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Development of Cotton Straw Reinforced TPU Composite and Investigation of Its Mechanical Properties

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Abstract: ***In daily life, thermoplastic has a vital role in the environment but due to its non-biodegradable properties its harmful effect to environments. So it in necessary to make the biodegradable composite. In various studies and a lot of research, it is found that natural fibers are available in an abundant form in the environment and there is a lot of research is in progress to utilize natural fiber with plastic to make it biodegradable. Due to its good mechanical properties and ease of availability engineers, researchers, industrialists, professors, scientists have a key interest to utilize natural fiber-based composite. This research work deals with the fabrication of cotton straw reinforced TPU composite by injection molding techniques. To enhanced good mechanical properties, the cotton straw fiber is soaked in 8% NaOH solution, and different five proportions of fiber and matrix are prepared 0:100, 10:90, 20:80, 30:70, 40:60. This research result indicates that the mechanical properties of the composite are better than pure thermoplastic polyurethane while doing various tests like Tensile strength, flexural strength, wear test, shore hardness, and also SEM is used to examine the failure surface of samples.***

Keywords: Natural fiber composite, Cotton straw, TPU (thermoplastic polyurethane), Mechanical properties

I. INTRODUCTION

Traditionally natural fiber-based materials are used in small-scale industries to fabricate carpets, mats, ropes and bags. Due to its good mechanical properties, ease of availability, and low-cost many research and entrepreneur are attracted to building natural fiber-based composite [1-5]. Natural fiber-reinforced composite is the structural composite. it is a heterogeneous mixture of polymer matrix with fibers. The manufacturing cost of natural fibers reinforced composites is economical and it can be easily recycled. The natural fiber is grouped into three categories (leaf, stem and seeds) and the properties may vary from the place where fiber is extracted (either leaf, stem or roots). In practice, the main component of natural fiber is cellulose and they also consist of micro-fibrils in a formless matrix of lignin and hemicellulose. These fibers consist of various fibrils that run all over the length of the fiber. The hydrogen bonds and other linkages present in the fiber provide the necessary strength and stiffness. The natural fiber is obtained from various plants like kenaf, bananas, sisal, bamboo, jute, bamboo, cotton and sugar cane etc [6]. More essentially is the environmental concern to replace synthetic fiber with natural fiber. Hence, researchers doing lots of research to get a better method to replace synthetic fiber with a composite made from natural fiber and polymers [7]. The use of natural fiber as a raw material is increased in automobile, manufacturing, packaging and sports industries. Natural fiber has few limitations, due to high moisture absorption characteristics it's mechanical properties will vary but researchers have been focused on increased mechanical properties of natural fiber-based composite through the various combination of techniques. Sakthivel M et al [8] investigated the mechanical properties of natural fiber polymer composite and they find that while using natural fiber the energy for production is reduced by 80% and the cost of production is reduced by 5% as compared to reinforced fiberglass components. Denis Mihaela Panaitescu et al [9] investigated the effect of hemp fiber length on the mechanical and thermal properties of composite made up of hemp and polypropylene (PP)/poly[styrene-b-(ethylene-co-butylene)-b-styrene) (SEBS). They found that composite with longer fiber consists of higher crystallinity and storage modulus was increased by 82-90%. The fiber of different lengths was obtained in a laboratory mill with an adjustable die and they investigate the composite was made up of fiber length of 2.5 mm and more are good material for an electric vehicle due to reduced weight and environmentally. Naresh k et al [10] investigated the mechanical and thermal properties of NaOH treated Sisal fiber polymer composite and they replaced asbestos brake lining material with sisal fiber composite as asbestos and other brake materials are not eco-friendly [11-19]and they found 20% sisal composite have better mechanical and thermal properties. Cotton is primarily known as white gold. In 2020- 21 the yield of cotton is 498 kg per hectare [20] and the production of the cotton stalk is two to three tonnes per hectare [21].

Mainly the cotton stalk is used as a raw biomass material to produce value-added bio-composite products [22]. Cotton stalks kept in the field after harvest are a breeding ground for pink bollworm, boll weevil and other pests. Burning the cotton stalks in the field is the preferred method to save future crops from these insects [23]. It creates environmental pollution while burnt 1 million metric tonnes of cotton stalk produces approximately 0.85 million metric tonnes of Carbon dioxide [24]. Cotton stalk structure and dimensions are similar to common species of hardwood it consists of cellulose 47.80 %, Hemicellulose 77.50% whereas hardwood contains 45 -50% cellulose and 70-78% Hemicellulose [25].The cotton stalk fiber has properties to use in fiberboard manufacture with resin (urea formaldehyde and phenol formaldehyde) as fiber length was 8.18 cm [26]. As per various research, it was found that there is little work was done on cotton stalk fiber in composite so this research is based on making cotton straw fiber and TPU (thermoplastic polyurethane) based composite. As per testing results, the mechanical properties (Tensile strength, flexural strength, shore hardness) of the composite are increased and its wear rate is decreased. Also using SEM to investigate the failure mode of the composite during Tensile strength.

II. MATERIALS AND METHODS

A. *Extraction of Material*

In this cotton straws were collected from the Haryana field (Jind & Bhiwani) and TPU of U92 Covestro grade is used and it was purchased from Rai Innotech Polymers Pvt. Ltd, New Delhi. The fiber was extracted by putting a cotton straw into a water drum for 3 weeks. This process is carried out for softening of straw. After 3 weeks some impurities were removed from the cotton straw. The fiber was extracted by manual removal of the external layer or by the manual decortication, hackling and scratching method. Then separation of cotton straw wood and fiber was done manually. To eliminate dust particles and other foreign particles from long fiber, these were washed with water and then dried in Sunrays for 4 hours as shown in Fig 1(a).

B. *Chemical Treatment*

Cotton straw fibers were cut manually into 4 to 5 mm sizes. The soaking of Cotton fibers was carried out for 2-3 hours in an 8% NaOH solution. To obtain the pH = 7, NaOH-treated fibers were cleaned with distilled water and followed by drying in an oven at 100- 105°C for 2 hours. Further fibers were soaked in a 10% Maleic Anhydride (MA) solution in acetone for 2 hours. Again to obtain the pH=7, MA treated fibers were washed with distilled water as shown in figure 1(b). To investigate the effect of varying the content of cotton straw fiber on tensile, flexural and wear properties of cotton straw reinforced thermoplastic polyurethane composite, samples were prepared by taking 10%, 20%, 30%, and 40% cotton straw fiber by wt. in TPU. Also 100 % TPU samples were prepared for comparison point of view. The description samples composition given in Table 4.1 Where □$_f$ (density of cotton straw) = 1.60 g/cc [26] and □$_f$ (density of TPU) = 1.23 g/cc. Injection molding machines (Model: NG80, Manufacturing Company: Neelgiri) were used to fabricate samples of tensile and flexural specimens by putting corresponding mixtures in the machine.

(a) (b)

Fig 1 (a) Extraction of fiber (b) Cutting of fiber, Soaking of Cotton Straw fiber in 8% weight NaOH, Maleic Anhydride , After Soaking of Cotton straw fiber in 10% weight acetone + MA.

C. Sample Preparation and Testing

The flexural test specimen, tensile test specimen and wear test specimen are prepared as per respective standards ASTM D638, ASTM 790 and ASTM G99 shown in fig 2

Fig 2 Tensile strength, flexural strength and wear test specimen of different composition

1) *Tensile Strength Analysis:* The tensile test was conducted on UTM (Model: AG – IS, Capacity 100KN, make: SHIMADZU) available at CIPET, Murthal, Haryana. Dumbbell shape samples (Fig 2) were prepared for the tensile test and three samples were prepared for each composition. The gauge length of specimens was kept as 50 mm. The result of tensile strength was considered an average of three samples result consist the same composition.
2) *Flexural Strength Analysis:* Flexural tests were conducted on UTM (Model: H50KS, Capacity 50N, make: TINIUS OLSEN) available at IIT Ropar, Punjab. A short beam shear test was performed on samples (Fig 2) for obtaining the flexural strength. The shorter beam shear test is a 3-point bend test that was conducted on the UTM at IIT, Ropar. The calculation of flexural strength of the specimen was done as per ASTM D638 Standards where P is the load applied, L is the length of span and b & t are respectively the width and thickness of the specimen.
3) *Wear Test Analysis:* Wear test was conducted on Pin on Disc Apparatus (make: DUCOM) at NITTR, Chandigarh. In wear test where the wear of the material, weight reduction and friction of each composition are investigated while fixing the parameter (speed and load).
4) *Shore Hardness Analysis:* The Shore hardness test of the specimen was done on the Shore D durometer at NITTTR, Chandigarh. the shore durometer is a device to measure the hardness of elastomer, polymers and rubber (Fig 4.15).
5) *Scanning Electron Microscope (SEM) Analysis:* To investigate the morphology of the failure of tensile specimens and its mode of fracture surface. The Fractured or failure surface was investigated under a Scanning Electron Microscope (SEM) available at Chandigarh University, Gharuan (Mohali). The details of machines are Model: JSM-IT500, Make- JEOL (Fig- 4.16 (a)). The fractured surface or part of the specimen was cut in 2-3 mm pieces and coated with Gold in the D11-29030SCTR Smart coater machine before SEM (Fig 4.16 (b)). The gold plating was done to make fiber-reinforced polyurethane composite as an electric conductive material for test purposes The Gold plated samples were mounted on the stubs with silver paste and then it was placed inside the SEM machine [27]. The vacuum was created in the SEM machine to get a clear image for investigation. The SEM helped us to examine the effect of tensile load on the bonding between cotton straw and the TPU matrix.

III. RESULTS AND DISCUSSION:

A. Tensile Strength

Three similar composition samples were taken and tensile tests were conducted on them for each of the fabricated composites (pure TPU, 10% fiber, 20% fiber, 30% fiber & 40% fiber) and each sample result shown in fig 3.

Table 1: Tensile strength of different samples

Specimen Notation	Specimen No.	Tensile Strength (MPa)	Mean Tensile Strength (MPa)	Standard Deviation (MPa)
T0	1	11.23	11.93	0.60
	2	12.30		
	3	12.26		
T1	4	9.55	9.57	0.37
	5	9.99		
	6	9.17		
T2	7	11.92	12.66	0.66
	8	13.20		
	9	12.86		
T3	10	12.66	12.38	0.29
	11	12.41		
	12	12.07		
T4	10	15.00	14.46	0.76
	11	14.79		
	12	13.59		

To analysis, the final tensile strength of the sample, the average of these three specimens was considered or noted. The average results of each composition sample are reported in Table 1 and shown in fig 4. Result shows that 40% fiber composition (T4) sample have maximum tensile strength and 20% composition have minimum tensile strength and it find that composite of 40% fiber consist better tensile strength than PURE TPU.

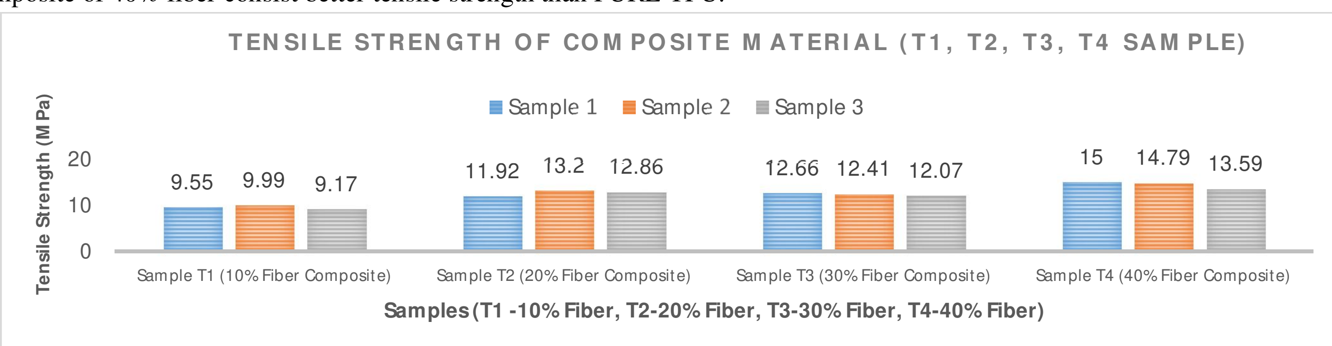


Fig 3: Tensile strength of various composition

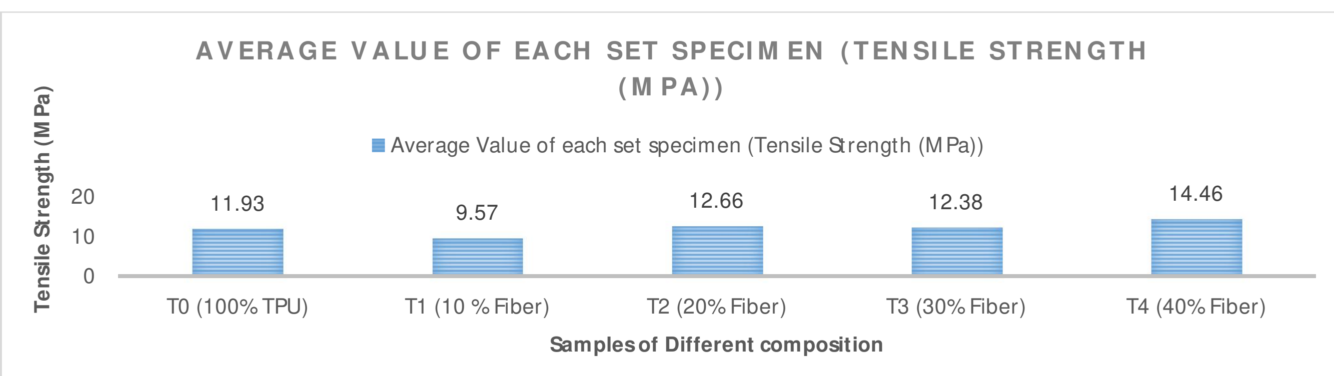


Fig 4: Average value of each set specimen (Tensile strength)

B. Flexural Strength

Three samples of each composition were taken and flexural tests of all samples (Pure TPU, 10% fiber, 20%, 30% fiber, 40% fiber) were tested in Mini-UTM at IIT Ropar as per ASTM D790 standard and result shown in figure 5 and Table 2. To calculate the final flexural strength of three samples of each composition. Average of all three samples taken of same composition shown in fig 5. It is observed that the mean Flexural strength of F2 (20% fiber) is maximum and F0 (Pure TPU) is minimum. Deepak et al. (2018) also observed the same result (approximately) from composite made from natural fiber reinforced HDPE.

C. Shore Hardness analysis

Shore hardness of various samples of different compositions measured as per Shore D durometer. During Analysis it was noted that pure TPU consist of lower hardness as compared to cotton straw reinforced TPU. The Shore hardness of 40 % Cotton straw reinforced TPU was maximum and its analysis that shore hardness of composites was increased as the cotton straw percentage increased in reinforced TPU respectively as shown in Table 3.

Table 1: Flexural strength of different samples

Specimen notation	Specimen No.	Flexural strength (MPa)	Mean Flexural strength (MPa)	Standard deviation (MPa)
F0	1	3.92	4.39	0.68
	2	4.08		
	3	5.17		
F1	4	8.50	7.97	1.21
	5	6.58		
	6	8.83		
F2	7	13.3	13.23	0.0.50
	8	13.7		
	9	12.7		
F3	10	12.6	10.11	2.35
	11	7.92		
	12	9.83		
F4	13	13.3	11.81	3.10
	14	13.9		
	15	8.25		

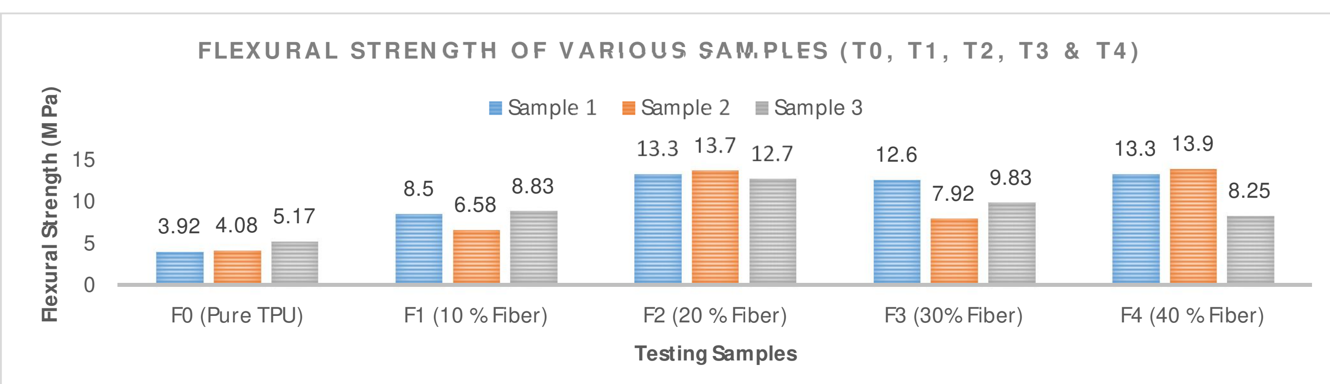


Fig 5: Flexural strength of various samples

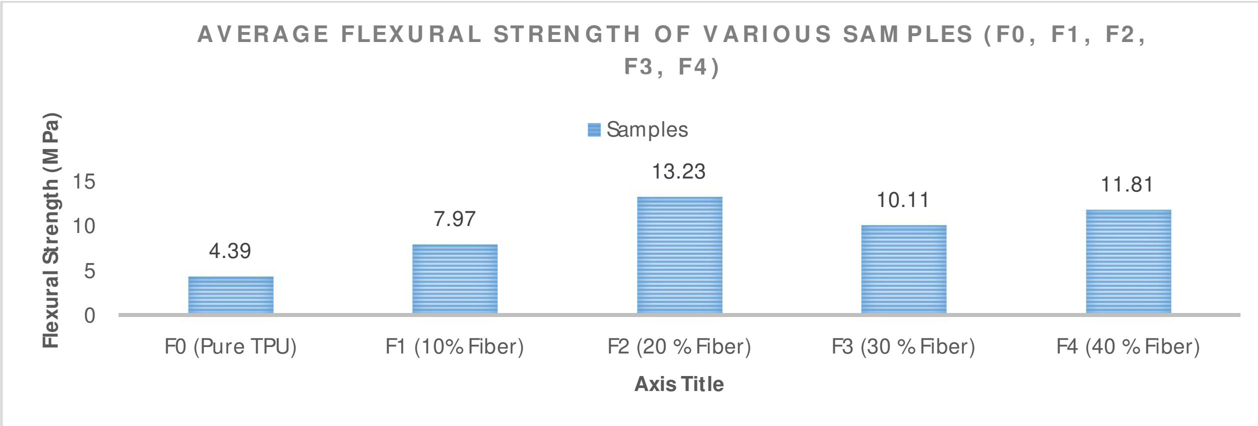


Fig 6: Average flexural strength of various samples

Table 3 : Shore Hardness of different samples

Samples	Pure TPU	10% fiber	20% fiber	30% fiber	40% fiber
Shore Hardness 'D'	19	20.5	21.5	25.5	28

D. Wear Analysis

Wear analysis of various compositions of specimens (Pure TPU, 10%, 20%, 30% and 40% fiber) were tested on the pin on disc apparatus at NITTTR Chandigarh. As per tested results, it was observed that the wear rate of pure TPU is higher as compared to composite. it was notified that when the hardness of the material increased its wear rate decreased [28] which means the harder the material lowers the wear rate. As per the Shore hardness test (Table 5.3) of composite made from 10%, 20%, 30% and 40% cotton straw fiber were consisting high hardness than pure TPU therefore its wear rate also decreased with an increase in hardness.

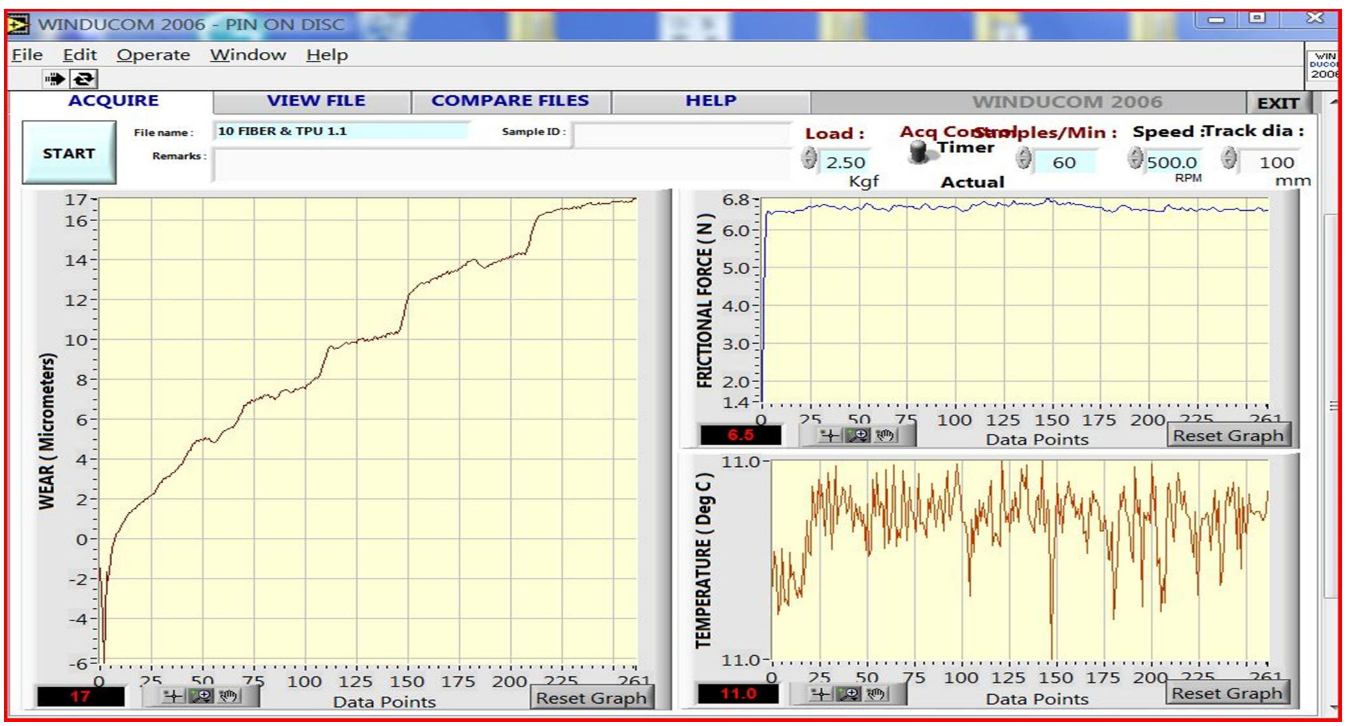
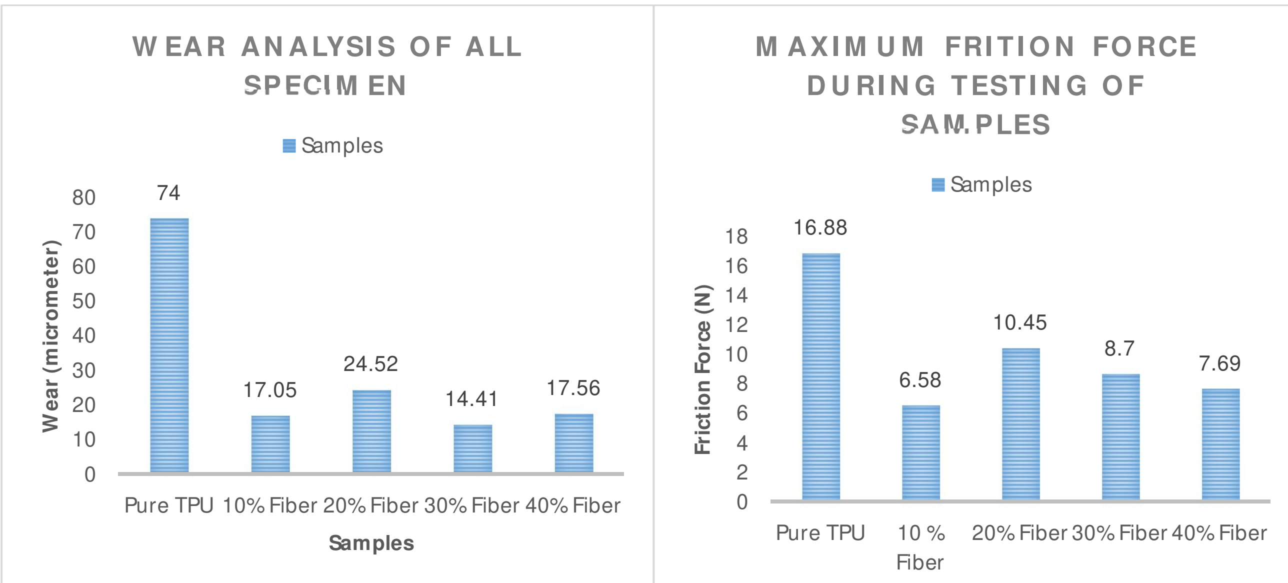


Fig 7: Wear test of 30 % fiber based composite.

Table 3 : Wear test of different composition smaples

S.No	Samples	Load (N)	Speed of Disc (rpm)	Time (minutes)	Weight loss (grams)	Max. Friction force (N)	Wear (micrometer)
1	Pure TPU	25	400	4	0.0051	16.88	74
2	10% Fiber	25	400	4	0.0040	6.58	17.05
3	20% Fiber	25	400	4	0.0025	10.45	24.52
4	30 % Fiber	25	400	4	0.0024	8.70	14.41
5	40% Fiber	25	400	4	0.0025	7.69	17.56

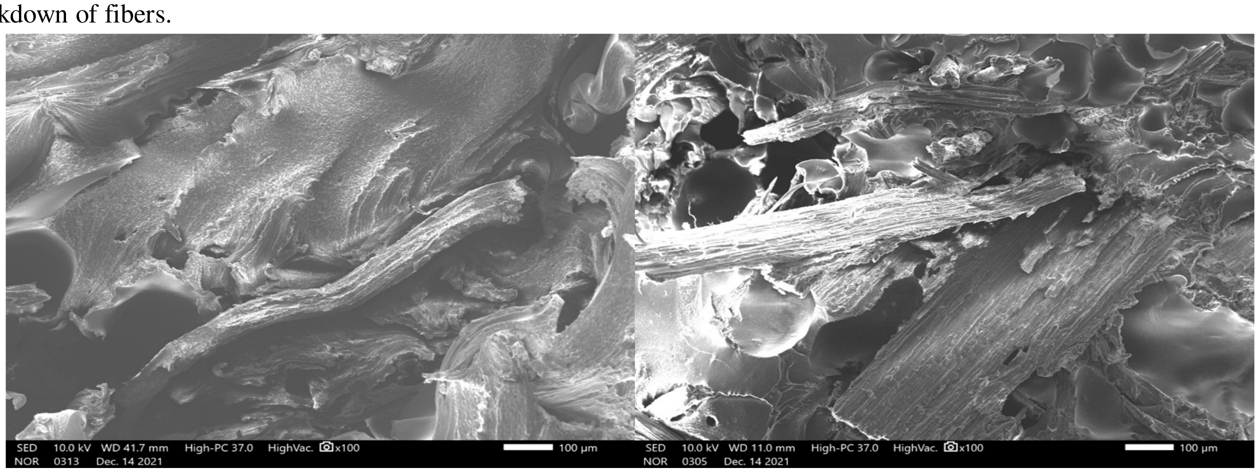


(a) (b)

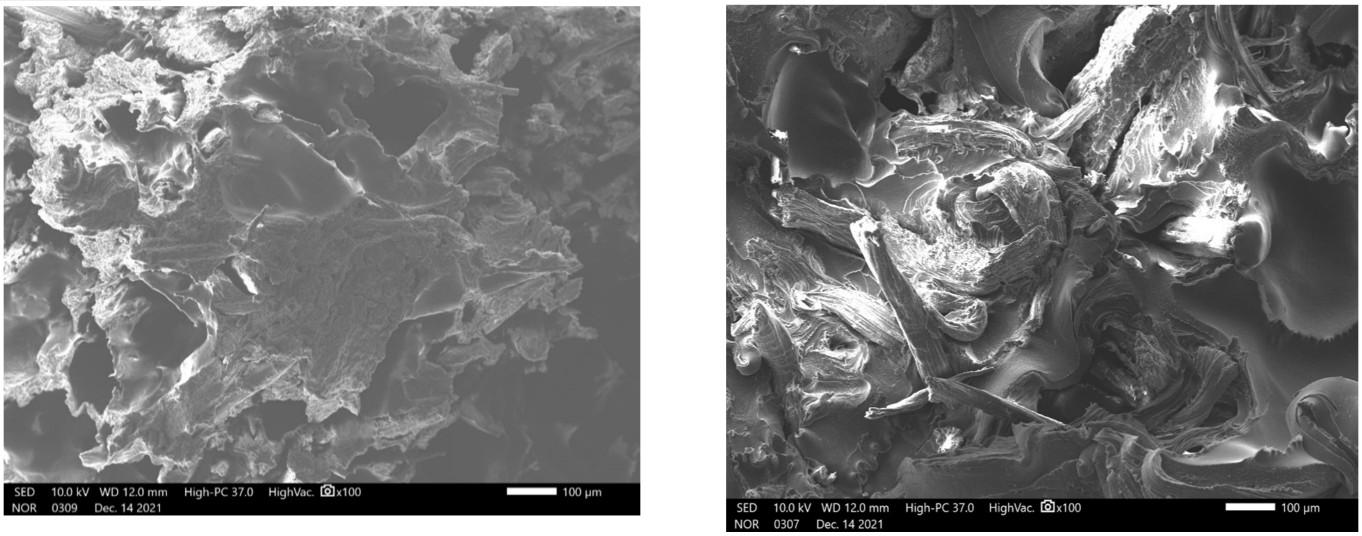
Fig 8(a) Wear analysis of all specimen, 8(b) Maximum friction force during testing

E. Scanning Electron Microscope Analysis

SEM test was performed to investigate the fractured surface of composite made from cotton straw reinforced TPU. It examines the fractured surface and interfacial adhesion between TPU and Cotton straw fiber matrix. The SEM image of the failure surface has been investigated under 100 X and the image reveals that maximum failure of the surface is done due to poor adhesion of fiber in TPU. It also reveals that during tensile load fiber is a pullout from TPU and in a few samples failure is notified due to fractured fiber or breakdown of fibers.



(a) (b)



(c) (d)

Fig 9 Scanning Electron Micrographs (a) 10% Cotton straw fiber reinforced TPU composite (b) 20% Cotton straw fiber reinforced TPU composite (c) 30% Cotton straw fiber reinforced TPU composite (d) 40% Cotton straw fiber reinforced TPU composi

IV. CONCLUSION

The study indicates that injection molding can be successfully used for making eco-friendly cotton straw reinforced TPU composite. The reinforcement of Cotton fibers into TPU matrix increase the Shore Hardness and 40% fiber sample is reported maximum shore hardness. The Tensile Strength increases with the addition of cotton straw into TPU matrix. The 10% fiber sample is reported lowest tensile strength and the 40% fiber sample is reported maximum tensile strength. The flexural strength increases with the addition of cotton straw into TPU matrix. The average of 20 % fiber samples is reported as maximum flexural strength and the average of 10% fiber samples is reported as minimum flexural strength but in individual samples, 40% fiber (sample 2) is reported as maximum flexural strength. The wear rate decreases with an increase in fiber percentage in TPU composite. Pure TPU is reported maximum wear rate and 30 % fiber reported minimum wear rate. During result analysis it has shown that the mechanical properties of cotton straw reinforced composite is better than TPU and its various mechanical properties (Tensile strength, flexural strength, shore hardness) is improved and also its wear rate decreases. During SEM investigation of tensile fractured samples it is found out that failure of samples happens due to pullout of fibers and fractured of fiber.

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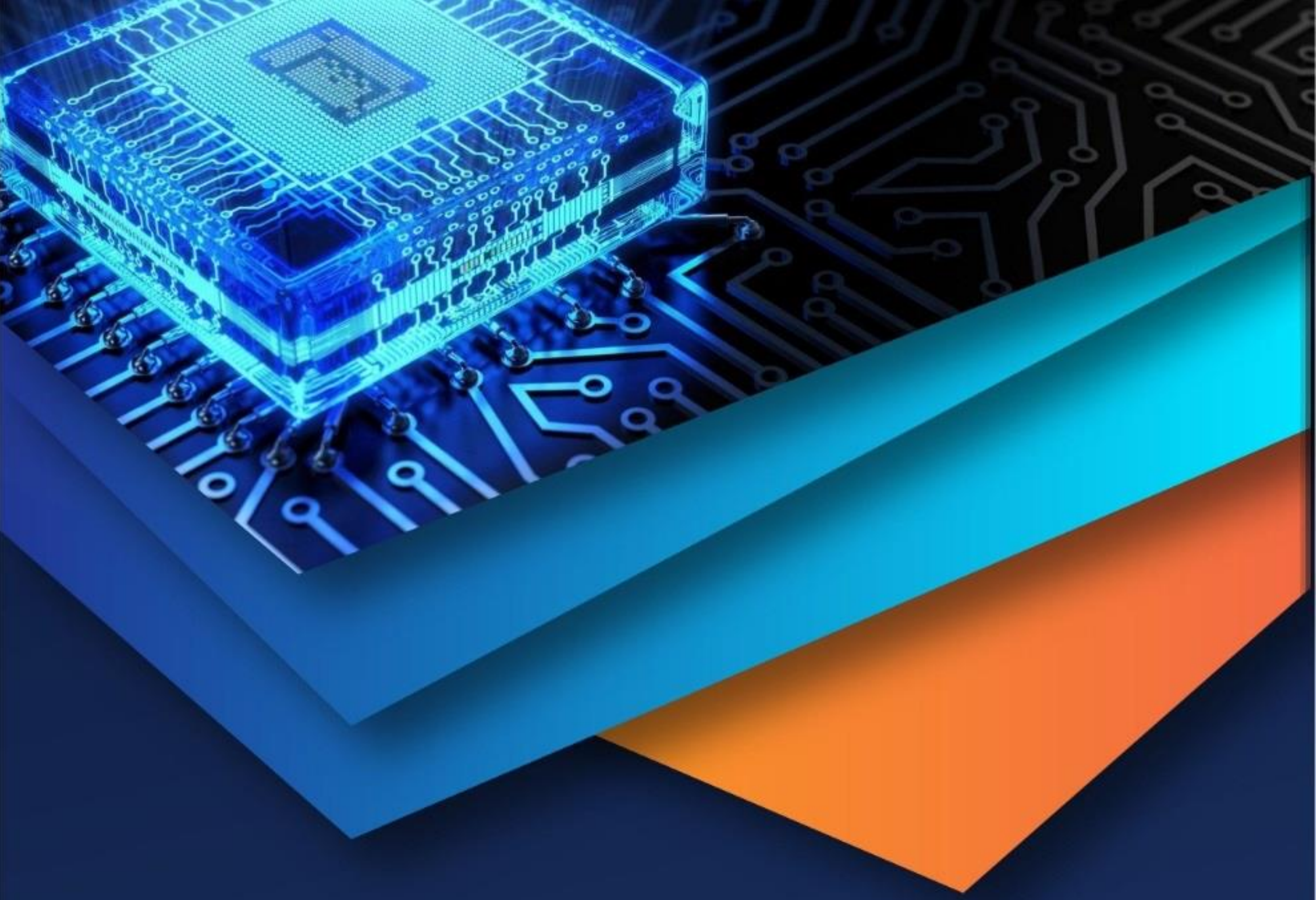

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