

An Insight on the Influence of Fiber Content on Plant Fiber Reinforced Brake Pads.

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Abstract-

The concept of bio-brakes has gained popularity in a short period due its potential to replace conventional brake material. Metal and mineral fibers used in a conventional brake pads contributes a major share in non-exhaust brake wear debris and pollution causing fatal health issues. Replacement of metal and mineral fibers with potential candidate plant fiber can reduce hazardous pollution. In order to increase the use of the plant fiber in brake pads, specific behavior and effects of their individual properties and characteristics must be studied. This article summarizes the observations of the effect of plant fiber content on the performance and properties of the plant fiber reinforced brake pads and also the influence of various treatments and manufacturing process on them.

Keywords- *Plant fibers reinforced brake pads; Fiber content; Friction and wear; Tribological Properties; Mechanical Properties, Treatments.*

I. INTRODUCTION

In 1979, a ban was imposed on the use of asbestos in many countries due to its carcinogenic nature [1], [2]. Brake pad was one of the major applications where asbestos was a primary ingredient. This ban initiated an extensive research trend for finding alternative material for the replacement of asbestos. Many new types of brake pads were later invented. New generation brakes pads are primarily reinforced with metal fibers. It is reported that metallic fibers and minerals fiber used as reinforcement material in modern brake pads contribute a major share in non-exhaust particulate matter (PM) pollution [3]–[5]. The effects of the brake wear debris on human health have been briefly reported earlier [6]–[12]. To avoid fatal pollution, these reinforcement material has to be replaced with eligible nonpolluting fibers. The effects of the brake wear debris on human health have been briefly reported earlier [6]–[12]. This lacuna initiated a major trend among researchers for the application of natural fiber composites (NFC) in friction material.

Researchers have reported many candidate brake pad compositions till now [2], [13]–[24], where bio-products were used as an ingredient to reduce the use of potential pollutant ingredient in brake pad composition. Bio-products are primarily being used as filler materials. Since conventional reinforcement material has potential pollutant nature, replacement of the metallic and mineral fiber with plant fiber could significantly reduce the emission of hazardous brake wear debris. Many studies have proved the candidature eligibility of the plant fibers as reinforcement material. This article summarizes

the observations and effects of the plant fiber content on the mechanical and tribological properties of the proposed brake pad composition.

II. EFFECT OF THE PLANT FIBER CONTENT ON BRAKE PAD STRUCTURE

As reported in many studies [2], [13]–[24][25]–[32], friction samples exhibiting better friction properties, also exhibit better mechanical properties. It makes evident that structural integrity and adhesion between ingredients are the key factors that simultaneously affect tribological as well as mechanical properties. The specific amount of the plant fibers as a reinforcement improves friction and wear performance [28], [33] (Table 1). Plant fiber to binder ratio significantly affects the structural integrity of the brake pad. When natural fiber to binder ratio exceeds optimum ratio, then fiber doesn't have enough binder to bind substrate together, moreover when plant fiber to binder ratio is less than optimum ratio, there are not enough fibers to reinforce the friction composite, in both cases, brake pad structure ultimately loses its binding power and in turn loses its performance, when subjected to the high temperature. Optimum plant fiber content varies for every friction composition as it can be observed in table 1. Accumulation of the excessive resin on the surface is undesirable since excessive use of binder is hazardous and carcinogenic [34], [35], also binder allows easy abrasion of the matrix, which in turn results in poor interfacial bonding between reinforcement fibers, matrices, and binders. Since the proportion of all ingredients matters in braking performance [26], [36]–[38]. In order to increase the content of plant fiber, plant fiber to binder ratio is desirable to be always greater than unity, as achieved by Xin et. al. [30] with sisal fibers, There is no accurate model exist to predict the properties and performance of plant fiber-based brake pad before experimentation. Finding out the share of each property and characteristic of the fiber in brake pad composition is still a challenge.

Table 1: Compositions of Plant fiber-reinforced brake pads.

Friction composition	Other ingredients	Samples with varying fiber content	Optimum natural fiber content	Binder Content	Fiber to binder ratio	Reference
Pineapple fiber	Phenolic Resin 10%, Lapinus fiber 20%, Alumina 5%, Graphite 5%, Vermiculite 5%, Barium Sulphate (Balance)	5,10,15,20 (wt.%)	5 wt.%	10 wt.%	1:2	[39]
Banana fiber/ Phenolic Resin	Phenolic resin(balance), Graphite (10%), Ca (OH)2(6%), CaCO3 (10%), Al2O3 (2%), MoS2 (2.6%), Sb2S3(2%), MgO (3%), SiC (3.4%), Steel wool (12%), PAN fiber (12%)	0,7,14,21 (wt.%)	7 wt.%	28 wt.%	1:4	[26]
Hemp fiber/ Phenolic Resin	Phenolic Resin 10%, Lapinus fiber 20%, Alumina 5%, Graphite 5%, Vermiculite 5%, Barium Sulphate (Balance)	5,10,15,20 (wt.%)	5 wt.%	10 wt.%	1:2	[40]
Coconut Fiber/ Phenolic Resin	Aluminium (20%, 15%), Graphite 5%, Zirconia Oxide 2%, Titan Oxide 11%, Phenolic Resin 40%, Hexamethyle-Tetramine 6%	5,10 (%)	10 %	40 %	1:4	[41]
Pine needle/ Phenolic Resin	Compound mineral fiber, phenolic resin, vermiculite, porous iron powder, BaSO4, Petroleum Coke, Artificial Graphite, Alumina, Antimony sulphide, Friction powder, Carbon black (All ingredients are in balance with pine needle fiber)	0,3,5,7,9 (wt.%)	7 wt.%	14 wt.%	1:2	[42]
Coir Fiber/ Phenolic Resin	Aluminium (Balance), Silicon Carbide (20%), Graphite (10%), Aluminium	0,5,10,15,20 (wt.%)	5 wt.%	10 wt.%	1:2	[32]

	Oxide (13%), Zirconium oxide (2 %), Paper Ash (Balance), Resin (10%)					
Bamboo Fiber/ Phenolic Resin	composite mineral fiber, phenolic resin, vermiculite powder, foam iron, BaSO ₄ , Petroleum coke, Graphite, Al ₂ O ₃ , Sb ₂ S ₃ , Friction powder, Zinc stearate, Carbon Black, Glass Fiber	0,3,6,9,12 (wt.%)	3 wt.%	12.62 wt.%	1:4.2	[37]
Jute Fiber (JH)/ Phenolic Resin	Wollastonite, Basalt fiber, Zircon, Baryte, Vermiculite, Graphite, Hazelnut shells, Phenolic Resin (All ingredients are in balance)	0,5.6,9,14.6,23.6 (vol.%)	5.6 vol%	20.2 vol%	1:3.6	[38]
Flax Fiber/Phenolic Resin	Wollastonite, Basalt fibers, Zircon, Baryte, Vermiculite, Natural graphite, Phenolic Resin, Cardanol based benzoxazine (All ingredients are in balance)	0,5.6, 9, 14.6, 23.6 (vol.%)	5.6 vol%	14.6 vol%	1:2.6	[43]
Sisal Fiber/ Phenolic Resin	Phenolic resin powder (15%), Copper (10%), Barite (15%), Felspar (10%), ZnO (3%), Friction Powder (5%), Sb ₂ S ₃ (2%), Clay (Balance)	10,15,20,25,30 (wt.%)	20 wt.%	15 wt.%	4:3	[36]

III. EFFECT OF PLANT FIBER CONTENT ON FRICTION AND WEAR

Since friction and wear are the system responses [44], they are sensitive to several factors including mechanical properties, manufacturing processes, and parameters. The stability of the friction coefficient is always preferred over high magnitude fluctuations of friction coefficient. The candidate friction sample is selected based on the stability of the friction coefficient and wear rate. As it can be observed that, majority of the brake samples follows friction influence laws stated by Öztürk et al. [45]. Though the majority of the studies reported an increment in wear rate with the increase in fiber content, many are studies exhibit little deviation to this statement as shown in Table 2. Similarly, thermal degradation of the plant fiber significantly affects friction properties [37], [38], [40].

Table 2: Tribological Properties of the plant fiber-reinforced brake pads.

Fiber /Binder	Tribological Test/ Standard	Testing Machine	Friction Coefficient	Wear	Unit for wear rate	Ref.
Pineapple fiber/ Phenolic Resin	IS 2742 standard	Chase Machine	PF- 1 (5% PF) showed most stable coefficient (0.4-0.6), followed by PF -2 (10% PF), PF- 3 (15 % PF), PF-4 (20% PF).	Wear of composition increases with an increase in fiber content. PF-1 (5 wt.%) exhibited least (.0035) specific wear and PF-4 (20 wt.%) exhibited highest (\approx .006) wear rate	cm ³ /(N-m)	[39]
Banana fiber/ Phenolic Resin	NA	Pin-on-disc tribometer	NA	Wear of composition increases with increase in fiber content BP-0(0.0039) showed least wear followed by BP-	g	[26]

				7(.0060) <BP-14(0.0106) < BP-21 (.0129)		
Hemp fiber/ Phenolic Resin	IS2742 Part- 4	Chase Machine	FH- 1 (5% Hemp) showed a most stable coefficient of the friction followed by FH -2 (10% Hemp), FH- 3 (15 % Hemp), FH-4 (20% Hemp). COF ranged between 0.544 (5% Hemp)-0.512 (20% Hemp)	Wear of composition increases with an increase in fiber content. FH-1 showed the least wear (1.08 g) where FH-4 showed the highest wear (1.69 g).	g	[40]
Coconut Fiber/ Phenolic Resin	ASTM A 159	NA	C2 composition exhibited a very stable μ profile (between 0.39-0.50) across the range of pressing force followed by C1 (5% fiber content) between 0.30-0.43.	C2 (10% fiber) composition showed the least and stable wear rate (between 0.07-0.03 gm) across the range of pressing force. C1 showed a relatively wear rate (0.19 to 0.13 gm).	g	[41]
PALF Fibers/	NA	Pin- on disc test. EN31 pin type.	NA	Wear rate increases as fiber content increases, 5% PALF fiber composition showed the least wear rate (between 2-3 mg/m). The highest wear rate was shown of 30% PALF composition (between 4-5 mg/m).	mg/m	[29]
Pine needle/ Phenolic Resin	GB5763- 2008 Chinese national standard	JF 150D-II tester	FC-0 showed the highest and stable μ ranging between 0.33-0.44. Following FC-0, FC-3 showed the second-highest but fluctuating μ . FC-5 showed the most stable μ profile with a relatively low rangeability of μ .	FC-7 showed the least wear rate even at high temperature, whereas FC-3 showed the highest wear rate as temperature increases followed by FC-9, FC-0, and FC-5	cm ³ /(N- m)	[42]
Coir Fiber/ Phenolic Resin	SAE J66	Chase machine	NA	S1 coir fiber showed the least wear rate (8.5% weight loss) followed by S2 (8.7%), wear rate increased as coir fiber content increases. S5 Composition showed a sudden rise in wear rate with 34.3% weight loss, where S4 showed 17.7% weight loss in wear.	weight loss%	[32]
Bamboo Fiber/ Phenolic Resin	China National Standard, 1998	JF 150d-II	3% bamboo composition showed a stable friction coefficient across the range of temperature, followed by 6%, 9%, 0% then followed by 12%. Friction coefficient profile of 3% bamboo-	3% bamboo composition showed the least wear followed by 0%	$\mu\text{m}^3/(\text{N}-\mu\text{m})$	[37]

			composite showed steep increment after 250°C			
Jute Fiber (JG)/ Phenolic Resin	SAEJ661 standards	JF160 d	As jute content increases μ decreases, JH-0 exhibited the highest value of μ (0.615 at 290°C and 0.538 at 346°C) followed by JH-5.6 (0.582 at 290°C and 0.405 at 346°C).	JH-9 showed the least wear rate followed by JH-14.6. JH-5.6 and JH-1-23.6 exhibited similar wear. JH-0 showed the highest wear rate compared to all other contestants in the JH group.	mm ³ /Nm	[38]
Flax Fiber/Phenolic Resin	Chinese National Standards. GB 5763-2008	Wanda JF151 tester	F-0 showed the most stable friction performance followed by F-5.6 and F-9 which showed better μ . With the addition of flax fiber friction performance depressed	F-14.6 composition showed the least wear as well as stable wear profile across temperature variation. Where FH-0 showed the highest wear rate as temperature increases.	cm ³ /(N-m)	[43]
Sisal Fiber/ Phenolic Resin	NA	D-SM tester	S3 composition with 20% sisal fiber showed the highest and stable μ across all temperature range. Followed by S2(15%) and S1(10%). Range of the μ for S1 was between 0.35-0.5	20% sisal fiber composition showed a rise in wear rate as temperature increases, followed by steel fiber and glass fiber. Asbestos fiber showed least wear	cm ³ /(N-m)	[36]

Friction films primarily influence the friction and wear performance. Fiber content affects the formation of friction films in multiple ways. Plant fibers tend to agglomerate due to contrast affinity of plant fiber and binder towards the water. An increase in plant fiber content may cause the formation of non-uniform friction films due to fiber agglomeration affecting friction performance [39], [40]. High temperature also affects the mechanical properties and in turn, it affects the friction properties [37]. Plant fibers are pulled out from the friction material surface due to weaken bonding due to high temperature and stress. Pulled out fibers and other debris can cause three-body friction, removing more material from the surface, if that debris gets caught between tribo-surface it may cause furrow effect [46] on the contact surface. This phenomenon increases the friction coefficient as well as the wear rate of the friction composition [36], [42] This could be some of the reasons for the poor performance of friction sample with high fiber content. Though specific patterns or trends can't be observed between fiber content and friction properties some rough guidelines can be derived from the study. Since optimum fiber content is different for every composition, it can be concluded that only a specific amount of the plant fiber content is useful to enhance overall properties.

IV. EFFECT OF PLANT FIBER CONTENT ON MECHANICAL PROPERTIES

Mechanical properties of the brake pads also affect the braking performance. Some trends in mechanical properties can be observed in the bio-based brakes pads based on fiber content as shown in Table 3. Hardness seems to vary with fiber content. In the majority of the studies, it is observed that hardness decreases with an increase in plant fiber content. But in some studies, the hardness of the friction samples seems to vary irrespective of the plant fiber content. Selected candidate friction samples with optimum fiber content may or may not be having better hardness among all friction samples. It is difficult to comment on the hardness pattern. In the study conducted by Kumar et. al.[27], the hardness increases with a decrease in the hemp fiber content, and on the contrary, exact opposite behavior can we observe with the banana fiber-based brake pads[47], where hardness seems to increase with the increase in banana fiber content. Porosity and hardness are always seeming to behave in contrast manner.

Porosity also affects friction performance. Lower porosity results in higher friction coefficient and friction performance. Lower porosity avails more contact areas between mating surfaces which enhance friction performance. [32]. Similarly, porosity promotes the water and oil absorption properties of the brake pad, which harms the brake pad performance. Porosity seems to increase with an increase in fiber content [48], [49]. The strong interfacial adhesion between the brake pad ingredients reduced the porosity and enhanced structural strength. When a brake pad is pressed against the rotor to reduce relative motion, the brake pad experiences the high compressive as well as shear stress. Compressive strength imparts the ability to sustain all kinds of stresses experienced by brake pad during vehicle braking. Compressibility seems to increase with an increase in fiber since porosity also promotes compressibility (table 3). The orthotropic nature of the plant fiber makes it difficult to predict the properties of the brake pad before manufacturing and testing. Plant fibers exhibit good mechanical properties. Precise study regarding the influence of organic content in plant fiber on mechanical properties can enable the use of plant fibers on the commercial level.

Table 3: Mechanical Properties of the plant fiber-reinforced brake pads

Fiber/Binder	Hardness	Porosity	Compressive strength/ Compressibility	Water Oil absorption	Ref.
Pineapple fiber/ Phenolic Resin	The hardness (HRR) remains in the range of 96–115 and found to decrease with the increased pineapple or Kevlar content.	Porosity remains in the range of 4.34–7.36 % and it was found to increase with the increase of pineapple fibers	Compressibility increases with an increase in fiber content. The range for compressibility is observed between 1.16% -2.02%	Water absorption increases with an increase in fiber content. The range is found to be between 2.04%-3.62%	[39]
Standard/ Testing apparatus	TRSN-BD Tester	JIS D 4418 standard	ISO 6310 standard	ASTM D 570-98	
Banana fiber/ Phenolic Resin	As fiber content increases hardness increases, BP-0(83 HB)>BP-7 (83 HB)>BP-14(82 HB)> BP-21(86 HB)	NA	NA	NA	[26]
Standard/ Testing apparatus	Brinell hardness tester	NA	NA	NA	
Hemp fiber/ Phenolic Resin	As fiber content increases hardness decreases, FH-1(111.2 HRR)>FH-2 (109.8 HRR)>FH-3(107.6 HRR)>FH-4(100.2 HRR)	Porosity Increases as fiber content in the composition increases viz. FH-1(6.82) < FH-2 (7.24 %) < FH-3 (7.82%) < FH-4 (9.36%).	Compressibility increases with increase in fiber content. FH-1(1.12%) < FH-2 (1.18 %) < FH-3 (1.32%) < FH-4 (1.50%).	Water Absorption increases with increase in fiber content. FH-1(1.18%) < FH-2 (1.34 %) < FH-3 (1.85%) < FH-4 (2.38%).	[40]
Standard/ Testing apparatus	TRSN-BD Tester	JIS D 4418:1996	ISO 6310	ASTM D570-98	
Coconut Fiber/ Phenolic Resin	C2 10% (61 HRS)> C1 5% (59 HRS)	In oil C1(0.29%)> C2 (0.16%) and in water C1 (0.75%)> C2 (0.55%)	10% coconut fiber sample exhibited optimum compressive strength C2(38.7788 N/mm2)> C1(27.6141 N/mm2)	In oil C1(0.29%)> C2 (0.16%) and in water C1 (0.75%)> C2 (0.55%)	[41]

Standard/ Testing apparatus	NA	NA	NA	NA	
PALF Fibers/	10% PALF composition showed the highest hardness (101.6 HBN) followed by 30% > 20% > 5%	NA	Compressive strength increases as fiber content increases, 30% PALF composition showed the highest compressive strength (around 107.25 MPa)	As fiber content increases water absorption increases. 30% PALF composition showed the highest water absorption (around 4.5 %)	[29]
Pine needle/ Phenolic Resin	FC-3 showed highest hardness of 107.4 HRR followed by FC5(106.8 HRR)>FC7(105.4 HRR)>FC0 (103.4 HRR)> FC9(103.3 HRR).	NA	NA	NA	[42]
Standard/ Testing apparatus	Rockwell hardness tester HRSS-150	NA	NA	NA	
Coir Fiber/ Phenolic Resin	S2 exhibited the highest hardness (63.92 HRS), followed by S3 and S1. S4 showed the lowest harness value of 25.93 HRS.	S2 showed the least porosity (between 10-15 %) and the highest hardness followed by S3 and S1. S4 and S5 showed a significant increment in porosity as fiber content increases	Only S2(5% coir fiber) and S3(10% coir fiber) were tested. Both samples exhibited almost similar compressive properties with 414.75 MPa compressive strength and 408.74 MPa and 0.66 MPa as initial and final breaking strengths.	As porosity increases water and oil absorption increases	[32]
Standard/ Testing apparatus	Malaysian standard MS 474 PART 2: 2003	JIS D 4418: 1996/ Tensiometer	UTM	NA	

V. FIBER TREATMENTS AND MANUFACTURING PROCESSES AND PARAMETER

Fiber treatments are proven to enhance the properties of plant fiber [50]–[54]. Different treatment methods are adopted by the researchers for treatment including physical and chemical treatments as shown in Table 4. Chemical treatments are adapted according to the expected outcome since chemical treatments change the concentration of the organic ingredients, NaOH alkali treatment is the most common treatment adapted for plant fibers. [53]. Similarly, physical treatments like heating treatments, sun drying are common treatments adapted for the enhancement of general properties.

Post manufacturing treatments are mainly provided for curing of the binder for proper adhesion since uneven cooling can develop cracks and undesirous deformities in the brake pads. Manufacturing processes and parameters also contribute a major share in structural strength and properties of the plant

fiber-reinforced composites [55]. Many processes are been used for the manufacturing of plant fiber-based brake pads but compressive molding has been common amongst all. New manufacturing processes are emerging in this field. It can be observed from Table 4 that, processing parameters like pressure, curing temperature, curing time are adapted according to the author's methodology. Curing temperature range seems to vary between 150°C-170°C, similarly applied pressure also seems around 15 MPa to 25 MPa with few exceptions. Since most of the parameters are may be adapted according to the conventional practice observed in brake pad manufacturing. It is difficult to comment on the specific

Table 4: Fiber treatments and manufacturing processes and parameters.

	Fiber Pre-Treatment	Manufacturing Technique	Machine Model	Time	Pressure	Temperature	Post Treatment	Ref.
Pineapple fiber/ Phenolic Resin	The procured pineapple fibers were treated with 5 wt.% of sodium hydroxide solution for 24 h. After washing them with distilled water, the fibers were oven-dried for 5 h at 60 °C. Then, the fibers were cut to a length of ~2–6 mm and used for the composite fabrication.	Compression molding	NA	10 Min	15 MPa	155°C	Heated in the oven for 3 Hrs. at 170°C	[39]
Banana fiber/ Phenolic Resin	NA	Hot Compaction	NA	10 Min	15 MPa	150°C	Heated at 100°C for 8 Hrs.	[26]
Hemp fiber/ Phenolic Resin	Treated with 2% NaOH Solution for 24 Hrs. then washed with distilled water and dried for 5 hrs. in the oven at 60°C	Compression molding	NA	10 Min	15 MPa	155°C	Heated in the oven for 3 Hrs. at 170°C	[40]
Coconut Fiber/ Phenolic Resin	NA	Cold pressing followed by hot pressing	Na	Na	20 KN	Preheated at 200°C for 60 min in the oven	Heated at 100°C for 480 min in oven. Cooled in the open air for 48 Hrs. at 25°C	[41]
PALF Fibers/ Epoxy	Treated with NaOH solution for 1 Hr., then sun-dried for 5 Hrs.	Hand layup method	NA	NA	NA	NA	NA	[29]
Pine needle/ Phenolic Resin	Firstly treated with a mixture of HCHO and C6H6 (1:1) for 2Hrs at 25°C, then fibers were steeped into NaOH (2 wt.%) solution for 2 Hrs. at 25°C, then fibers were risen with distilled water and neutralized with H2SO4 (1 wt.%) solution for 30 min, then steeped in distilled water for 10 min at 25°C again. Finally, fibers were heat-treated in the oven at 100°C for 4 Hrs.	Compression molding	JFY50	30 Min	40 MPa	160°C	Heated in three steps, 60 min at 140°C, 180 min at 160°C, 360 min at 180°C	[42]

Coir Fiber/ Phenolic Resin	NA	Hydraulic pressing machine	Na	10 min	20 Kg	Preheated at 170°C	Sintered in the furnace for 5 Hrs. at 200°C	[32]
Bamboo Fiber/ Phenolic Resin	The bamboo pieces were immersed into the softener solution (2% vol NH ₃ H ₂ O, 4% vol CON ₂ H ₄) and boiled for 1 h at 100 C. Kept in NaOH (4% vol) solution for 30 min at 70 C. Softened fibers in pieces were broken mechanically and carded into a fiber bundle. fibers were dried in an oven at 60 C for a half-hour after being washed with water	Compression molding	JF 980B	30 Min	25 MPa	165°C	Heated in three steps, 1 Hr. at 140°C, 3Hrs. at 150°C, 6 Hrs. at 180°C	[37]
Jute Fiber (JG)/ Phenolic Resin	Raw jute fibers were dried at 80°C for 30 min, then treated with 12% NaOH solution at room temperature at 1 hr. Finally, fibers were treated with 1 M HCL for 30 min.	Compression molding	Wanda JFY 60	6 Min	25 MPa	165°C	Heated in the oven for 3 Hrs. at 170°C.	[38]
Flax Fiber/ Phenolic Resin	Flax fibers were treated by drying at 80 C for 30 min, 12% NaOH solution at room temperature for 1 h, and 1M HCl steam for 30 min	Compression molding	Wanda JFY 60	6 Min	25 MPa	165°C	Heated in the oven for 3 Hrs. at 170°C.	[43]
Sisal Fiber/ Phenolic Resin	Sisal fiber was a dip into 10% NaOH- Ammonia base liquor at 200 V for 2Hrs, then rinse with distilled water and for neutralization, it was treated with H ₂ SiO ₃ , then treated in Na ₂ B ₄ O ₇ -HCHO-NaHSiO ₃ (10 wt.%) solution. Then fibers were dried and heat-treated at 210°C for 1 Hr.	Compression molding	NA	10 Min	20 MPa	158°C	NA	[36]

effect of specific manufacturing parameters on the brake pad. Precise study on treatments and manufacturing could assist in the industrial utilization of the plant fibers.

VI. DISCUSSION

The use of a specific amount of natural fiber improves the properties and performance of the brake pad. That optimum fiber content of plant fibers varies for every composition. Hardly any model exists to predict the optimum content of plant fiber before manufacturing and testing of the brake pads. Optimum fiber contents reported till now are observed to be within 10% ,with a few exceptions of course. Wear and friction properties also get affected by plant fiber content. Quite good friction coefficients exhibited by various compositions, but friction coefficient and wear rate seem to experience fluctuations and poor stability with an increase in fiber content. Plant fiber content also affects mechanical properties. Hardness, porosity, and water /oil absorption are the properties that have a partial influence on each other. An increase in plant fiber content promotes porosity in the brake pad material, and porosity promote oil/water absorption. An increase in plant fiber content also seems to increase the compressibility of the composite. Hardness also seems to decrease with an increase in fiber content

with, few exceptions. For enhancing the performance of plant fibers, different fiber treatments, and manufacturing processes are adapted. Though it is very difficult to make a statement regarding trends and specific effects of plant fiber content on specific properties, some guidelines can be derived from this study for any further work.

VII. CONCLUSION

It can be concluded from this study that, the use of a certain amount of the plant fiber reinforcement enhances friction and wear performance of brake pads. Variation in plant fiber content causes variation in mechanical as well as tribological properties. Though it is difficult to make specific and confident comments on variation of plant fiber content on the performance of NFRC brake pad materials, some initial guidelines and understanding can be derived from this study. This study reveals the fact that plant fiber does have the potential to replace conventional reinforcement material like metals and minerals used in brake pads. Even then precise study is needed to understand specific behavior and influence of plant fiber content on the brake pad's mechanical and tribological performances, so as to increase the use of plant fiber reinforced brake pads.

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