Fabrication and Mechanical Properties of Short Sisal Fiber Reinforced Epoxy Composite

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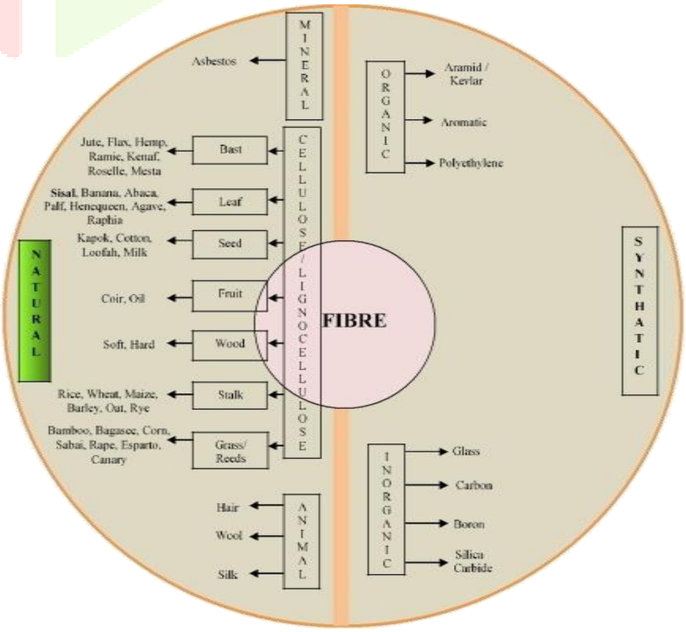
Abstract: In ancient history of composite, it was first time used by Egyptians and Mesopotamian which were construct strong and durable buildings with mixture of straw and mud about 1500s B.C. Later Mongols invented first bow which was made by mixture of bone, wood and animal glue [1]. But according "Mar-bal" incorporation history was composite around 3400 BC which was used by ancient Mesopotamians in ancient time. They created plywood using the glue and wood strips at different angles. Egyptians prepared death masks with composite about to 2181-2055 BC. In about 1200 AD Mongols invented first composite bow. The bow was small and accurate and had extremely strength. In 1800's there was great revolution in the chemistry in which polymerization produces synthetic resins. In early 1900's different type of plastics such as polyester, vinyl and phenolic was developed. First glass reinforced polymer composite was prepared in thirties.

I. INTRODUCTION

In ancient history of composite, it was first time used by Egyptians and Mesopotamian which were construct strong and durable buildings with mixture of straw and mud about 1500s B.C. Later Mongols invented first bow which was made by mixture of bone, wood and animal glue [1]. But according "Mar-bal" incorporation history was composite around 3400 BC which was used by ancient Mesopotamians in ancient time. They created plywood using the glue and wood strips at different angles. Egyptians prepared death masks with composite about to 2181-2055 BC. In about 1200 AD Mongols invented first composite bow. The bow was small and accurate and had extremely strength. In 1800's there was great revolution in the chemistry in which polymerization produces synthetic resins. In early 1900's different type of plastics such as polyester, vinyl and phenolic was developed. First glass reinforced polymer composite was prepared in thirties. Unsaturated polyester was patented and epoxy was introduced in thirties. During the World War II composites were produced from the research. In this time requirement of different goods were produced by composite materials such as boat hulls and electronic equipment etc. the composite was commercialized after the WW II. In 1947 a fully composite automobile was prepared and tested. In 1950 there was revolution of manufacturing methods of composite such as pultrusion, resin moulding transfer and vacuum bag moulding etc. The carbon fibre composites were available commercially before but carbon fibre as patented in 1961. Carbon was improved the stiffness of the thermoset hence sports, marine, automobile product manufactured by the carbon reinforced composites. Polyethylene come into existence around late 1960's. In the middle of 1990's there was mainstream of composite manufacturing and construction. It was the cost effective, lightweight, and good replacement of traditional materials like metals.



S.No.	Fibres	Species*	Origin*	Diameter (μm)	Density (g/cm^3)	TS (MPa)	TM (GPa)	Specific Modulus (GPa $\times cm^3/g$)	Elongation (%)	Ref.
1	Abaca	Musa textiles	Leaf	10-30.0	1.5	400-980	6.2-20	9	1.8-4.8	[16]
2	Agave	-	-	-	1.4	350	4.2	-	20	[17]
3	Alfa	Stippa tenacissima	Grass		0.89	35	22	25	5.8	[16]
4	Bagasse	-	-	10-34.0	1.25	222-290	17-27.1	18	1.1	[16]
5	Bamboo	(>1,250 species)	Grass	25-40	0.6-1.1	140-800	11-32.0	25	2.5-3.7	[16]
6	Banana	Musa indica	Leaf	12-30.0	1.35	500	12	9	1.5-9	[16]
7	Coconut	Cocos nucifera	Fruit	-	1.1	140–225	3–5	-	25–40	[18,19]
8	Coir	Cocos nucifera	Fruit	10–460	1.15–1.46	95–230	2.8–6	4	15–51.4	[16]
9	Cotton	Gossypium sp.	Seed	10–45	1.5–1.6	287–800	5.5–12.6	6	3–10	[16]
10	Curaua	Ananas erectifolius	-	7–10	1.4	87–1150	11.8–96	39	1.3–4.9	[16]
11	Flax	Linum usitatissimum	Stem	12–600	1.4–1.5	343–2000	27.6–103	45	1.2–3.3	[16]
12	Hemp	Cannabis sativa	Stem	25–600	1.4–1.5	270–900	23.5–90	40	1–3.5	[16]
13	Henequen	Agave fourcroydes	Leaf	-	1.2	430–570	10.1–16.3	11	3.7–5.9	[16]
14	Isora	Helicteres isora	Stem		1.2–1.3	500–600	-	-	5-6.0	[16]
15	Jute	Corchorus capsularis	Bast	20–200	1.3–1.49	320–800	30	30	1–1.8	[16]
16	Kenaf	Hibiscus cannabinus	Stem		1.4	223–930	14.5–53	24	1.5–2.7	[16]
17	Nettle	Urtica dioica	Stem	-	-	650	38	-	1.7	[16]
18	Oil Palm	Elaeis guineensis	Fruit		0.7–1.55	150–500	80–248	0.5–3.2	17–25	[16]
19	Piassava	Attalea funifera	Leaf		1.4	134–143	1.07–4.59	2	.8–21.9	[16]
20	PALF	Ananus comosus	Leaf	20–80	0.8–1.6	180–1627	1.44–82.5	35	1.6–14.5	[16]
21	Ramie	Boehmeria nivea	Stem	20–80	1.0–1.55	400–1000	24.5–128	60	1.2–4.0	[16]
22	Raw date palm	Phoenix dactylifera	Leaf	100–1000	-	58–203	2–7.5	-	5–10	[20]
23	Sisal	Agave sisilana	Leaf	8–200	1.33–1.5	363–700	9.0–38	7	2.0–7.0	[16]
24	Wood	(>10,000 species)	Stem	-	1.5	666	26	-	-	[17]

Table 1. 1 Physical and mechanical properties of natural fibres

*Reference: Maya Jacob John,Rajesh D. Anandjiwala "Recent Developments in Chemical Modification and Characterization of Natural Fibre-Reinforced Composites'' Polymer Composites-2008, DOI 10.1002/pc.20461

Table 1. 2 Chemical composition of natural fibres

S.No.	Fibres	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Pectin (%)	Wax (%)	Ash (%)	Moisture (%)	Ref.
1	Sisal	65.8	12.0	9.9	0.8	0.3	4.2	10.0	[21]
2	cotton	82.7	5.7	28.2	5.7	0.6	-	10.0	[21]
3	Jute	64.4	12.0	0.2	11.8	0.5	.5-5.1	10.0	[21]
4	Flax	64.1	16.7	2.0	1.8	1.5	13.1	10.0	[21]
5	Ramie	68.6	13.1	0.6	1.9	0.3	-	10.0	[21]
6	Bamboo	73.8	12.5	10.2	0.4	-	2.3	11.7	[22]
7	Hemp	55-80.2	12-22.4	2.6-13	0.9-3	0.2	0.5-0.8	6.5	[23]
8	Abaca	56-63	15-17	7.0-9.0	0.3	0.1	3.2	-	[23]
9	Henequen	77.6	4.0-8.0	13.1	-	-	-	-	[23]
10	Kenaf	37-49	18-24	15-21	8.9	0.5	2.4-5.1	-	[24]
11	Oil Palm	42.7-65	17.1-33.5	13.2-25.3	-	0.6	1.3-.6	-	[25]
12	Wheat straw	32.0	20.5	17.4	-	-	-	8.0	[26]
13	Sugar Cane	28.3-55	20-36.3	21.2-24	-	0.9	1.4	-	[27]
14	Coir	32–43	0.15–0.25	40–45	3–4	-	-	8.0	[28]
15	Banana	48-60	10.2-15.9	14.4-21.6	2.1-4.1	3.0-5.0	2.1	2.3	[29]
16	Pine apple	57.5-74.3	80.7	4.4-10.1	1.1	3.3	0.9-4.7	-	[30]

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S.No.	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)	. Ref.
1	60	28	8	0.5	[34]
2	73	10.1	7.6	3.1	[35]
3	78	10	8	1	[36]
4	66-72	12	14.0-10.0	-	[37, 38]
5	85-88	-	4.0-5.0	-	[39, 40]
6	47-78	10.0-24.0	7.0-11.0	0.6-1	[41]
7	85-88	-	4.0-5.0	-	[42]
8	65	12	9.9	-	[43]
9	60	11.5	8	-	[44]

Table 1. 3 Chemical composition of sisal fibre in various research papers

Table 1. 4 Mechanical properties of sisal fibre in various research papers

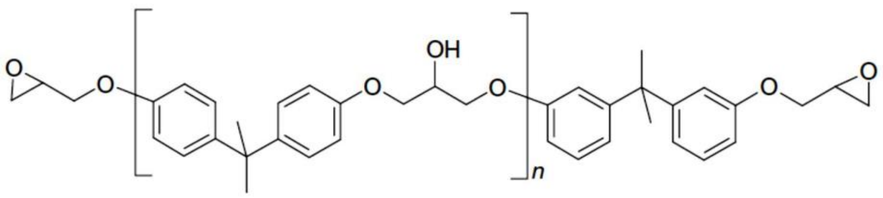
S.No.	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation (%)	Ref.
1	550	24	2.4	[45]
2	400-700	7.0-20.0	2.0-14.0	[45]
3	468	22	-	[46]
4	400-700	9.0-38	2.0-14.0	[41]
5	400-700	9.0-20.0	5.0-14.0	[42]
6	530-630	17-22.0	3-7.0	[36]
7	400-700	9.0-20.0	5.0-14.0	[37]
8	434	17.5	-	[47]
9	568-640	9.0-22.0	5.0-7.0	[48]
10	793.8	9.74	8.15	[49]
11	350	12.8	7.0-8.0	[43]

Table 1. 5 Mechanical properties of thermoplastic matrix

S.No.	Thermoplastic	Grade	Density (g/cm^2)	Tg (°C)	Tm (°C)	TS	TM(GPa)	Impact Strength	Elongation (%)	Ref.
1	Polypropylene	Molpen HP500V	0.910	-10	170.9	28.0	2	-	20	[52, 53]
2	Polylactide	2002D	1.24	47.0	154.8	56.3	3.6	-	5	[53]
		4032D	1.24	50.7	171.2	65.8	3.6	-	7	[53]
3	Polyester	Unsaturated	1.2			61	4	-	2.5	[54]
4	Nylon Or Polyamid	11	-	-	-	30–70	-	16–110 J/m	2–56	[52]
		12	-	-	-	25–59	-	16–160 J/m	0.60–200	
		46	-	-	-	30–214	-	40–100 J/m	0.6–53	
		6	-	-	-	37–98	-	10–98 J/m	0.40–25	
		610	-	-	-	47–66	-	35–50 J/m	2.4–100	
		612	-	-	-	26–173	-	29–89 J/m	2.0–32	
		66	-	-	-	42–91	-	10–95 J/m	0.7–19	
5	Phenolic plastics	-	-	-	-	0.2	9	-	-	[52]
6	Polyethylene	HDPE	0.96	-	130	26	1.4	-	-	[52, 55]

		LLDPE	0.93	-	124	14	0. 450	-	-	[52, 55]
		LDPE	0.92		108	12	0. 180	-	-	[52, 55]
7	PVC	-	1.35	90	199	48	3.300	-	145	[52, 55]
8	Polystyrenes	-	1.04-1.06	95	84-106	46	2.9	0.17 J/cm	3-4	[52, 57]
9	Acrylonitrile-butadiene-styrene (ABS)	-	1.05	102	105	46	2.5	3.5 J/cm	-	[52, 55]
10	Poly(Lactic Acid)	4032D	60.68	165.7		42.5	2.6	-	1.2	[56]
		TE-2000	1.25	-	165	-	-	-	-	[57]
		2002D	1.24	60	153	48-110	3.5-3.8	13 J/m	2.5-100	[58]
11	Poly(ethylene terephthalate) PET	-	1.37	75	250	47	3.1	79 J/m	50-300	[58]
12	Polyetheretherketone (PEEK)	-	1.32	143	334	92	3.6	83 J/m	2.0	[59, 60]
13	Polycarbonate	-	-	151	-	59.82*	-	-	-	[61]
14	Polyphenylene	-	1.32	-	-	70	-	-	-	[62]
	sulfide									
15	Polysulfone	-	1.25	-	-	75	-	-	-	[62]
16	Polyamideimide	-	1.38	-	-	95	-	-	-	[62]
17	Polyimide	-	1.46	-	-	120	-	-	-	[62]
18	Polyetherimid	-	-	-	-	105	-	-	60	[62, 63]
19	Polyethersulfone	-	-	-	-	11.9	-	64.08J/m*	40	[63]
20	Polysulfones	(Bisphenol A)	1.24	-	-	70.3	2.482	64.08J/m*	-	[63]
		Polyether	1.37	-	-	84.1	2.696	85.44J/m*	-	
		Polyphenyl	1.29	-	-	71.7	2.137	640.8J/m*	-	

** 1 kgf/cm^2=0.980665 bar, 1 ft-lbs/in=53.4 J/m, 1 kgf-cm/cm=9.80655 J/m*



Materials

Matrix materials

Matrix materials are different types as discuss in details in last chapter such as metals, ceramics and polymers which used in composite fabrication. Polymer matrix is very popular due to low cost and simple fabrication manufacturing methods as compared with ceramics and metals. As discussed polymer matrix is two types thermosets and thermoplastics. In this work thermoset polymer are selected. Thermosets are epoxy, polyester, phenolic and vinyl ester

Flexural test-;

Flexural testing specimens are prepared as per standard ASTM D 790. The dimensions of the rectangular shaped flexural specimens are 80 mm × 20 mm × 3.2 mm with span length 48 mmFigure 4.5 shows the specimens of flexural test for S20 composite. These specimens are also tested on the Tinius Olsen H 10 K-L (bi-axial testing machine, load capacity 10 kN, shown in Figure 4.4) with 2 mm/min crosshead speed. The flexural testing is done using a three point bending.

RESULT AND DISCUSSIONS

Mechanical properties

Tensile test

Tensile strength and modulus of epoxy and short sisal fibre reinforced composite are tabulated in the Table 5.1 and Table 5.2 and the graph is plotted with corresponding data in Figure. It is observed that there is no enhancement in tensile strength of epoxy by reinforcement of short sisal fibre but tensile modulus is increased. The tensile strength of composite is depends on the various parameter such as length of reinforcement, type of matrix, orientation of fibre and manufacturing technique etc. The reason of the decreased tensile strength is that applied load may be transfer in all direction due to orientation of fibre or it may be due to insufficient force transfer from epoxy to the fibre because of poor adhesion between fibre and matrix. Tensile properties of the composite S10 are seen maximum as compared to all the sisal fibre composites. Tensile strength of S10 is found 24.61%, 19.26% and 20.26% more than S5, S15 and S20 respectively and tensile modulus of S10 is observed 9.17%, 19.62% and 24.38% more than S5, S15 and S20 respectively.

Table 5. 1 Tensile test result of sisal fibre reinforced epoxy composites

Composites	Max. Force (N)	S.D.	Max. Displacement (mm)	S.D.	Tensile Strength (MPa)	S.D.	Tensile Modulus (GPa)	S.D.
E (a)	2175		10.60		52.28		0.225	
E (b)	1818		9.56		43.70		0.219	
E (c)	1880		9.88		45.19		0.227	
E (d)	1918		9.50		46.11		0.222	
E (e)	1794	152.37	8.38	0.80	43.13	3.66	0.254	0.014
Avg.	1917	152.37	9.58	0.80	46.08	3.66	0.229	0.014
S5 (a)	1329		7.66		31.94			
S5 (b)	1379		7.99		33.14			
S5 (c)	1317		6.53		31.66			
S5 (d)	1278		7.09		30.72			
S5 (e)	1416	54.06	6.44	0.68	34.04	1.30		
Avg.	1344	54.06	7.14	0.68	32.30	1.30		
S10 (a)	1816		9.45		43.65		0.228	

S10 (b)	1644		9.18		39.52		0.227	
S10 (c)	1834		8.03		44.09			
S10 (d)	1538		8.35		36.97			
S10 (e)	1540	144.15	7.47	0.82	37.02	3.47		
Avg.	1674	144.15	8.50	0.82	40.25	3.47		
S15 (a)	1478		8.30		35.52			
S15 (b)	1313		8.39		31.55			
S15 (c)	1359		7.50		32.67			
S15 (d)	1390		8.61		33.42			
S15 (e)	1481	73.89	7.81	0.45	35.59	1.78		
Avg.	1404	73.89	8.12	0.45	33.75	1.78		
S20 (a)	1391		8.36		33.43			
S20 (b)	1568		8.44		37.69			
S20 (c)	1393		8.50		33.47			
S20 (d)	1316		8.28		31.62			
S20 (e)	1296	107.29	7.00	0.63	31.15	2.58		
Avg.	1393	107.29	8.12	0.63	33.47	2.58		

Table 5. 2 Summary of tensile test results of sisal fibre reinforced epoxy composites

Composites	Tensile Strength (MPa)	S.D.	Tensile Modulus (GPa)	S.D.
E	46.08	3.66	0.229	0.014
S5	32.30	1.30	0.229	0.021
S10	40.25	3.47	0.250	0.023
S15	33.75	1.78	0.209	0.018
S20	33.47	2.58	0.201	0.020

Where; F is ultimate failure load in N, L is span of the supporting centre in mm, b and d are the width and thickness of specimen for flexural test correspondingly in mm, m is slope of tangent to the initial straight portion of the load-deflection curve.

Impact test

Impact properties of epoxy and short sisal fibre reinforced epoxy composites are shown in Table 5.5 and Table 5.6 and graph is plotted with corresponding data which is shown in Figure 5.3. Impact properties have enhanced by the reinforcement of sisal fibre into epoxy matrix. It is observed that impact properties of S20 are found to maximuImpact properties of S20 are found 387.57%, 294.46%, 102.23% and 50.29% more than E, S5, S10 and S15 respectively.

Table 5. 5 Impact test results of sisal fibre reinforced epoxy composites

Composites	Impact Energy (J)	S.D.	Impact Strength (kJ/m^2)	S.D.
E (a)	0.1457		6.0711	
E (b)	0.1328		5.5371	
E (c)	0.1296		5.4038	
E (d)	0.1340		5.5871	
E (e)	0.1380	0.0062	5.7538	0.2566
Avg.	0.1360	0.0062	5.6706	0.2566
S5 (a)	0.1719		7.1658	
S5 (b)	0.1695		7.0657	
S5 (c)	0.1780		7.4201	
S5 (d)	0.1645		6.8573	
S5 (e)	0.1567	0.0080	6.5321	0.3343
Avg.	0.1681	0.0080	7.0082	0.3343

Conclusions

The conclusions drawn from the present investigations are as follows:

- Tensile strength of epoxy is not improved by the reinforcing of sisal fibre while tensile modulus, flexural properties and impact properties are found to be improved.
- Tensile properties of the composite S10 are seen maximum compared to those of other sisal fibre reinforced composite.
- Flexural strength is found maximum of S15 while flexural modulus is found of S10.
- Impact properties of sisal fibre reinforced composite are found maximum for the composite S20.

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