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Preparation And Characterization of a Novel Natural Fiber Based Composite For Tribological Applications

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ABSTRACT: -
This paper presents the fabrication and characterization of a composite material made with natural fibers namely Uttareni and Narepa along with orange peel powder as filler material in epoxy resin by hand layup method to study the mechanical properties of the composites. The test specimens were cut as per ASTM standard.Metallurgical studies were conducted to analyze the structural properties of the specimens. Compression, Hardness, impact, flexural, XRD and metallurgical tests were conducted on these fabricated composites. Test results exhibitedsignificant improvement in mechanical properties of hybrid composite material without filler when compared to other combinations of composite materials of this work.

INTRODUCTION

Natural fibre reinforced composites have emerged as potential environmentally friendly and cost-effective option to synthetic fibre reinforced composites. The availability of natural fibres and ease of manufacture have tempted researchers to try locally available inexpensive fibres and a study of their feasibility for reinforcement purposes and the extent to which they satisfy the required specifications of good reinforced polymer composite for tribological applications. With low cost and high specific mechanical properties, natural fibres present a good, renewable and biodegradable alternative to the most common synthetic reinforcement, i.e., glass fibre . Despite the interest in and environmental appeal of natural fibres, their use has been limited to nonbearing applications due to their lower strength and stiffness compared with synthetic fibre reinforced polymer composite. The stiffness and strength shortcomings of bio-composites can be overcome by structural configurations and better arrangement in the sense of placing fibres in specific locations for the highest strength performance. During the last few years, a series of works have been taken up for the replacement of the conventional synthetic fibre by natural fibre composites. For instance, hemp, sisal, jute, cotton, flax and broom are the most commonly used fibres for the reinforcement of polymers like polyolefin], polystyrene, and epoxy resins. In addition, fibres like sisal, jute, coir, oil palm, bamboo, wheat and flax straw, waste silk and banana have proved to be good and effective reinforcement in thermoset and thermoplastic matrices.

Natural fibers are compounds combining cellulose, hemicellulose and lignin; they can be derived from leaves (e.g., sisal), bast (e.g., flax, hemp), seeds (e.g., cotton) or fruit (e.g., coir). The most important advantages of natural fibers relate to environmental issues: they are biodegradable and carbon positive, since they absorb more carbon dioxide than they produce (Bogoeva Gaceva et al. 2007).

The rising concern about environmental issues and the need to find a realistic alternative to glass or carbon reinforced composites have led to an increased interest in polymer composites filled with natural organic fibers, derived from renewable and biodegradable sources (Cristiano Fragassa, 2017).

High demand has been placed on natural fibres by the automotive, construction, electrical and electronic industrial markets, making it very competitive. However, the largest consumers of natural fibre composites are the automotive and construction industries (Mohammed L et al, 2015).

The preference for natural fibre emanated from the growing environmental concern, which has led to continuous research on natural fibres and their composite for engineering material applications in place of synthetic fibre (Assarar M et al, 2011)

Productions of composite often involve huge investment in material acquisition. One way of reducing the production cost but still maintaining the properties of the composite is by using natural filler such as rice husks from the waste stream and also a synthesised matrix from the waste stream. Rice husks have been chosen due their availability, low cost, low density, high specific strength and modulus, and recyclability (Rahman et al., 2015).

Natural fibre composites are being utilized increasingly in highperformance, structurally demanding applications, in part because of their material properties and in part because they are a more sustainable choice than other engineering materials, such as mined or petroleum-based materials. Natural fibre composites have excellent specific strength and stiffness properties, meaning that they are very strong and very stiff, but also lightweight (Shah, 2014).

Alavudeen et al. [1] studied the effect of hybridisation on the mechanical properties of banana/kenaf hybrid composites. They reported that the hybridisation of kenaf with banana fibres enhanced the mechanical strength when compared with the individual fibre-based composites. Similarly, another report says that the hybridisation of sisal with oil palm improved the mechanical properties of the composites. Some researchers have investigated the effect s of hybridisation on mechanical properties of banana/sisal composites.

Boopalan et al. (2013) studied the effect s of different weight ratios of jute and banana fibre s on mechanical and moisture absorption properties of jute/banana fibre reinforced epoxy composites. Their study revealed that the tensile, flexural and impact strengths were found to be maximum for 50 :50 weight ratio of jute and banana fibres in the hybrid composites.

Moreover, many natural fibres such as kenaf, hemp, flax, jute, sisal, banana, coir and pineapple leaf fibres , among others , are drawing more considerable attention as a green reinforcement in the formulation of composite materials.

Senthilkumar K, Saba N, Chandrasekar M, Jawaid M, Rajini N, Alothman OY, et al. Evaluation of mechanical and free vibration properties of the pineapple leaf fibre reinforced polyester composites. Constr Build Mater 2019. doi: 10.1016/j.conbuildmat.2018.11.081.

A study by (Bilba et al. 2007) used banana leaf fibre as the reinforcement of a composite material, which revealed good improvement in the mechanical properties of the produced composite. The material was also found to degrade under natural environmental conditions.
In this work, a novel combination of fibres called Uttareni, Narepa with the orange peel bio filler were taken with treated and untreated forms. The bio fillers are reinforced in epoxy material to prepare composite specimens. Then specimens are cut and their characterization with metallurgical analysis was carried out.

2. MATERIALS AND METHODS

In this work, composites were prepared using treated and untreated bio fillers in epoxy resin by hand lay-up method to study the metallurgical and mechanical properties of the composites fabricated. Three different natural fibres viz. Uttareni, Narepa along with orange peel powder as bio filler material were used for the preparation of composites. 07 composite specimens were fabricated with different volume fraction percentage of treated bio filler and epoxy polymer as shown in Table 1.

(a) Orange peels (b) Sun dried orange peels(c) Powdered orange peels

Fig. 1. Composite materials

Fig.2a)Narepa fiber (hardwickia binata)   Fig.2 b) Uttareni fiber (achyranthes aspera)

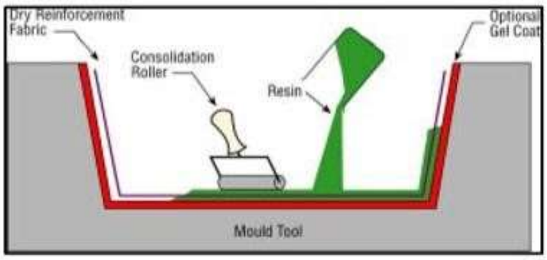


Fig.3   Hand lay-up technique

COMPOSITE SAMPLES PREPARATION

In order to develop composite samples, a mold of 15 cm × 15 cm (length × width) and 1.5cm thickness was prepared. A mold release spray was applied at the inner surface of the mold for quick and easy release of the composite. Fibers were uniformly distributed within the boundaries of the mold. In order to ensure uniform fiber distribution, the spreading was done layer by layer so that the averaging effect will minimize the variation of mass. This method was especially beneficial at low fiber content. No visible voids were found in the prepared samples. A mixture of epoxy and hardener (CHS HARDENER P11) was prepared as per manufacturer (SPOLCHEMIE) guidelines with a ratio of 100:10 and stirred well for uniform mixing. The mixture was dispensed over the fibers in the mold very carefully to ensure uniform distribution of epoxy throughout the samples.

Fig.4 Dried oranges and its peel with sieve analysis & preparation of the mould



Composite without FillerFiller composite   Narepa (uni directional) composite

Narepa (unidirectional) with filler Uttareni (uni directional) Hybrid with filler

Fig.5Preparation of natural fiber reinforced composite

Table 1. Volume fraction of Natural Fibre with Bio Filler and Epoxy Polymer

Specimen	Natural Fibre (Vol %)	Bio Filler (Vol %)	Epoxy Polymer (Vol %)	Treatment of Bio Filler/Natural Fibre	Orientation of the Composite
1	-	orange peel powder (20%)	80%	Treated (with sodium hydroxide alkali solution)	Unidirectional
2	Narepa (30%)	-	70%	Treated	Unidirectional
3	Narepa with Bio filler: Narepa(30%)	10%	60%	Treated	Unidirectional
4	Uttareni (30%)	-	70%	Treated	Unidirectional
5	Uttareni with Biofiller: Uttareni (30%)	10%	60%	Treated	Unidirectional
6	Hybrid (Narepa(35%)+ Uttareni (35%))	-	30%	Treated	Bi Directional
7	Hybrid with Bio filler (Narepa(30%)+ Uttareni (30%))	10%	30%	Treated	Bi Directional

3. **CHARACTERIZATION**

Compression Test:

To investigate the compression properties of the samples, universal testing machine Zwick/Roell Z100 by ASTM D 7264 standard was used. Samples were cut as per ASTM standards as $60 \times 60 \times 10$mm for testing. Ten measurements were taken and the average was reported.

The length, width and depth of each specimen were measured by Vernier Caliper before the test. Each specimen was placed centrally between the two compression plates, such that center of the moving head is vertically above the center of the specimen. Load was applied on the specimen by moving the movable head of the universal testing machine until the specimen breaks. The Ultimate compressive strength was calculated along and across the grains for all samples. The compressive strength was calculated by using equation (1).

Compressive Strength= Maximum load/Cross sectional are of the specimen (1)

Fig.6 Universal testing machine

Flexural Strength Testing

In order to investigate the Flexural strength of the composites, the samples were cut into size 150×20×10mm as per the ASTM standards and the test was performed by universal testing machine Zwick/Roell Z100 by ASTM D 7264 standard. The distance between the supports was taken less than 13.3cm so there will be stress induced in the specimen, then the bending stress induced gives the flexural strength of the specimens. The gauge length of 70mm, extension rate of 1mm/min and load of 7kN was used. The flexural strength was calculated by using equation (2)

$$\text{Flexural stress} = \frac{M}{I} \times Y \qquad (2)$$

where M represents bending stress; I represent the moment of inertia; Y represents distance. Ten measurements were taken and the average was reported.

Impact Test

To investigate the Impact properties of the samples, Charpy Impact tester from Zwick/Roell HIT 50P, Ulm, Germany was used according to ISO 179/1 standard. The energy absorbed by the sample was calculated from the height the arm swings to after hitting the sample. A notched sample was used to determine impact energy and notch sensitivity. Samples were cut as per ASTM standards as $55 \times 10 \times 10$mm for testing. Ten measurements were taken and the average was reported.

Fig.7 Impact tester

The width and depth of each specimen were measured by Vernier Caliper before the test. Specimens were placed on the specific slot and the pendulum was allowed to Impact with 30J energy in order to hit and break the specimen. The absorbed energy was recorded, and the Impact strength was calculated with the calculated values of cross-sectional area for all samples. The Impact strength was calculated by using equation (3).

$$\text{Impact strength} = \text{Energy absorbed} / \text{cross sectional area of specimen} = E/BD \quad (3)$$

Where E, is the energy at break, in joules; B, is width of the specimens in millimeters; D, depth or thickness of the specimens in millimeters.

Hardness Test

To investigate the Hardness properties of the samples, Rockwell hardness test was used which consists of indenting the test specimen with a diamond cone or hardened steel ball indenter. The indenter was forced into the test material under a preliminary minor load 60kgf. The indenter used in this test was ¼ ball and the scale was L scale.The permanent increase in depth of penetration, resulting from the application and removal of additional major load was used to calculate the Rockwell hardness. Samples were cut as per ASTM standards E384-16 as $55\times 10 \times 10$mm for testing. Three trails were taken and the average was reported which gives the Rockwell Hardness Number of specimens.

Fig.8 Rockwell hardness Tester

X-Ray diffraction Test

This test is meant forstudy of the crystal structure and is used to identify the crystalline phases present in a material. The graph obtained in this test has a shifted peak when vary contents materials or vary temperature. The peaks on plane changed such as transfer to another degree, higher intensity, and lower intensity. As first part of data evaluation, diffraction peaks were identified. by performing the required steps.

Fig.9 X-ray diffraction machine

This analysis was carried out by using X-Ray Diffraction with small angle scattering and polycrystalline equipment (Rigaku's ART division technologies, Inc.) with a specimen size of 3cm × 1cm × 1cm.

RESULTS AND DISCUSSION

Mechanical Properties

Effect of Fiber Type on Compressive Strength of Composites:

Table2. Compressive Strength of Composite samples

S.No	Specimen	Load (KN)	Area along the grains (mm^2)	Area across the grains (mm^2)	Compressive strength along the grains (N/mm^2)	Compressive strength across the grains (N/mm^2)
1	Filler(orange peel powder)	24.7	629.901	3634.8792	39.21	6.79
2	Narepa	23.8	621.3166	3651.471	38.30	6.517
3	Narepa with filler	32.1	632.7054	3654.8058	50.73	8.78
4	Uttareni	28	633.596	3653.596	44.192	7.66
5	Uttareni with filler	29.6	628.1176	3642.1176	47.12	8.12
6	Hybrid	45.7	625.57	3647.545	73.05	12.52
7	Hybrid with filler	19.6	624.7428	3644.534	31.37	5.37

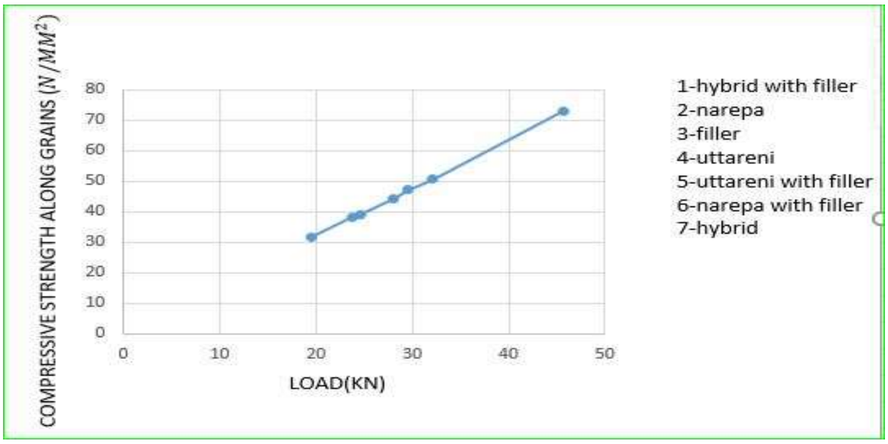


Fig. 10 Compressive strength of composite samples along grains

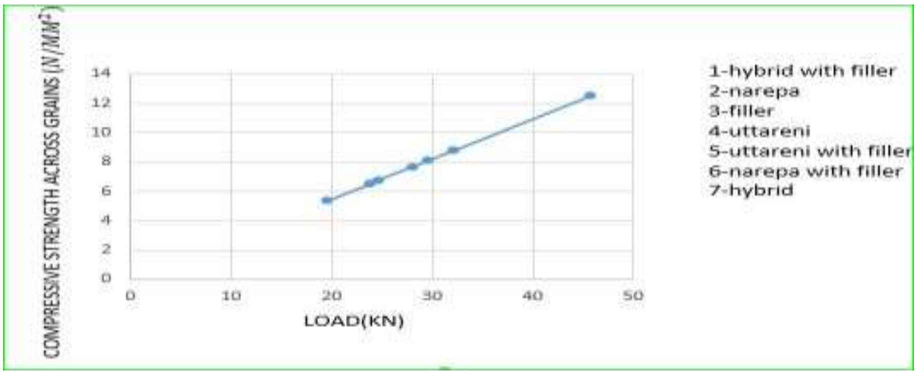


Fig. 11 Compressive strength of composite samples across grains

Compression test has been conducted for seven composite samples. From the results, it has been found that hybrid composite has maximum compressive strength when compared to remaining samples.

Effect of Fiber Type on Impact Strength of Composites:

The ability of the material to resist fracture when load is applied at high speed is known as impact strength. In composites with epoxy resin, the curing process enables the formation of a complex 3D network which increases the mechanical performance substantially. The impact properties of the composites with Narepa, Uttareni fibers and orange peel as bio filler have been investigated. There is a substantial improvement of impact strength as compared to that of pure green epoxy. The results revealed that the hybrid composite have relatively higher impact strength than the remainingcomposite samples as shown in Table 3.

Table. 3 Impact Strength of Composite samples:

S.NO	COMPOSITE SPECIMEN	ENERGY ABSORBED BY SPECIMEN(Joules)	CROSS SECTIONAL AREA (mm2)	IMPACT STRENGTH(j/mm2)
1	filler(Range peel powder)	2	115.13	0.017
2	Narepa	2	110.46	0.018
3	Narepa with filler	4	108.99	0.0367
4	Uttarreni	4	109.62	0.0364
5	Uttarreni with filler	4	108.36	0.0369
6	Hybrid	38	106.81	0.35
7	Hybrid with filler	20	109.14	0.183

Effect of Fiber Content on Impact Strength of Composites:

Izodimpact test has been conducted for the seven composite samples. It has been found that hybrid composite has possess more impact strength compared to remaining composite samples.It should be noted that tenacity of the hybrid fiber is higher than the Uttarreni and Narepa fibers with or without filler as shown in Table 3. Further, the hybrid fiber reinforced composites have higher impact strength than the Uttarreni and Narepa fibers composites.

Results revealed that when increasing fiber content, impact strength also increases (Figure 5). It has been observed that 10%, 15% and 20% of the Uttarreni and Narepa fibers content shows an impact strength of 0.0367J/mm^2 , 0.0369 J/mm^2 and 0.036 J/mm^2 , respectively.

It is also observed that, even though the cross sectional area is small for hybrid composite, it was absorbed an energy 38 joules with higher impact strength 0.35 J/mm^2 when compared to Uttarreni and Narepa fibers with or without filler composite samples. Overall, a 35% increase in impact strength is observed with the increase of fiber content from 10% to 20%. In a fiber reinforced composite system, the reinforcement is the main constituent which is responsible to bear the impact load.

Izodimpact test has been conducted for the seven composite samples. The results revealed that hybrid composite has possess more impact strength compared to remaining composite samples.

Effect of Fiber Type on Hardness of Composites:

The ability of the material to resist fracture when load is applied is known as hardness. In composites with epoxy resin, the curing process enables increases the mechanical performance substantially. The hardness properties of the composites with Narepa, Uttareni fibers and orange peel as bio filler have been investigated. There is a substantial improvement of impact strength as compared to that of pure green epoxy.

Table. 4 Hardness of Composite Samples

S NO	MATERIAL TAKEN	SCALE READING	INDENTOR	LOAD(Kgf)	ROCKWELL HARDNESS			ROCKWELL HARDNESS NUMBER(RHN) avg $=\frac{t1+t2+t3}{3}$
					Trail 1	Trail 2	Trail 3	
1	Filler(Orange peelpowder)	L	1/4 ball	60	69	60	65	64.66
2	Narepa	L	1/4 ball	60	70	65	76	70.333
3	Narepa with filler	L	1/4 ball	60	60	66	64	63.3
4	Uttareni	L	1/4 ball	60	61	61	61	61
5	Uttareni with filler	L	1/4 ball	60	69	67	65	67
6	Hybrid	L	1/4 ball	60	65	60	63	62.6
7	Hybrid with filler	L	1/4 ball	60	62	58	56	58.6

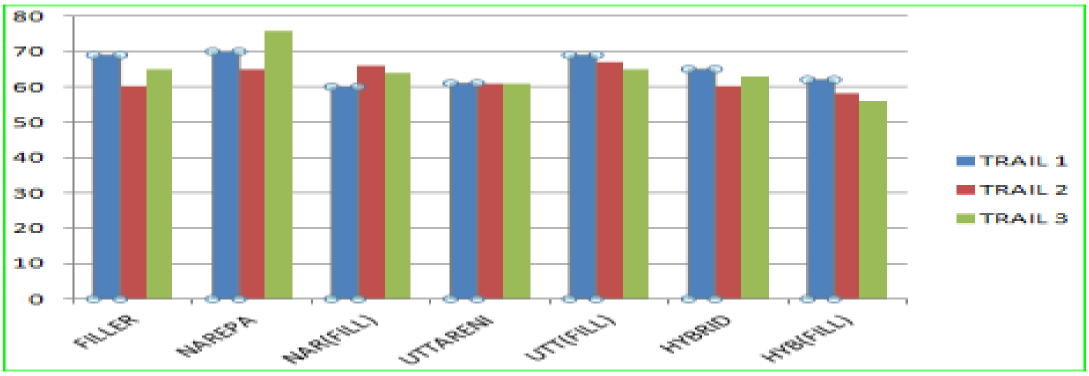


Fig. 12 Hardness of composite samples

Rockwell hardness test has been conducted for seven composite samples. It has been found that Narepa fiber reinforced composite has maximum resistance to indentation when compared to remaining composite samples as shown in above Table 4 and Fig. 12.

Effect of Fiber Type on Flexural Strength of Composites:

The ability of a material to resist bending deformation under load is called flexural strength. It mainly depends upon the type of reinforcement and matrix. Flexural test has been conducted for seven composite samples. The results of the study revealed that the flexural strength of the hybrid with filler reinforced composite is higher than the Uttarreni and Narepa fibers with or without orange peel bio filler composites as shown in Table 7 and Figure 6. It can be justified based on the fact that the tenacity of the hybrid with filler reinforced compositefibers is higher than the Uttarreni and Narepa fibers with or without fillerfibers. It is also well known that bending rigidity is directly proportional to the tensile modulus. Researchers have previously reported that by increasing the tenacity of the fiber, the flexural strength of the composites can be increased [35,36].

Table. 5. Flexural strength of composite specimens

S.No	COMPOSITE SPECIMEN	Load(w)KN	BENDING MOMENT(M)	MOMENT OF INERTIA(I)	FLEXULAR STRENGTH (N/mm^2)
1	Filler(orange peel powder)	0	0	1666.66	0
2	Narepa	0.5	18750	1666.66	56.25
3	Narepa with filler	0.5	18750	1666.66	56.25
4	Uttareni	0.6	22500	1666.66	67.5
5	Uttareni with filler	0.6	22500	1666.66	67.5
6	Hybrid	0.5	18750	1666.66	56.25
7	Hybrid with filler	1.1	41250	1666.66	123.75

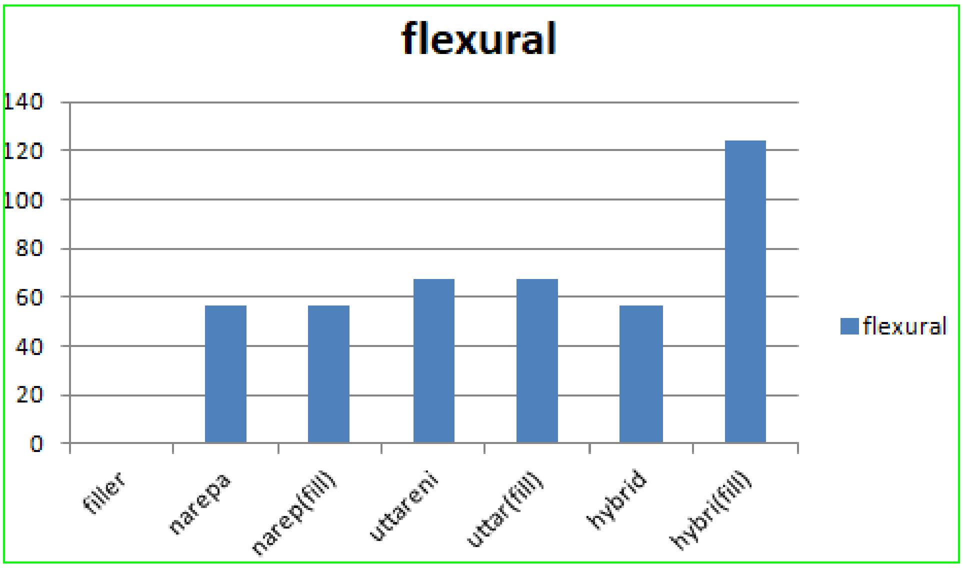


Fig.13 Flexural strength of composite specimens

Effect of Fiber Content on Flexural Strength of Composites:

It has been observed that when increasing fiber content, flexural strength also increases. The flexural rigidity has a direct proportionality with the modulus of elasticity or tenacity. The fiber reinforcement is the major load-bearing element in a composite system. By increasing the fiber volume fraction (FVF) from 10% to 20%, there is a substantial increase in flexural strength. FVF can be further increased by impregnation using the infusion method. As the set up used in the current investigation was a relatively simpler one, there was a restriction to maximum FVF and preparing void-free samples. Previously, researchers have found a significant increase in flexural strength by increasing fiber content in composites [37,38]

Flexural test has been conducted for seven composite samples. It has been found that hybrid with filler reinforced composite has maximum flexural strength when compared to remaining samples.

X-RAY DIFFRACTION TEST

X-ray diffraction is a technique that reveals structural information such as chemical composition, crystal structure, crystal in size strain preferred orientation and layer thickness. Therefore, X-ray diffraction is used to analyse a wide range of materials, from powders and thin films to Nano materials and solid objects. In powders, chemical phases are identified qualitatively and as well as quantitatively by using X-ray diffraction. High resolution reveals the layer parameters such as composition thickness, roughness and density in semi-conductor thin films. Polymers and composites by X-ray diffraction analysis determines to the degree of crystallinity for semi crystalline amorphous polymeric and composite materials.

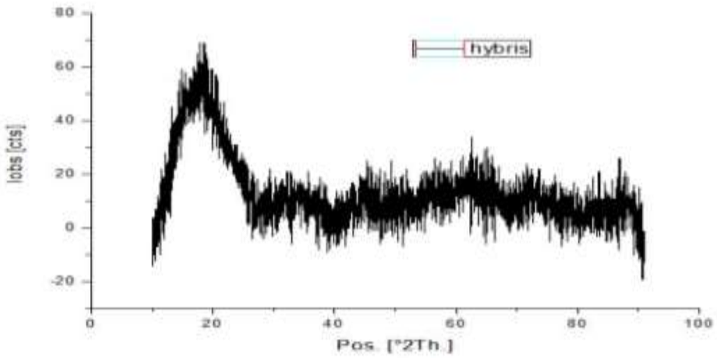


Fig. 14 X-ray diffraction analysis for hybrid composite

In this work from the results, it is revealed that all remaining composite samples higher values for maximum node as well as at minimum node when compared to Hybrid composite. Hybrid composite has maximum node at 70 and minimum node at -20. so up to maximum node 70 the composite has homogeneous after that it becomes heterogeneous. This indicates that Hybrid composite possess better chemical composition, crystal structure properties compared to remaining composite samples.

Metallurgical studies of natural fiber composite materials

In this work metallurgical studies of the prepared natural fiber composite have been conducted using Metallurgical microscopes. The images obtained are analyzed using Micro cam 4.0 software which is a metallurgical image analysis system for finding solutions in metallographic. It is a powerful integration of hardware and software that enables metallurgists to automatically capture images. It is a tool that provides enhancement and measurement visualization analysis and processing of image data.

In this work the obtained image of the composite specimens are tested for various parameters like particle measurement, density, nodularity, porosity, grain measurement and flakes. It is found from mechanical characterization results, the Hybrid with filler and without filler specimens possesses good mechanical properties when compared to other specimens of this study. So that the Hybrid with filler and without filler specimens have been considered for this metallurgical study. The results obtained are as follows.

Metallurgical study of Hybrid with Filler:

Before experiment

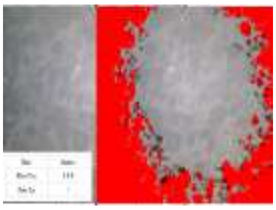
Particle measurement

Density

Nodularity

Porosity

Grain measurement



Flakes

Grain crack

Fig. 15 Various metallurgical parameters of Hybrid with Filler composite

Table. 6.Particle measurement details for Hybrid with Filler

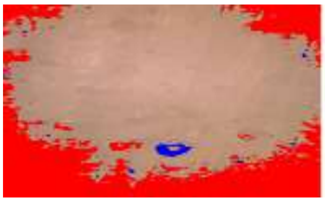
SL.NO	**1**	**2**	**3**	**4**	**5**
Length	55.613	532.979	45.898	621.599	80.749
Width	33.782	532.979	26.381	376.956	63.785
Area	2506.925	576828.255	692.521	143815.789	3109.418
Asp.Ratio	1.646	1.000	1.740	1.649	1.266
Roundness	43.250	30.087	40.323	40.725	65.262
Shape	0.023	0.033	0.025	0.025	0.015
Box Area	2506.92	576828.255	692.521	143815.789	3109.418
Centriod-X	130	102	254	565	572
Centriod-Y	164	279	395	412	277
Elongation	12.134	25.043	8.01	12.770	6.540
Orientation	149.00	1.000	86.000	136.000	82.000
Circle Diameter	113.03	1714.425	59.403	856.049	125.874
Sphere Volume	109104.62	30803452.63	15840.915	3406836.841	150712.695
Major Axis	55.613	532.97	45.898	621.59	80.749
Minor Axis	11.068	265.31	5.263	23.684	20.469
Thread Length	158.60	3642.35	63.588	1239.151	115.740
Thread Width	15.806	158.36	10.89	116.060	26.866
Fibre Length	174.41	3800.72	74.47	1355.210	142.605
Fibre Width	14.374	151.768	9.29	106.121	21.804
Min.Radius	15.345	729.47	5.88	108.790	22.638
Max.Radius	43.798	781.738	24.26	335.895	39.561

Metallurgical study of Hybrid without Filler:

Before experiment

Particle measurement

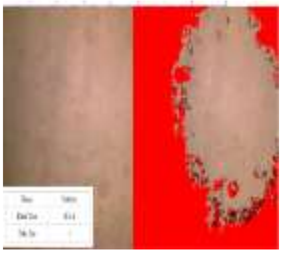
Density



Nodularity

Porosity

Grain measurement



Flakes

Grain crack

Fig. 16 Various metallurgical parameters of Hybrid without Filler composite

Table. 7.Particle measurement details for Hybrid without Filler

SL.NO	**1**	**2**	**3**	**4**	**5**
Length	708.97	708.97	27.972	106.64	708.97
Width	708.97	708.97	27.972	76.502	708.97
Area	1274743.76	1274743.76	3850.4	6087.2	127427.76
Asp.Ratio	1.000	1.000	1.000	1.394	1.000
Roundness	36.646	36.646	49.821	59.073	36.646
Shape	0.027	0.027	0.020	0.017	0.027
Box Area	1274743.76	1274743.76	3850.4	6087.2	127427.76
Centriod-X	302	302	302	354	302
Centriod-Y	263	263	352	362	263
Elongation	50.779	50.779	8.773	4.967	50.779
Orientation	0.000	0.000	12000	184000	0.000
Circle Diameter	2548.62	2548.62	140.071	176.119	2548.62
Sphere Volume	51023.49	51023.49	207678.96	412822.73	51023.49
Major Axis	708.97	708.97	27.972	106.645	708.97
Minor Axis	247.36	247.36	24.139	50.241	247.36
Thread Length	7883.78	7883.78	159.68	125.30	7883.78
Thread Width	161.692	161.692	24.113	48.580	161.692
Fibre Length	8045.47	8045.47	183.79	173.88	8045.47
Fibre Width	158.44	158.44	20.950	35.008	158.44
Min.Radius	678.52	678.52	33.701	29.422	678.52
Max.Radius	1053.85	1053.85	50.619	58.252	1053.85

Conclusions

Mechanical properties and Metallurgical studies of Uttareni and Narepa along with orange peel powder as filler material in epoxy resin composites with different reinforcement configurations were evaluated. This paper demonstrates that fibre configuration plays an important role in obtaining high mechanical strength. Different mechanical properties in the form of Compression, Hardness, impact, flexural, XRD and metallurgical tests were recorded for these composite specimens.

In this work, untreated and treated Uttareni and Narepa along with orange peel powder as filler were taken to study of the composites. It provides better filler and fiber interaction and good interfacial adhesion between filler/ fiber and fewer voids in the composite. Generally, high filler content results in good composite performance, but after a certain limit, the matrix does not adhere well with a saturated amount of filler, and the composite impact strength decreases. So this study encourages the inclusion of treated hybrid fillers in preparing particulate composites. Test results exhibitedsignificant improvement in mechanical properties of hybrid composite material without filler when compared to other combinations of composite materials of this work.

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