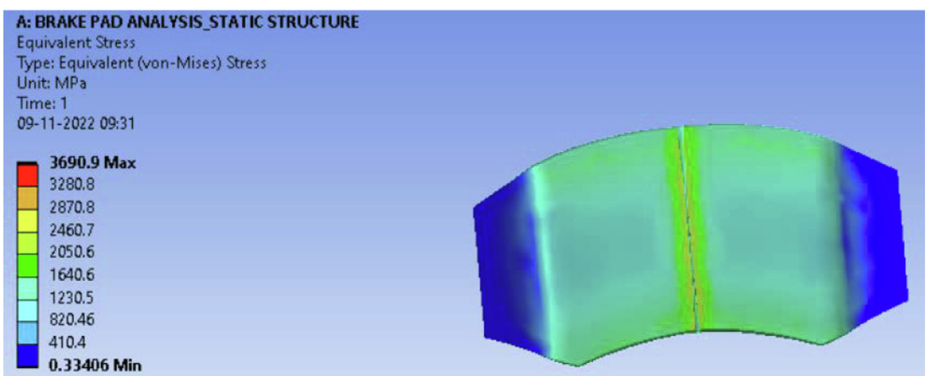


Fig. 6.2. Equivalent stress analysis of Abaca fiber.

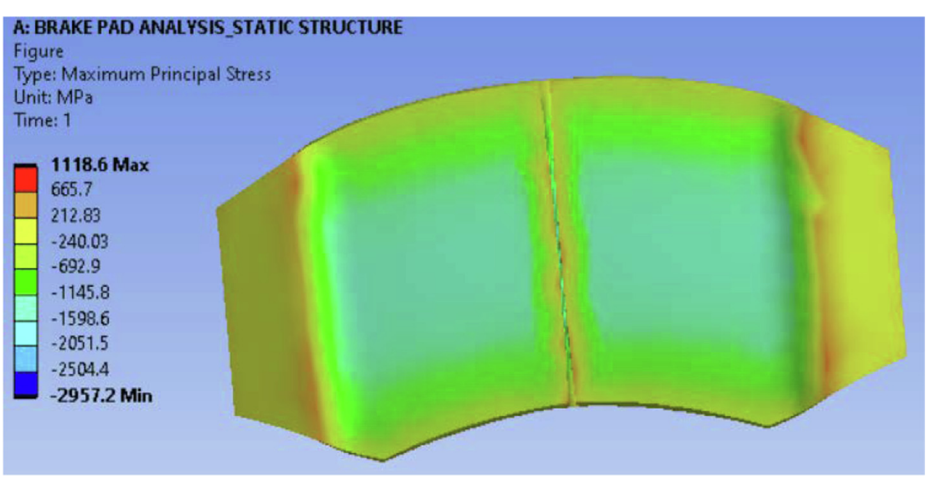


Fig. 6.3. Maximum principal stress for Abaca fiber.

just one brake pad through disc rotor has permitted. Each disc rotor could only have one brake pad applied during the simulation with the defined attributes from material properties. The contact settings set as frictional contact between pad and disc. Then, the disc rotor model's surface was set as the targeted surface, the brake pad model's front surface was set as the contact surface, and the coefficient of friction was applied in accordance with the material selected for the brake pad model. Then generate the mesh mod-

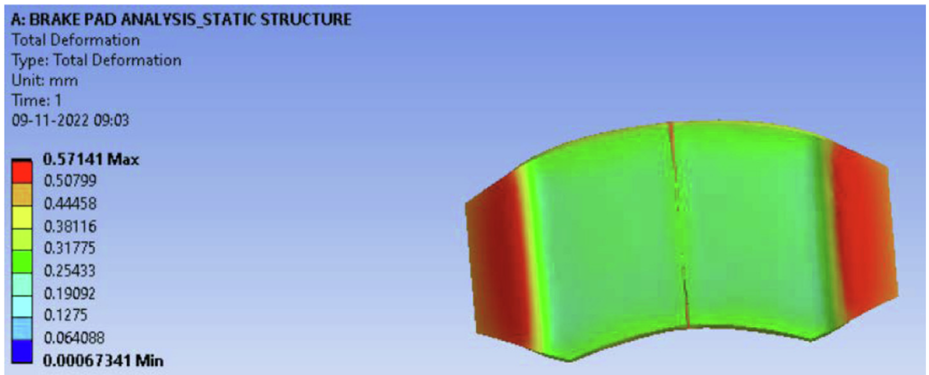


Fig. 7.1. Deformation analysis of Bagasse fiber.

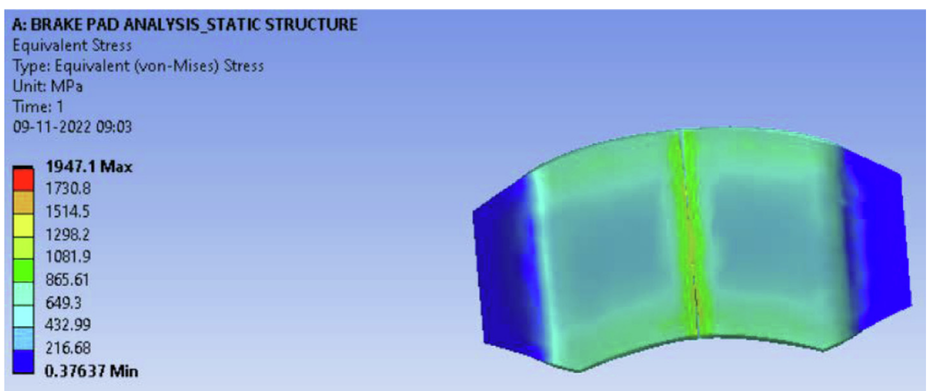


Fig. 7.2. Equivalent stress analysis of Bagasse fiber.

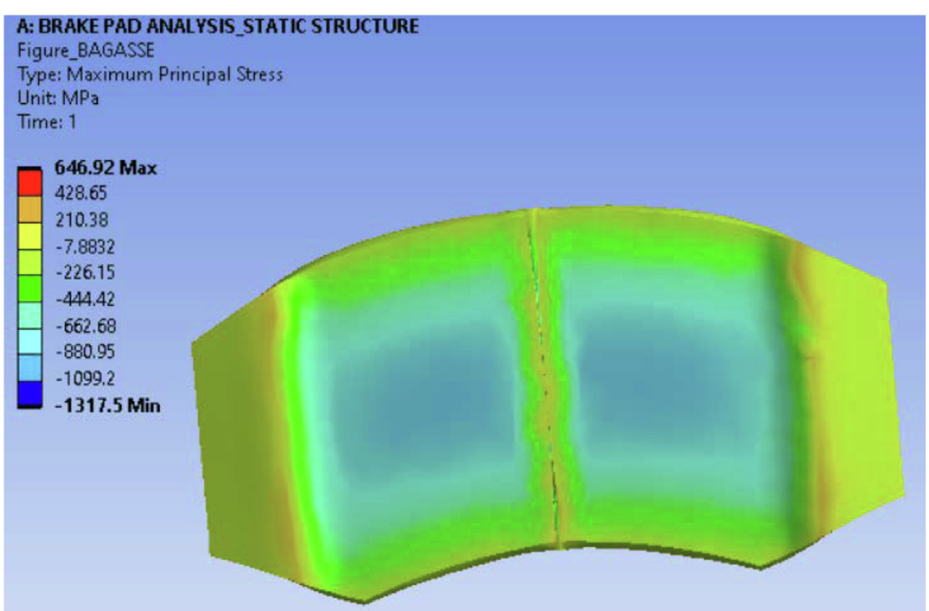


Fig. 7.3. Maximum principal stress for Bagasse fiber.

ules. The operating time was then set to one second and displacement of 0.2 mm was applied to the brake pad in a direction toward the disc rotor model. In order to get the simulation's desired results, namely the deformation and the maximum stress obtained by action.

7. Result and discussions

From Table 2, it is shown as deformation results s. The least requirement with the brake pad tends to occurs with minimum stress obtained and deformation occurs for each material.

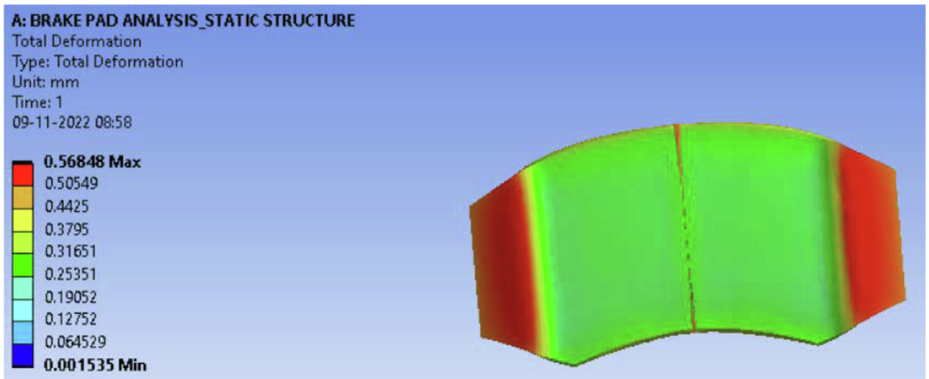


Fig. 8.1. Deformation analysis of Bamboo fiber.

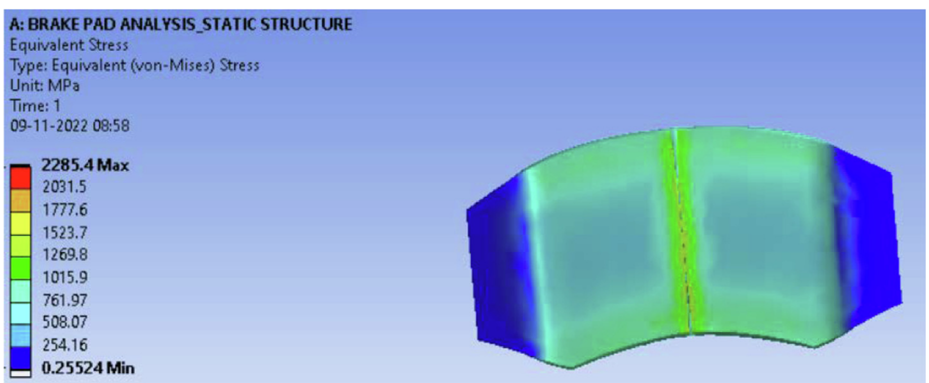


Fig. 8.2. Equivalent stress analysis of Bamboo fiber.

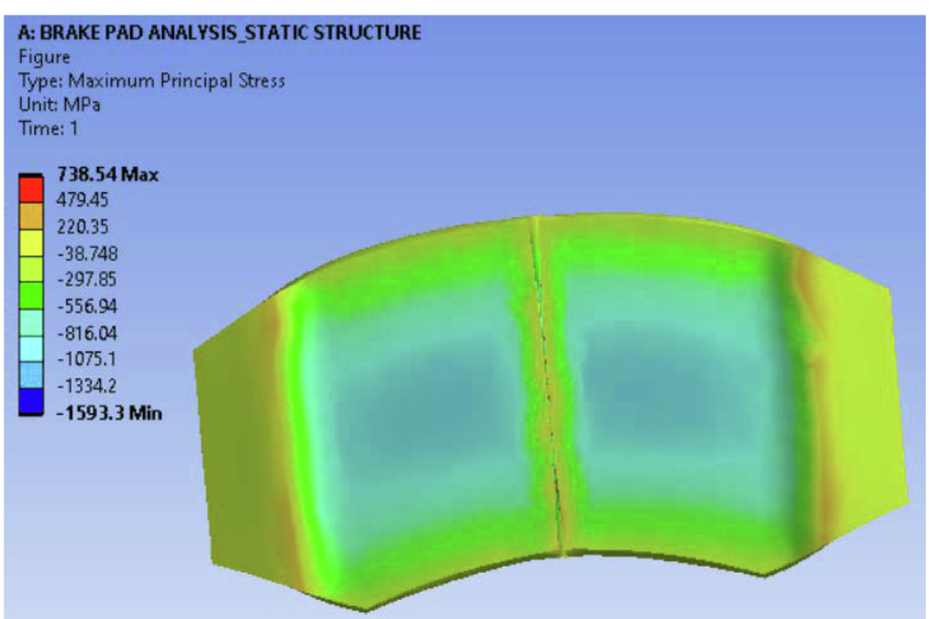


Fig. 8.3. Maximum principal stress for Bamboo fiber.

Table 2 describes the analytical values obtained from ANSYS simulation and its respective images which are shown in Figs. 6.1 to 20.3 as for different eco-friendly materials with respective to the boundary conditions applied for prediction in terms point stress, deformation and maximum stress values. In contrast to maximum primary stress, which is the real highest stress in the component fibres that are oriented toward the loading plane, equivalent stress refers to the theoretical average stress in the section of interest.

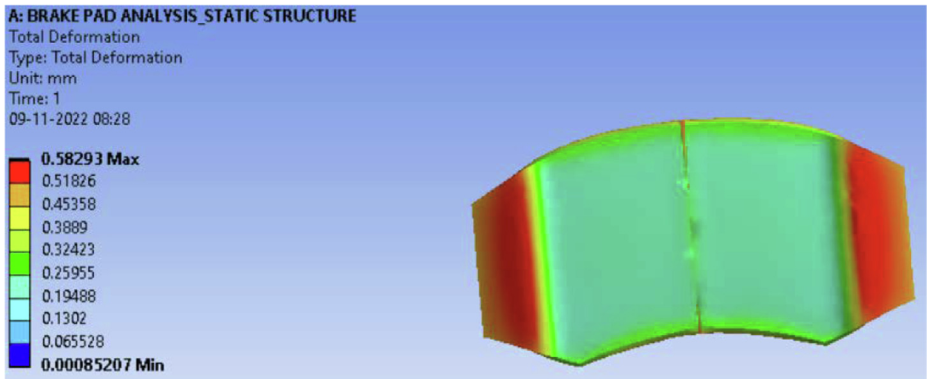


Fig. 9.1. Deformation analysis of Banana fiber.

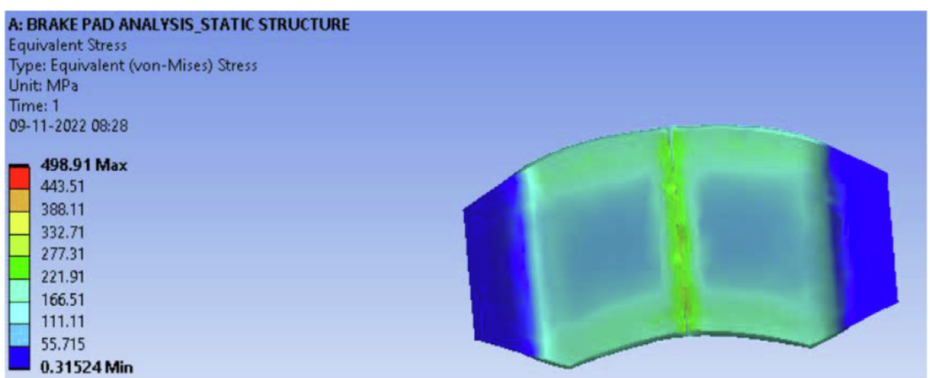


Fig. 9.2. Equivalent stress analysis of Banana fiber.

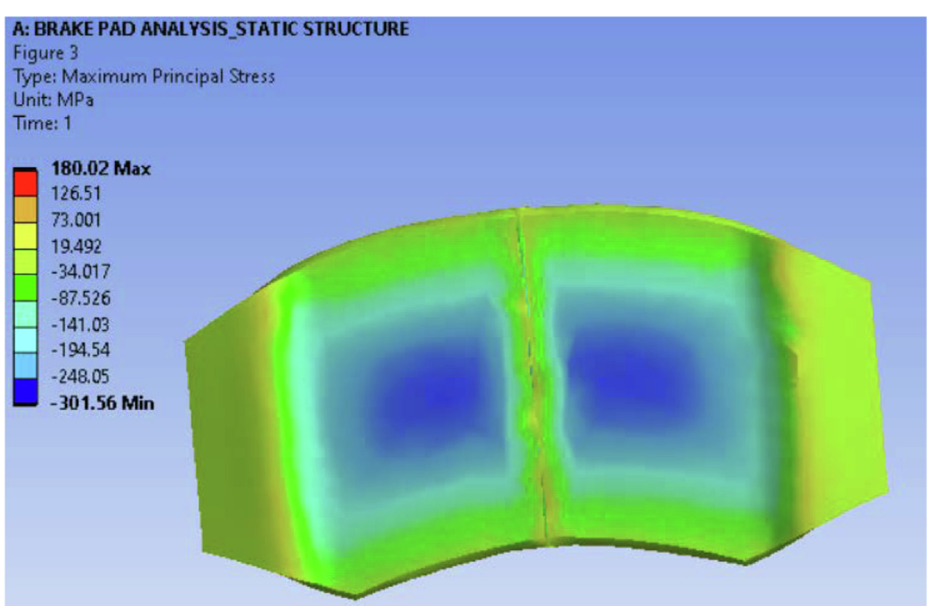


Fig 9.3. Maximum principal stress for Banana fiber.

The main difference between equivalent stress and maximum principal stress is that maximum principal stress is a point-specific value that indicates the highest stress at a specific location, while equivalent stress is a theoretical value that combines the effects of different stress components to assess overall stress in a component or material. While maximum principal stress tells us how much stress the object can experience and at what angle, equivalent stress takes into account the magnitudes and directions of the stresses in a component, and is often used to compare the overall stress state in different components or materials. Equivalent stress is a useful metric for comparing the stress levels in components that have different stress distribution patterns, whereas maximum principal stress is more useful for pinpointing critical locations where the material is most likely to fail.

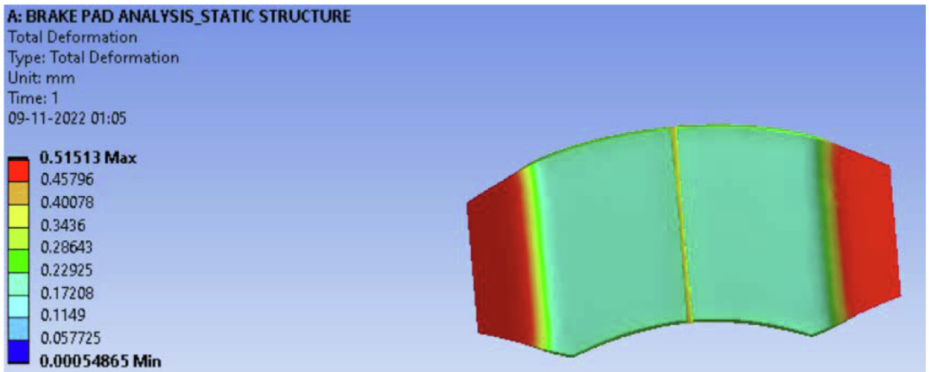


Fig. 10.1. Deformation analysis of Basalt fiber.

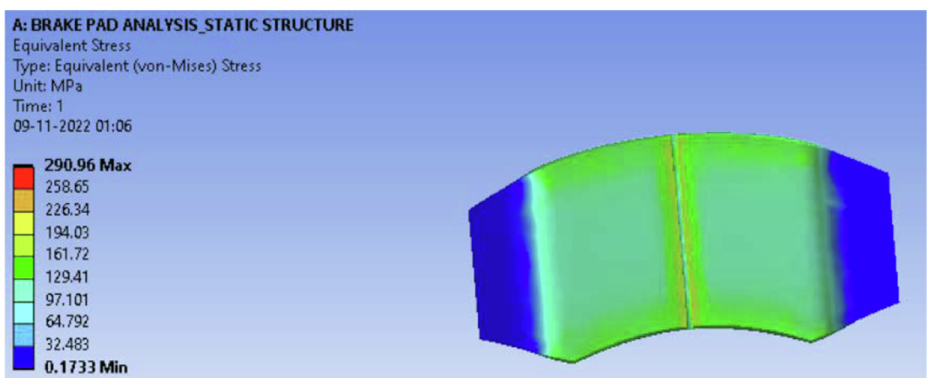


Fig. 10.2. Equivalent stress analysis of Basalt fiber.

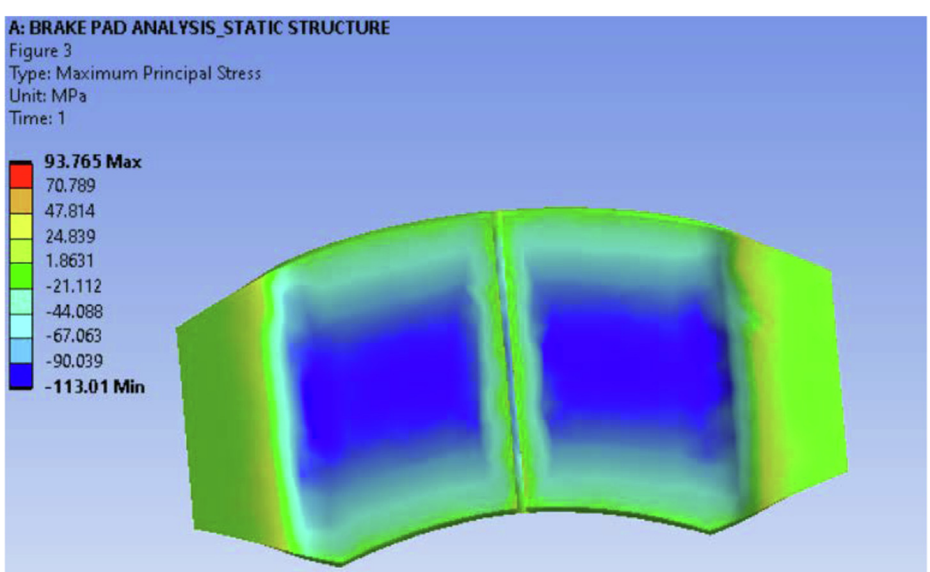


Fig. 10.3. Maximum principal stress for Basalt fiber.

The static structural condition results are obtained here with the force 45KN and thermal transient condition analysis would be a best selection to implement as a product profile. So from the results obtained,

The variation of friction coefficient with applied load was determined at a constant sliding velocity [12], frictional response under range of pressures [5] which can be described with the analysis of rotor presence. This study is about the load-applied constraints

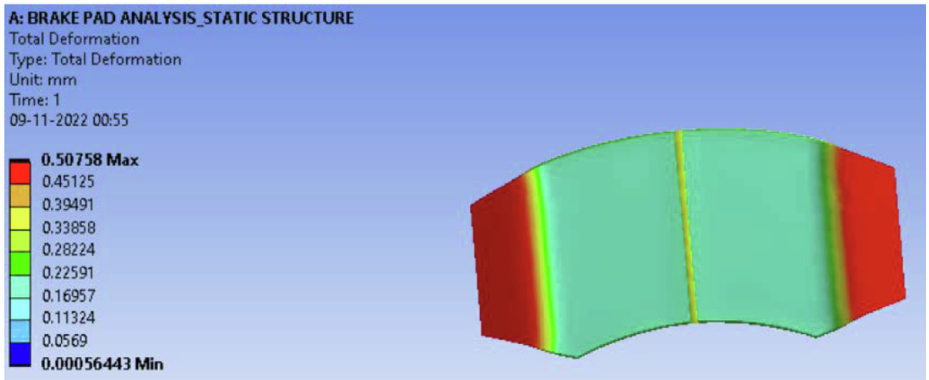


Fig. 11.1. Deformation analysis of Coconut coir fiber.

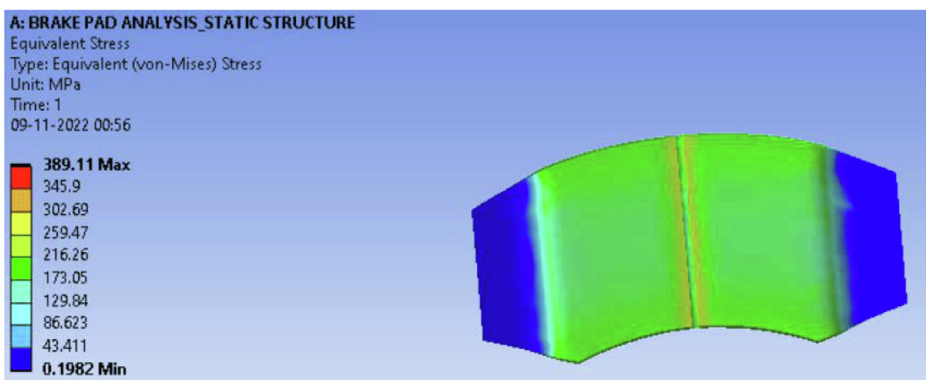


Fig. 11.2. Equivalent stress analysis of Coconut coir fiber.

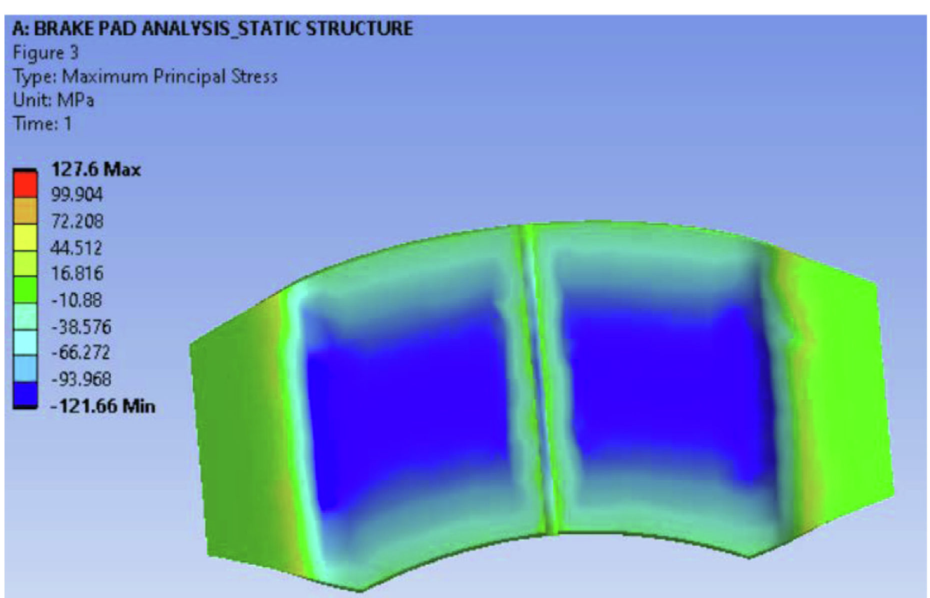


Fig. 11.3. Maximum principal stress for Coconut coir fiber.

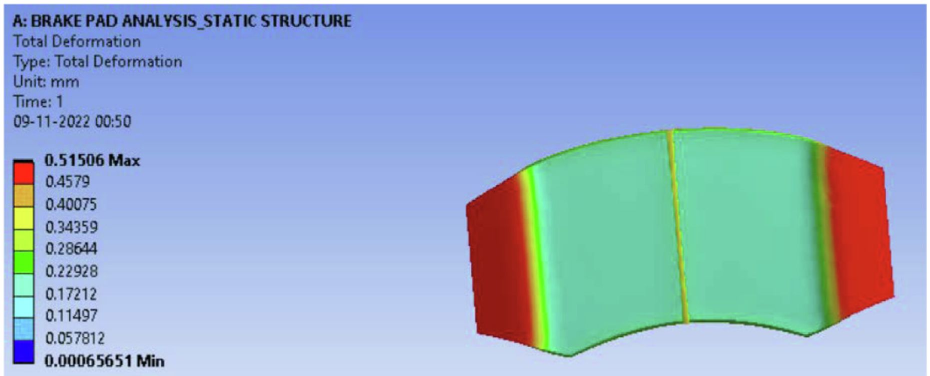


Fig. 12.1. Deformation analysis of Corn stalk fiber.

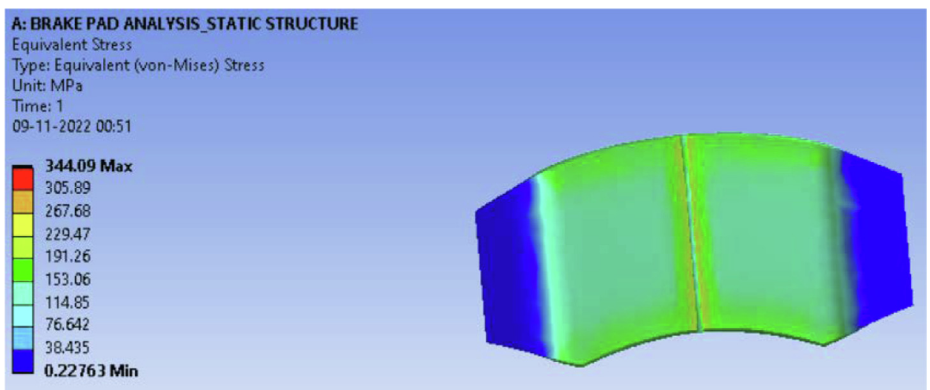


Fig. 12.2. Equivalent stress analysis of Corn stalk fiber.

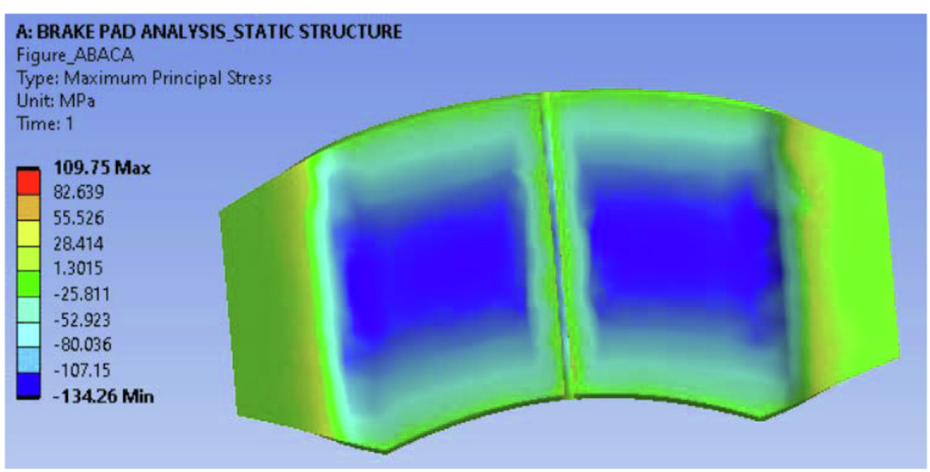


Fig. 12.3. Maximum principal stress for Corn stalk fiber.

only with respective to different fiber materials. The concept of implementing natural fiber products through various automobile components would make environment as non-waste economic background also. Different studies and experiments in various areas have also employed the use of Taguchi optimization [123] technique, S/N ratios, Variance analysis [124] to arrive at the best optimization parameters for their respective products. Some of the researchers explained about the coatings of surface treatment with composites [25,125] to improve frictional resistance, durability and other tribological parameters.

The aim is to identify materials that have higher friction coefficients [126] and lower wear rates to ensure longer-lasting, effective brake pads. The use of environmentally friendly materials is also being explored as an important consideration in modern brake pad design. All the results, which are conveyed through the prediction in ANSYS, makes a close value with each other. The influence of the mechanical and physical properties are correlated with the research study. Each fibers has the addition of fillers and coupling agent for improving tribological properties, but its not be sure whether is impact on environment or not. Those fibers are influ-

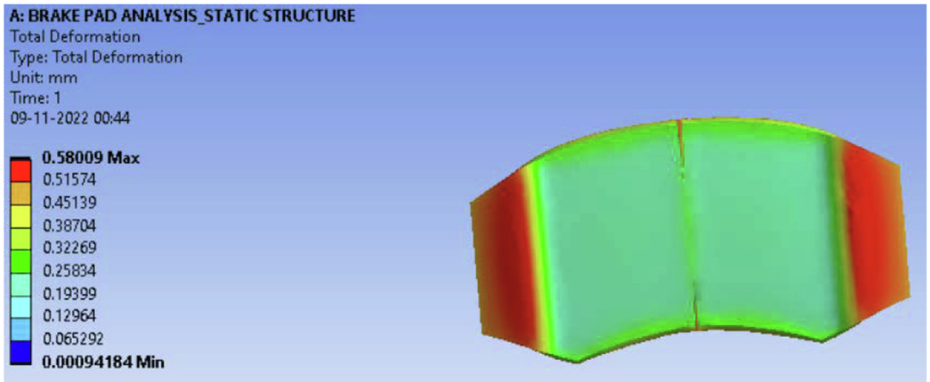


Fig. 13.1. Deformation analysis of Flax fiber.

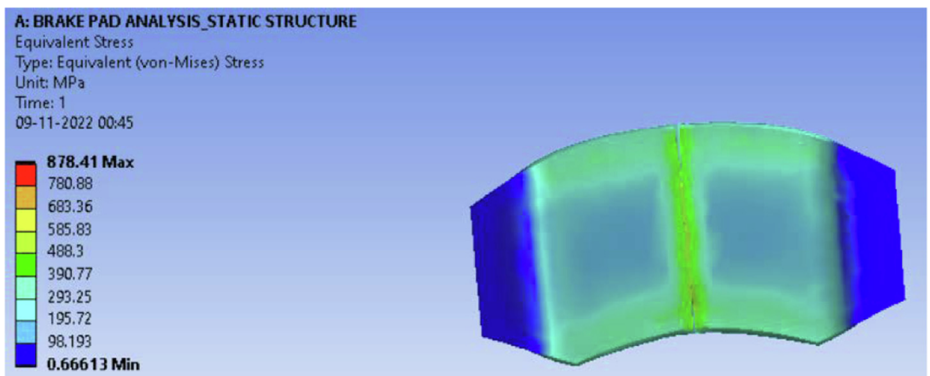


Fig. 13.2. Equivalent stress analysis of Flax fiber.

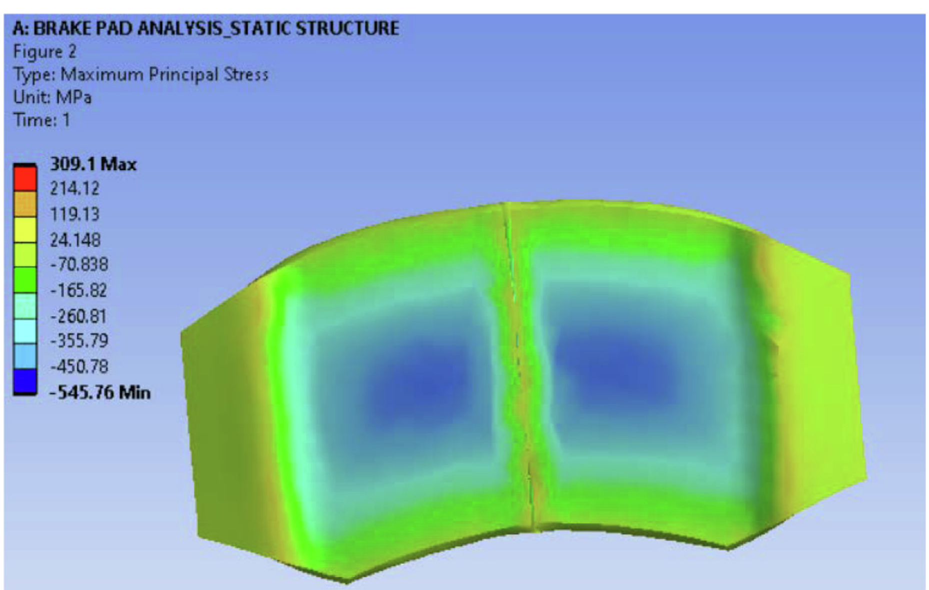


Fig. 13.3. Maximum principal stress for Flax fiber.

enced by epoxy resin and phenolic or poly lactic acid are not improvising as a eco-friendly material. To improve, the resin to be extracted from Agro wastes are added with the fibers.

The simulation results are based on the respective material reviews and its parameters. From the above graph results, Fig. 21 to Fig. 22 Fig. 23, it can be observed that six kind of

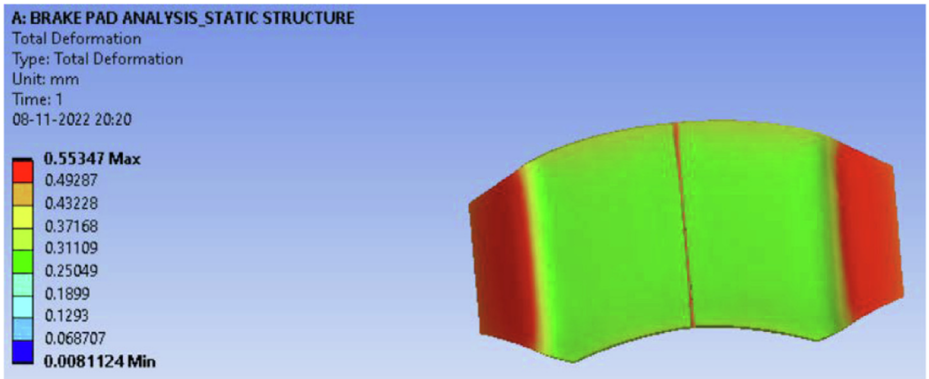


Fig. 14.1. Deformation analysis of Jute fiber.

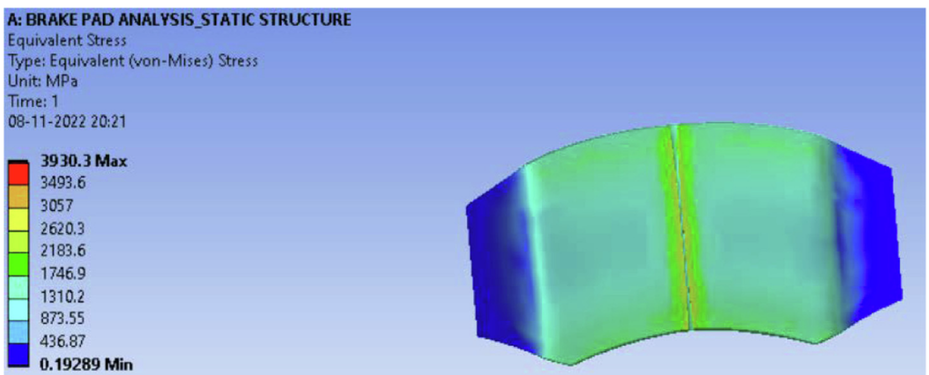


Fig. 14.2. Equivalent stress analysis of Jute fiber.

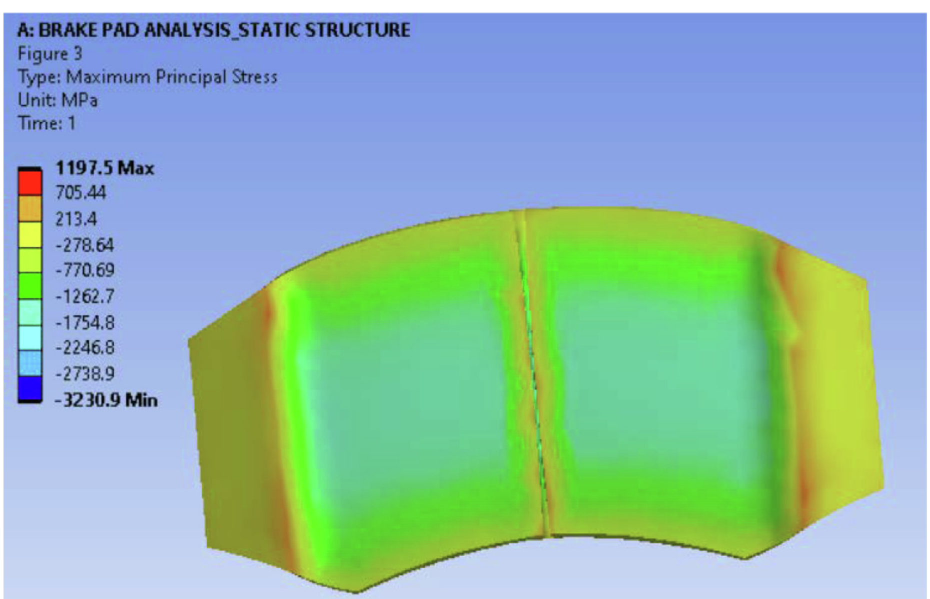


Fig 14.3. Maximum principal stress for Jute fiber.

natural fibers has the highest deformation namely banana fibers, flax fibers, Kapok fibers, oil palm fibers and pineapple fibers. Among the other fibers, Coconut coir fiber has the less deformation value, (Fig. 21) while comparing stress values, there is less stress obtained for basalt fiber and corn stalk fiber (Fig. 22 and Fig. 23). Also coconut fiber having little more deviation with coconut fiber. So it is preferable to select the Coconut coir as a brake-pad friction material.

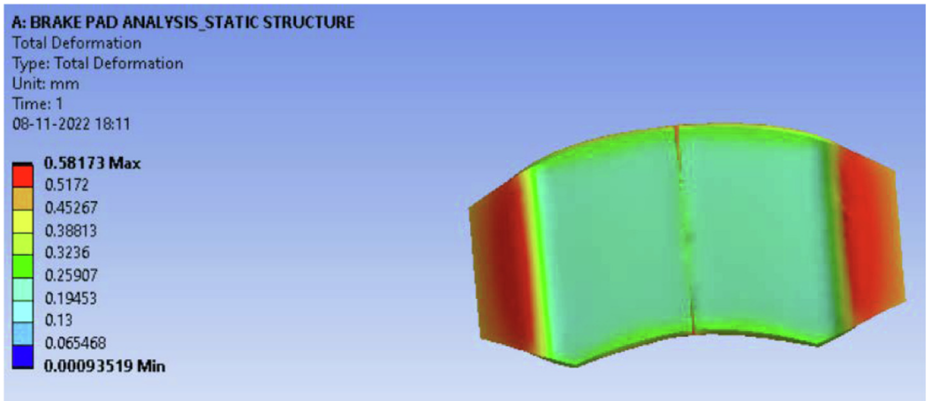


Fig. 15.1. Deformation analysis of Kapok fiber.

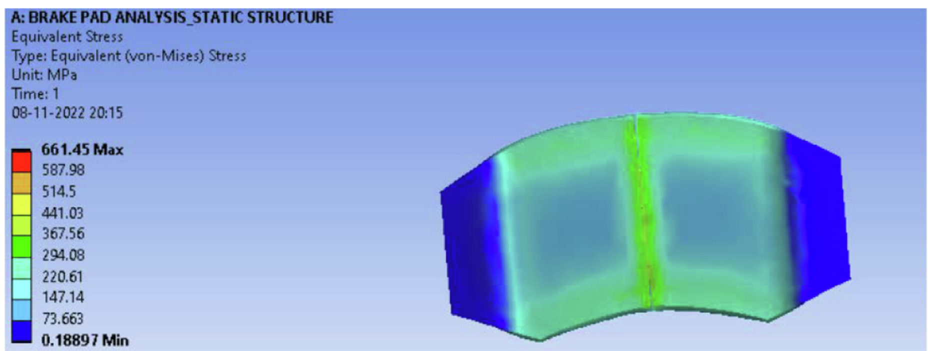


Fig. 15.2. Equivalent stress analysis of Kapok fiber.

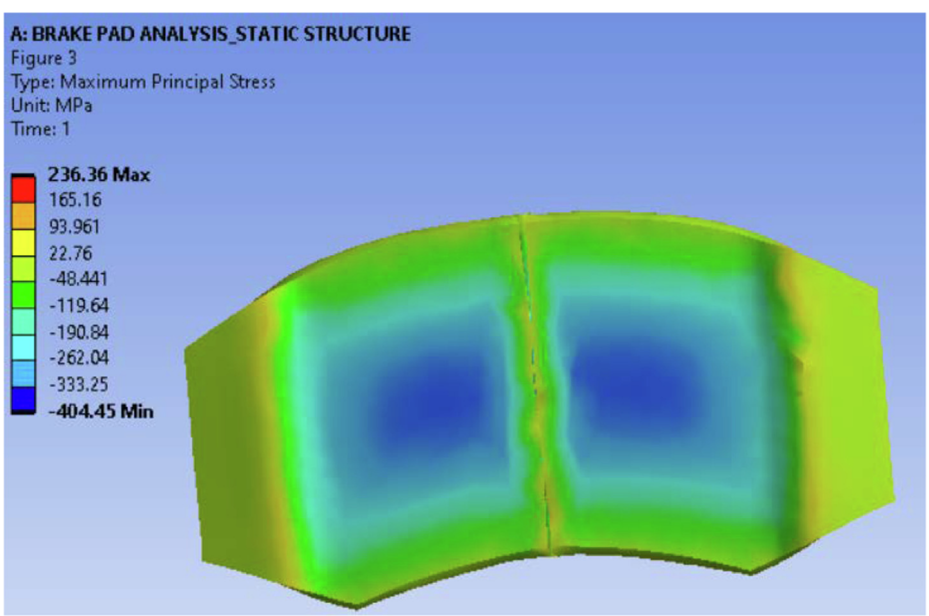


Fig. 15.3. Maximum principal stress for Kapok fiber.

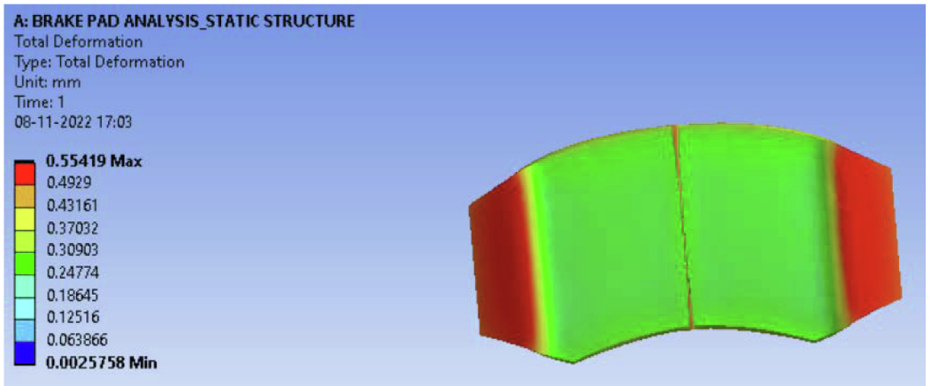


Fig. 16.1. Deformation analysis of Kenaf fiber.

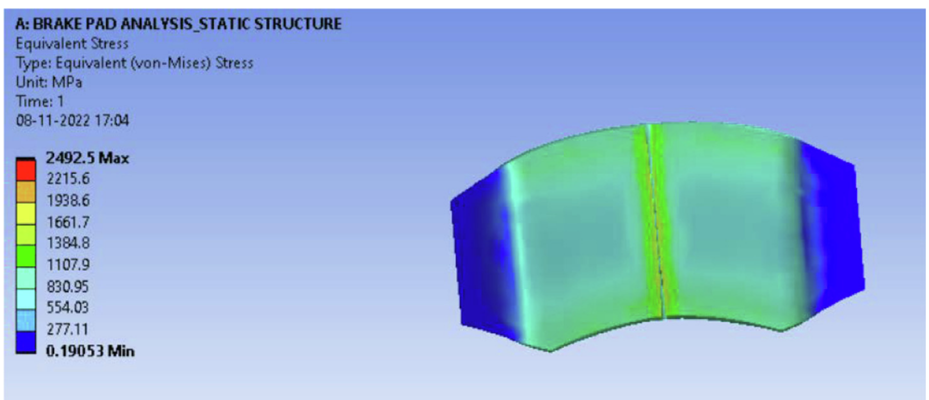


Fig. 16.2. Equivalent stress analysis of Kenaf fiber.

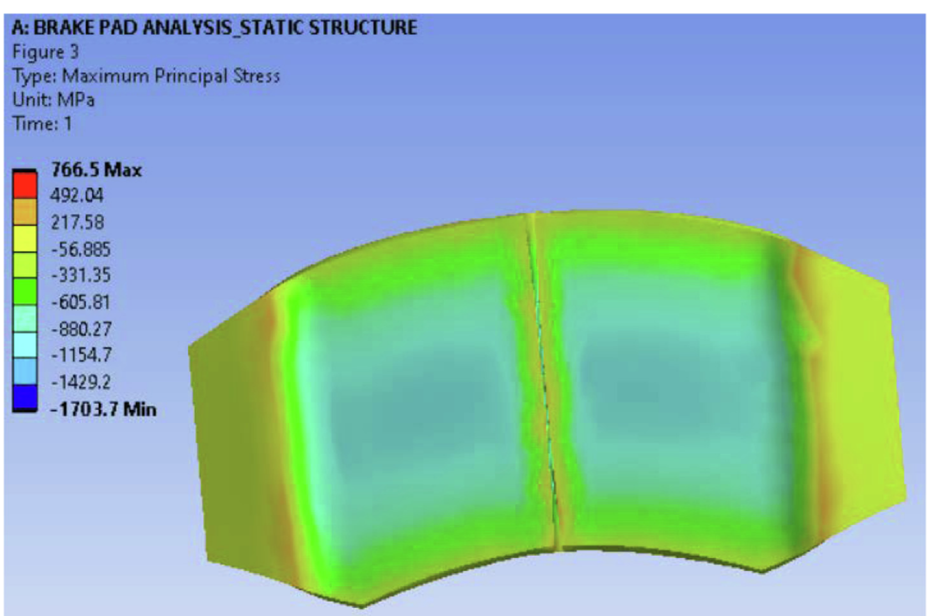


Fig 16.3. Maximum principal stress for Kenaf fiber.

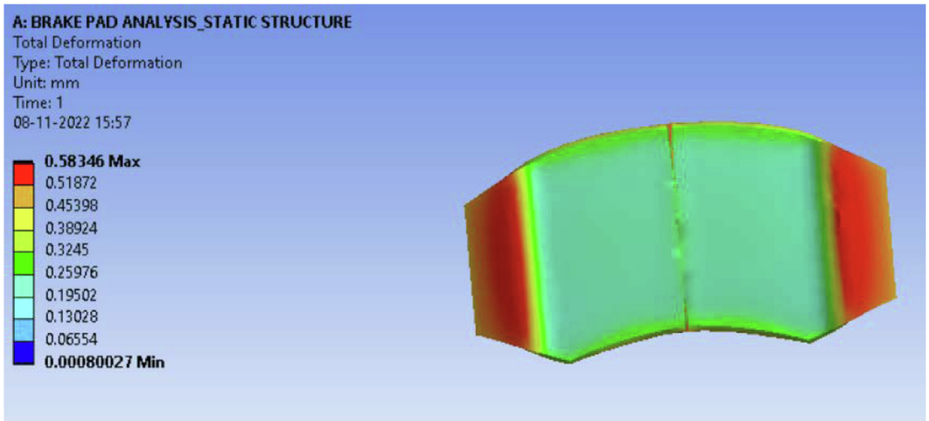


Fig. 17.1. Deformation analysis of Oil Palm fiber.

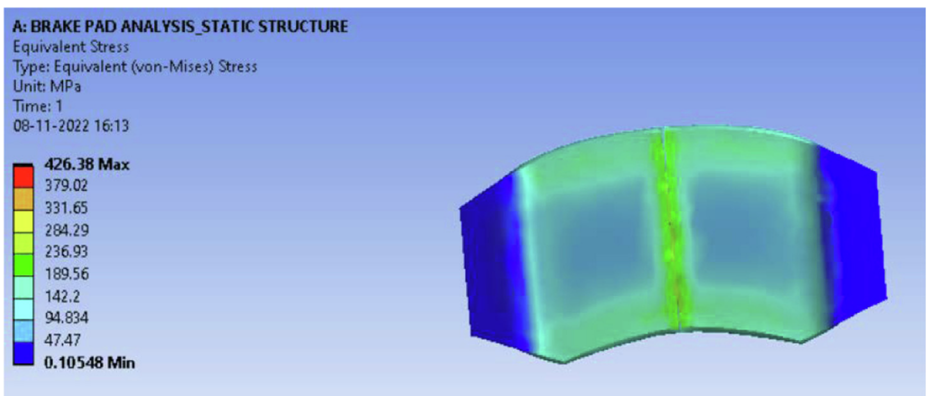


Fig. 17.2. Equivalent stress analysis of Oil Palm fiber.

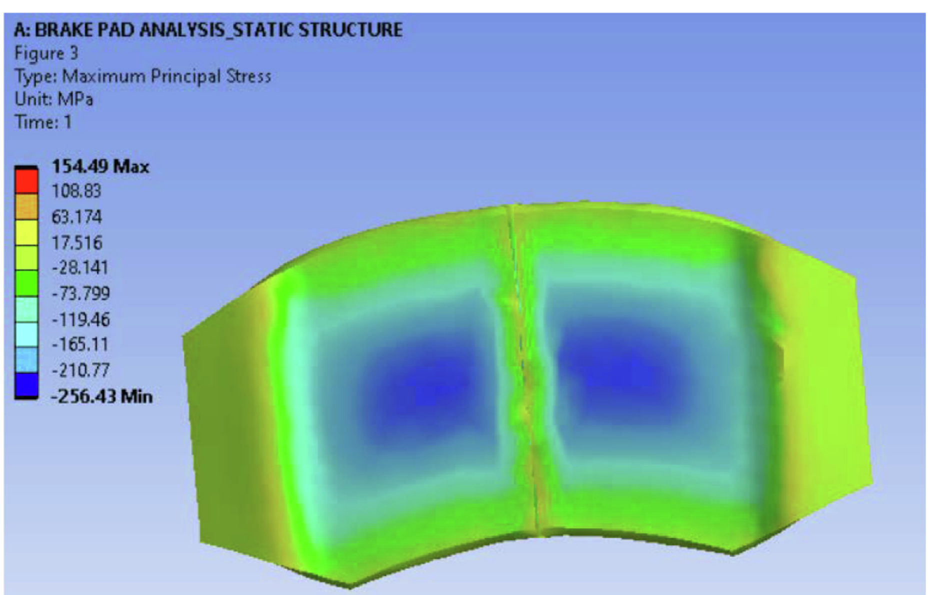


Fig. 17.3. Maximum principal stress for Oil Palm fiber.

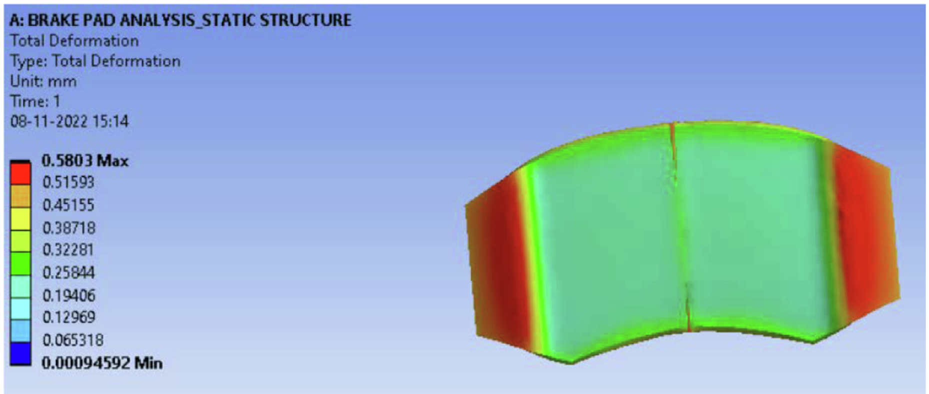


Fig. 18.1. Deformation analysis of Pineapple fiber.

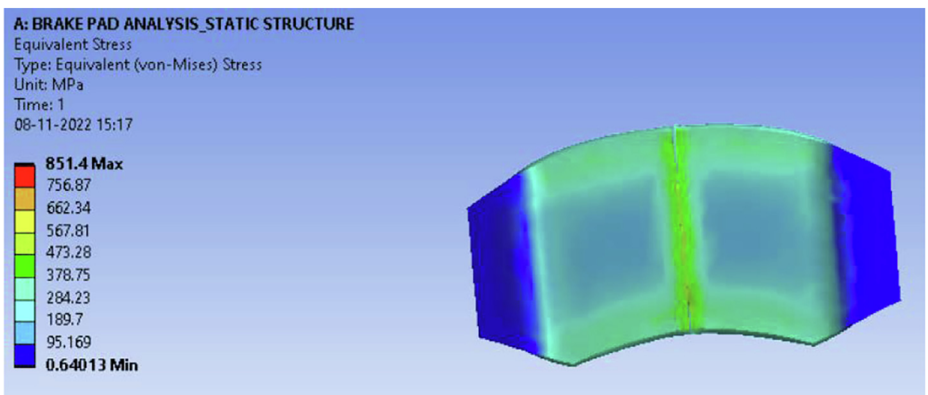


Fig. 18.2. Equivalent stress analysis of Pineapple fiber.

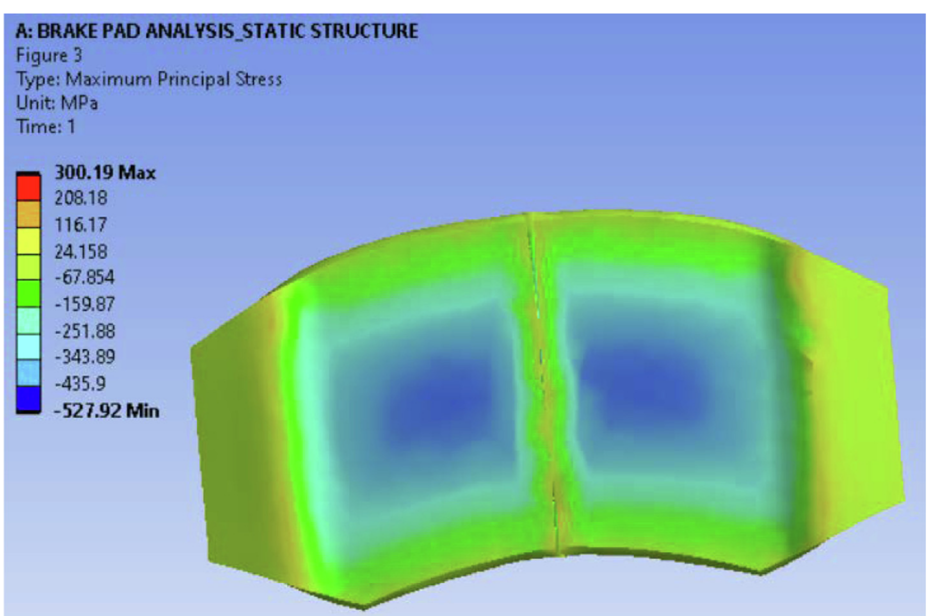


Fig. 18.3. Maximum principal stress for Pineapple fiber.

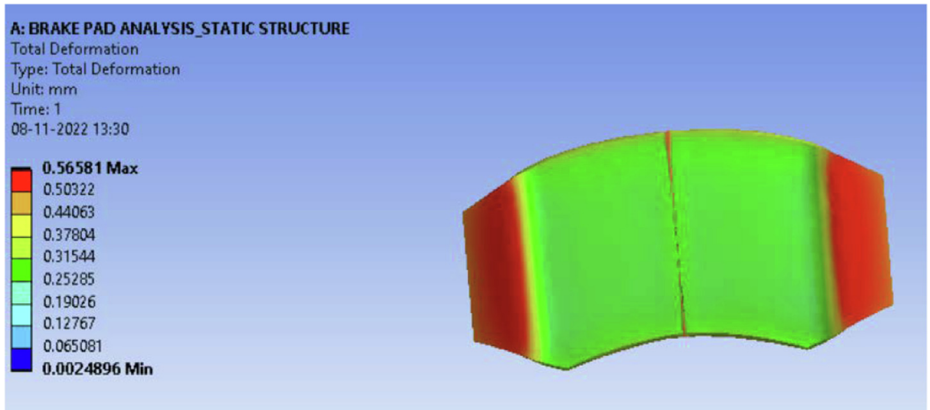


Fig. 19.1. Deformation analysis of Rice straw fiber.

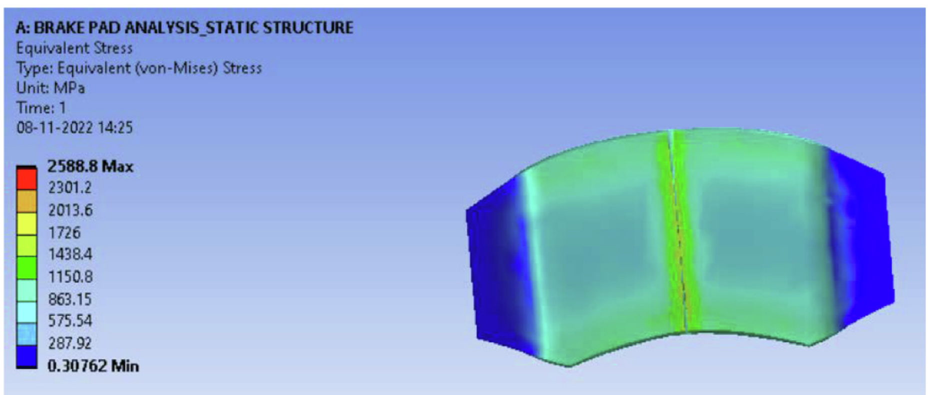


Fig. 19.2. Equivalent stress analysis of Rice straw fiber.

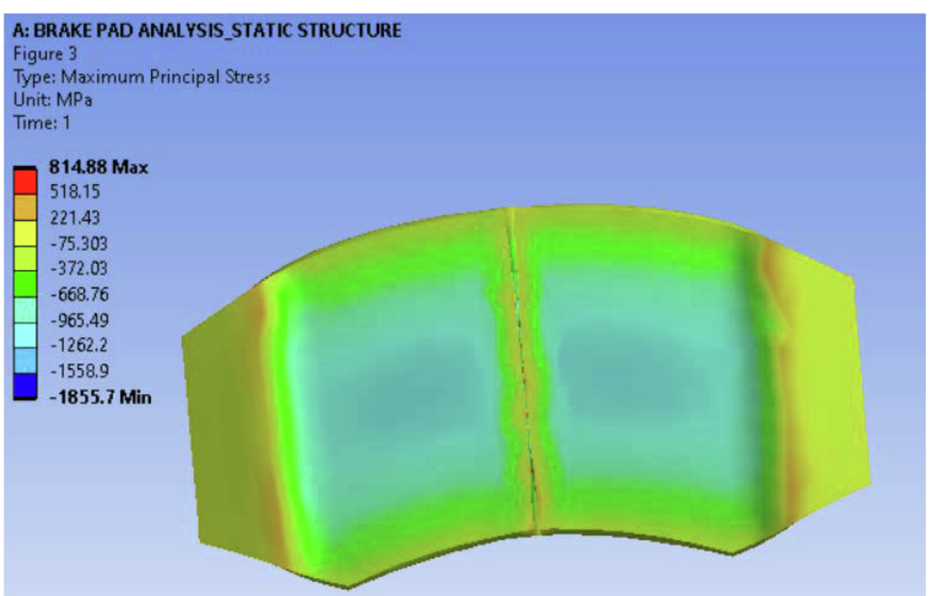


Fig. 19.3. Maximum principal stress for Rice straw fiber.

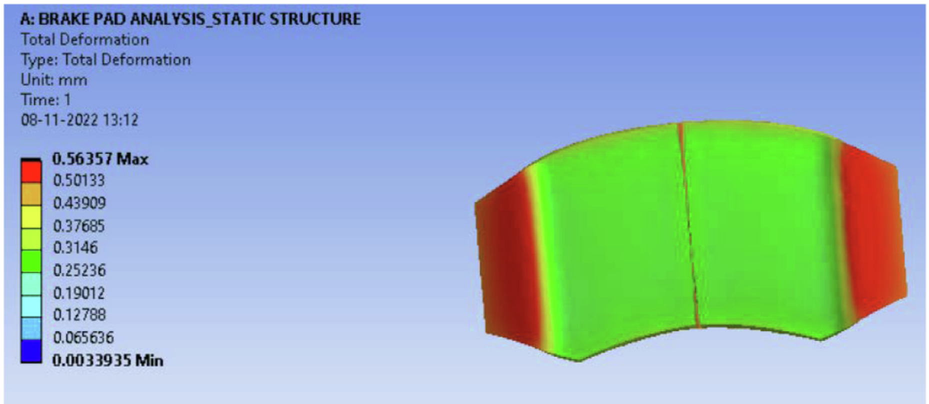


Fig. 20.1. Deformation analysis of Sisal fiber.

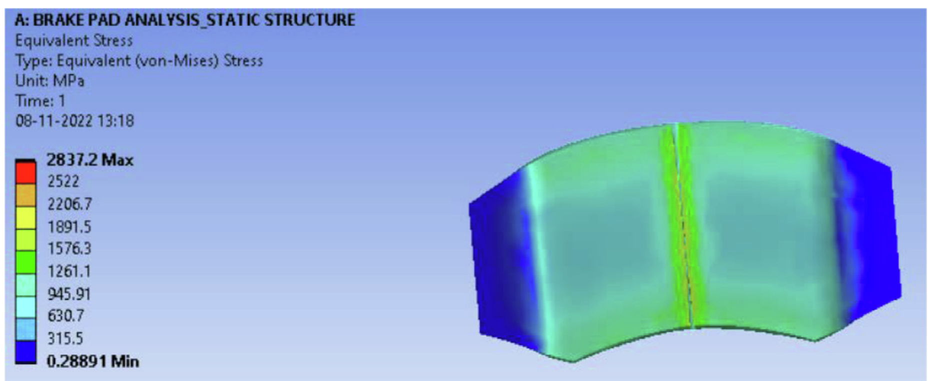


Fig. 20.2. Equivalent stress analysis of Sisal fiber.

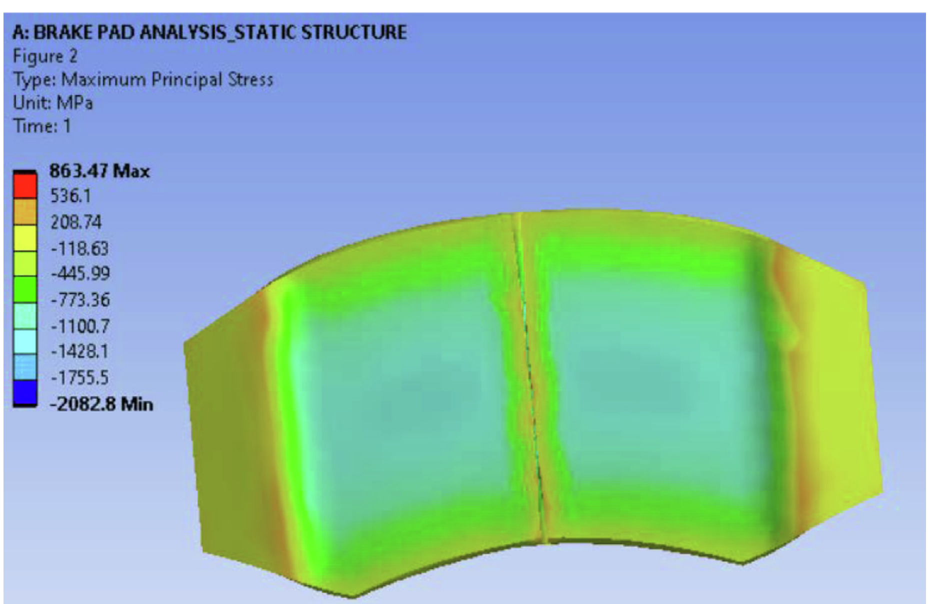


Fig. 20.3. Maximum principal stress for Sisal fiber.

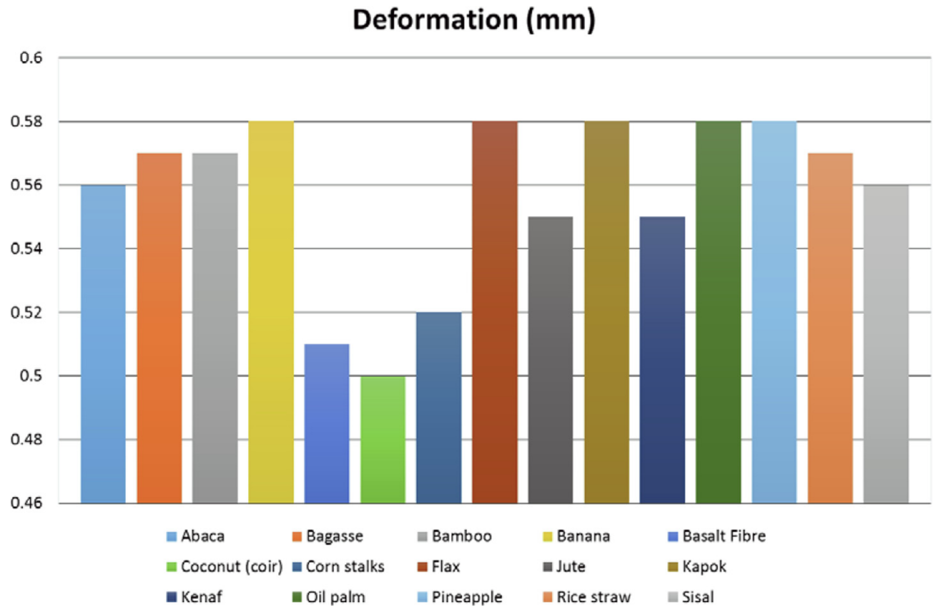


Fig. 21. Deformation vs Materials.

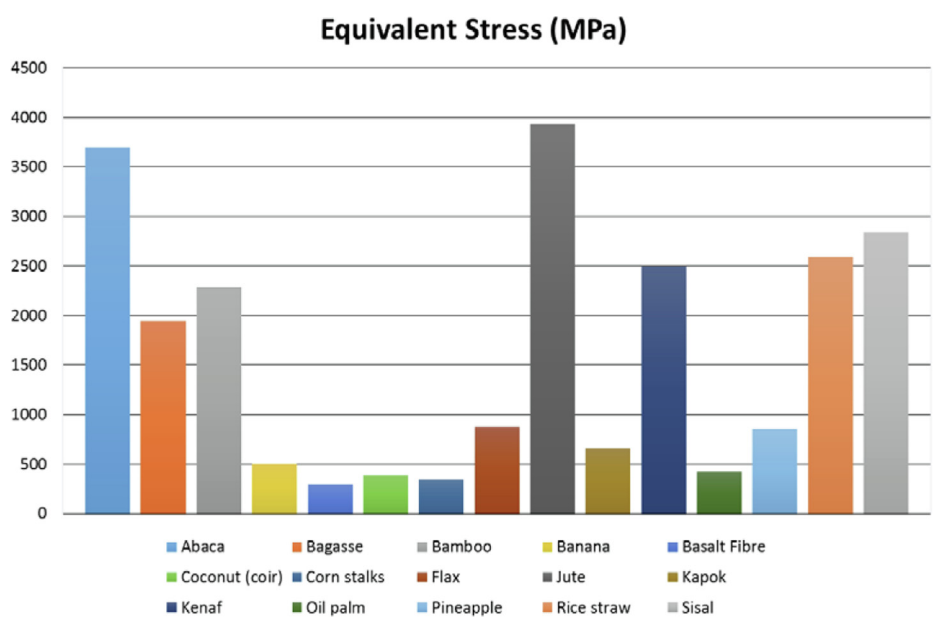


Fig. 22. Equivalent stress vs Materials.

8. Conclusion

The results discussed based on the analytical and simulation graph, as this method is a prediction process, it cannot be concluded with the automated results. By continuing the analysis to real time part level prediction, addition of coupling agents [73] to bonding between fiber ingredients. Also, the temperature of those natural fibers with maximum ultimate disintegration and many agro wastes [127] used in the production of brakepads. The involvement of tribological phenomena related to the improvement of various aspects of the results to be tested for performance, safety, and stability [1]. The testing of thickness swelling [128] in water is also an important parameter to conclude material in wet condition. The other important tribological parameters are conducted and proven through physical test of natural fibers in respective experimental setups [129]. The nature and properties of these tribo-reactions is important for developing more efficient and durable brake systems. Several studies to be investigated the based on the above parameters to find out the effects of tribo-reactions [130] on brake pad materials, and may have proposed strategies for improving the performance and durability of brake systems. Based on the search results, it appears that wear testing can be an important factor in selecting brake materials and components. Conducting various physical and friction-wear tests [Blau] can help determine the appropriate material for brake pads and other components. Additionally, it appears that there are different types of wear (e.g. erosive, abrasive) and mechanisms of wear depending on the materials involved. Therefore, it is important for manufacturers and mechanics to consider the specific types of wear a braking system may encounter and select materials

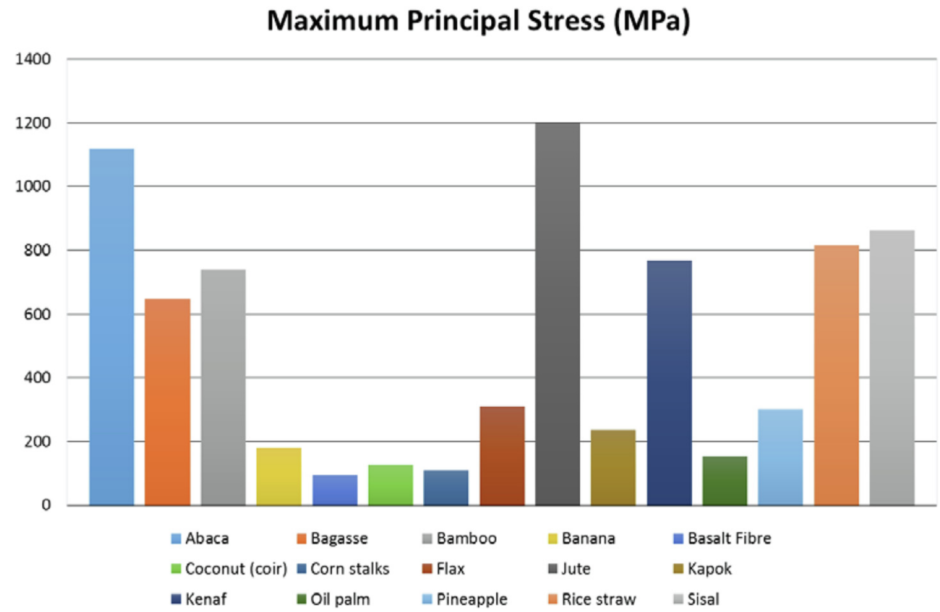


Fig. 23. Maximum stress vs Materials.

and components accordingly. Regular maintenance and inspection of braking components is also recommended to ensure their continued reliability and proper function.

Data availability

The data that has been used is confidential.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: M. Sunil Kumar Hemanth reports equipment, drugs, or supplies and writing assistance were provided by Noorul Islam Centre For Higher Education.

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