iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 Issue: II Month of publication: February 2022

DOI: https://doi.org/10.22214/ijraset.2022.40541

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue II Feb 2022- Available at www.ijraset.com

Fabrication and Depiction of Reinforced Human Hair Polymer Matrix Composites

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Abstract: In recent years, the use of fiber reinforced polymer composites in variety of applications play a major role due to their attractive properties such as light weight, fatigue resistance, easy moldability, high specific strength and modulus. Earlier researchers in past studies have shown that synthetic fiber reinforced polymer composites obtained a better mechanical properties but the applications are restricted to less because of high procurement and manufacturing cost and more weight. To overcome these, nowadays light weight natural fiber reinforced polymer composites are very widely used in the field of automobile, Aerospace, Marine, and Furniture's applications because of their recyclability, easy availability and low cost of materials and production. Human hair is a versatile material identified with a significant potential in the use of reinforcement in composites due to its excellent material properties.

The present work concentrates on the fabrication and study of various physical, mechanical and thermal properties of natural fiber reinforced thermo-set polymer matrix composites. The fabrication was done for eight different types of new set of natural fiber polymer composites which consist of human hair as reinforcement, Epoxy and Vinylesteras the resin with four different set of fiber volume fractions (70:30, 75:25, 80:20, 85:15 ratio of matrix and fiber respectively) using hand layup technique. Then the samples were prepared according to ASTM standard for testing mechanical properties such as Impact Energy, Rockwell Hardness and physical properties such as Density and water absorption. Theoretical density of composites was determined for validating actual density of fabricated composites. Rockwell Hardness was measured on both dry and water absorbed composite samples. Internal structure between fiber and matrix was analyzed by using Scanning Electron Microscope (SEM).

Keywords: Composites, Fiber reinforced polymer, Fabrication process, Hard Facing Electrodes, Hand Layup Technique, Scanning Electron Microscope.

I. INTRODUCTION

A composite material can be defined as a combination of two or more materials that results in improved mechanical and thermal properties than the individual components. The reinforcement and matrix are the two constituents of composites. The reinforcing phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger, and stiffer. The continuous phase is the matrix, which is a polymer, metal, or ceramic. Polymers have low strength and stiffness, metals have intermediate strength and stiffness but high ductility, and ceramics have high strength and stiffness but are brittle. The matrix (continuous phase) performs several critical functions, including maintaining the fibers in the proper orientation and spacing and protecting them from abrasion and the environment.

II. MANUFACTURING METHODS OF COMPOSITES

Construction processes are those used to bring various forms of fiber and fabric reinforcement together to produce the reinforcement pattern desired for a given composite part or end item. Construction processes include both manual and automated methods of fiber placement, as well as adhesive bonding and sandwich construction. Manufacturing of composites can be broken down into the following categories:

1) *Open Mold Process:* Some of the original FRP manual procedures for laying resins and fibers onto forms. Family of FRP shaping processes that use a single positive or negative mold surface to produce laminated FRP structures. The starting materials (resins, fibers, mats, and woven roving's) are applied to the mold in layers, building up to the desired thickness. This is followed by curing and part removal.
2) *Hand Lay Up Method:* Hand layup, or contact molding, is the oldest and simplest way of making composites which is shown in below fig.3.3. It is the Oldest open mold method for FRP laminates, dating to the 1940s when it was first used for boat hulls. Generally large in size but low in production quantity not economical for high production. Applications are standard wind turbine blades, boats, etc.

III. DESCRIPTION OF PROPOSED WORK

The composite materials consist of two phases such as discontinuous phase and continuous phase. The discontinuous phases consist of reinforcement material and continuous phase consist of matrix material.

A. *Human Hair*

Hair is used as a fiber reinforcing material in composites for the following reasons:

1) It has a high tensile strength
2) Hair, a non-degradable material
3) Available in abundance
4) Very low cost.

B. *Physical and Mechanical Properties of Human Hair*

Table 3.1 Physical properties of Human Hair

Fiber	Density, g/cm³	Diameter µm	Tensile Strength, MPa	Elongation at Break, %
Human Hair	1.32	17-180	400	216.94

(Source: International Journal of Mechanical and Industrial Engineering (IJMIE), ISSN No. 2231 –6477, Vol-2, Issue-1, 2012, [8])

In our work, the Human Hair is purchased from Om Balavinainayaga Enterprises, Chennai in India. The fibers are purchased in the size of 100 to 125 mm by the length as shown in Fig 3.1.The present work concentrates on the chopped type of fiber reinforcement. And the fiber size is selected as 30mm by length.

Figure 3.1 Human Hair Purchased From Industry

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C. Matrix Material

In the present work Epoxy LY556 and corresponding hardener HY 951 is used as the matrix material.

1) *Epoxy Resin: Epoxy is chosen as the matrix material for the present research work. Its common name is Bi-sphenol-A-Di-glycidyl-Ether and it chemically belongs to the 'epoxide' family. It has superior mechanical and electrical properties as shown in below Table 3.2.*

Table 3.2 physical properties of Epoxy resin.

Epoxy Resin Property	Value
Density, g/cm³	1.1-.14
Tensile Strength, Mpa	35-100
Compressive Strength, MPa	100-200
Impact Strength J/cm	0.3
Elastic Modulus, Gpa	3-6
Elongation , %	1-6
Water Absorption, (24 Hrs at 20ºc)	0.1-0.4
Cure Shrinkage, %	1-2

(Source: www.fibreglast.com)

2) *Vinylester Resin:* Vinyl Ester, or Vinylester, is a resin produced by the esterification of an epoxy resin with an unsaturated monocarboxylic acid. The reaction product is then dissolved in a reactive solvent, such as styrene, to 35–45 percent content by weight. It can be used as an alternative to polyester and epoxy materials in matrix or composite materials, where its characteristics, strengths, and bulk cost intermediate between polyester and epoxy. Table 3.3 shows the various Physical properties of Vinylester resin.

Table 3.3 Physical properties of Vinylester resin.

Vinylester Resin Property	Value
Density,g/cm³	1.1-1.3
Tensile Strength, Mpa	80-90
Compressive Strength, MPa	100-200
Impact Strength J/cm	0.28
Elongation , %	4-7
Water Absorption, (24 Hrs at 20ºc)	0.1-0.3
Cure Shrinkage, %	1-2.2

D. Hand Layup Technique

Open-molding is a term used for a number of methods. The simplest is hand lay-up molding. In this, the resins and reinforcement are deposited in a mold by hand or hand tools. This is also known as contact molding' as resin is in contact with air. Hand layup, or contact molding, is the oldest and simplest way of making composites. In the present work hand layup method is followed due to their simple principles to teach, low tooling cost. The tools used are silicon rubber with 5mm thickness, polyester lamination sheet, plywood, roller and weight for setting purpose. Typical applications are standard wind turbine blades, production boats, and architectural moldings.

E. Material Fabrication

Composites materials were fabricated with the size 300 mm × 300 mm square plate with 5 mm as the laminate thickness. The hand layup method was used for fabrication. Four different fiber compositions have been fabricated. The composition and designation of the composites prepared for this work are listed in Table 3.4. The epoxy resin (Araldite LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight. Vinylester resin and corresponding accelerator, catalyst and hardener were mixed in ratio of 10:1:1:1 by weight as recommended for human hair reinforced Vinylester composites. Human hair is reinforced randomly in polymer matrix by chopping it with fiber length equal to 20mm. The mould using plywood, silica rubber and lamination sheet were prepared. Next the epoxy resin is poured onto the mould then the chopped fibers are distributed uniformly over the resin. Finally the resin is applied on the randomly distributed fiber. Using another lamination sheet and plywood the mould was closed. The cast of each composite is cured under a load of about 50 kg for 24 hours before it removed from the mold. Finally the specimens for dynamic mechanical analysis are prepared according to ASTM standards using vertical Zig Zag cutting machine.

Before starting the fabrication process, the weight of the fiber and resin to make composite are calculated for selected volume fraction and fiber composition it has been listed as below table 3.5.

F. Study of Mechanical Properties

Often materials are subject to forces (loads) when they are used. Mechanical engineers calculate those forces and material scientists how materials deform (elongate, compress, twist) or break as a function of applied load, time, temperature, and other conditions. The various tests like Impact Strength, Water Absorption Test, Density Analysis, Hardness Test have been conducted to study the mechanical properties of polymer composites.

IV. RESULTS & DISCUSSIONS

This chapter presents the mechanical and physical properties of the human hair fiber reinforced with epoxy and vinylester polymer. The results of various characterization tests are reported here. This includes evaluation of impact strength, Hardness, Water absorption properties, both theoretical and experimental density has been studied and discussed.

A. Impact Strength

The below Figure 4.1 shows the Impact test specimens after performing the test in Impact testing Machine. The formula used to find out the tensile stress and tensile modulus or young’s modulus is given below,

Impact strength = mg (h0 – hf), in J

Where, m – Mass of Hammer in kg,

g – Gravitational acceleration,

ho – original height in mm,

hf- final height in mm.

The impact test is performed in three samples per composites. Totally of fifteen samples were tested and the values are directly noted form the dial gauge and is tabulated in below table 4.1.

Figure 4.1 Specimens used for performing Impact test.

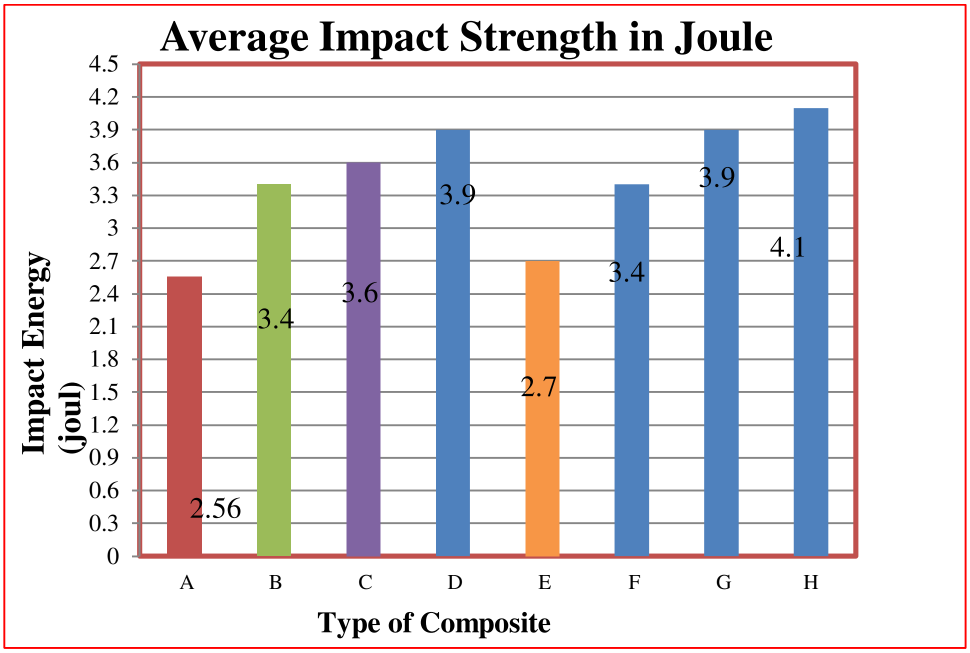

Figure 4.2 Average Impact Strength of the composites.

The figure 4.2 shows the impact energy found for the each composite. The graph shows that the impact energy of all the composite shows closer to each other. The composite with 15 Percentage of human hair in both epoxy matrix and vinylester matrix obtained lower impact energy than the other materials. Composite with 30 % of human hair reinforced composite has higher impact energy. The result shows that impact energy of composite are gradually increased in composite A, B and C and D. Similarly kind of result was observed for vinylester composite. From the impact energy test, it was found that while adding the human hair with polymer matrix the impact energy are increased as compared to pure matrix material.

Table 4.1 Impact test result of composites

Sl.No.	Composite	Specimen	Impact Strength (Joul)	Average Impact Strength (Joul)
1	A	A1	2.5	2.56
2		A2	2.3	
3		A3	2.9	
4	B	B1	3.4	3.4
5		B2	3.7	
6		B3	3.1	
7	C	C1	3.9	3.6
8		C2	3.4	
9		C3	3.5	
10		D1	3.8	3.9

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11	D	D2	4.2	
12		D3	3.7	
13	E	E1	2.4	2.7
14		E2	2.9	
15		E3	2.8	
16	F	F1	3.5	3.4
17		F2	3.1	
18		F3	3.6	
19	G	G1	4.2	3.9
20		G2	3.9	
21		G3	3.6	
22	H	H1	4.3	4.1
23		H2	4.1	
24		H3	3.9	

B. Water Absorption

The water absorption tests of Human Hair fiber reinforced composites were done as per ASTM 570 by immersion in water at room temperature. The samples were taken out periodically and after wiping out the water from the surface of the sample weighted immediately using a precise balance machine to find out the content of water absorbed. The specimens were weighed regularly at 24, 48, 72, 96, 120 and 144 hours. The water absorption is calculated by the weight difference. The samples used for conducting the experiments are shown in fig.4.34.

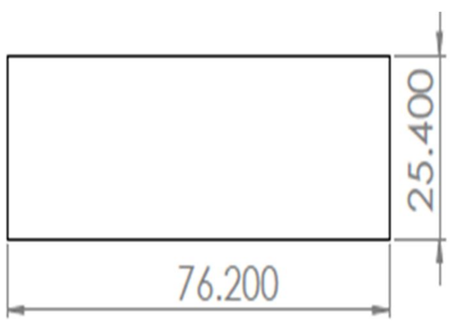

Figure 4.3 ASTM Standard Size of Water Absorption test specimen

Figure 4.4 prepared Water Absorption test specimen

The weight of the all the specimens are weighed regularly at every 24 Hrs. and the mass in grams are noted down. The table 4.7 shows the mass of the specimens at dry condition and wet conditions.

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C. Water Absorption Properties Various Composites

The mass of the specimens for human hair reinforced with epoxy matrix at every 24 hrs is weighed and it is tabulated below.

Table 4.2 Water Absorption Values of composites with Epoxy as the matrix material at Every 24 Hrs.

Sl.No.	Specimen	Mass of the Composite in Gram						
		Before Immersion	After 24 hrs (Day 1)	After 48 hrs (Day 2)	After 72 hrs (Day 3)	After 96 hrs (Day 4)	After 120 hrs (Day 5)	After 144 hrs (Day 6)
1	A1	12.51	12.522	12.53	12.539	12.542	12.55	12.559
2	A2	12.616	12.625	12.626	12.63	12.635	12.637	16.644
3	A3	12.071	12.081	12.082	12.09	12.093	12.098	12.1
4	B1	14.819	14.909	14.922	14.944	14.955	14.964	14.966
5	B2	16.547	16.576	16.592	16.616	16.625	16.64	16.646
6	B3	15.226	15.258	15.293	15.305	15.347	15.346	15.348
7	C1	14.213	14.923	15.024	15.065	15.123	15.198	15.288
8	C2	14.053	14.39	15.512	15.716	15.801	15.828	15.825
9	C3	15.356	15.878	16.177	16.29	16.59	16.644	16.742
10	D1	12.608	12.981	13.35	13.38	13.391	13.402	13.416
11	D2	14.51	14.768	14.98	15.022	15.091	15.144	15.15
12	D3	12.379	13.104	13.273	13.406	13.512	13.574	13.616

The table 4.7 and 4.8 shows gradual increase of the weight of the specimen at every 24 hrs. The moisture uptake by the specimen is increased when immersion time is increased. The values are getting closer after 4 to 5 days which was observed from the table 4.7 and table 4.8.

The mass of the specimens for human hair reinforced with vinylester matrix at every 24 hrs is weighed and it is tabulated below.

Table 4.3 Water Absorption Values of composites with Vinylester as the matrix material at Every24Hrs.

Sl.No.	Specimen	Mass of the Composite in Gram						
		Before Immersion	After 24 hrs (Day 1)	After 48 hrs (Day 2)	After 72 hrs (Day 3)	After 96 hrs (Day 4)	After 120 hrs (Day 5)	After 144 hrs (Day 6)
1	E1	11.217	11.249	11.267	11.272	11.275	11.276	11.278
2	E2	11.68	11.786	11.799	11.82	11.828	11.836	11.848
3	E3	10.021	10.123	10.135	10.17	10.203	10.221	10.235
4	F1	18.212	18.344	18.38	18.397	18.415	18.462	18.48
5	F2	18.19	18.252	18.269	18.27	18.295	18.305	18.307
6	F3	16.585	16.666	16.675	16.68	16.688	16.692	16.696
7	G1	16.06	16.244	16.252	16.28	16.291	16.36	16.426
8	G2	19.617	19.855	19.876	19.913	19.932	19.959	19.98
9	G3	19.378	19.475	19.497	19.512	19.523	19.556	19.561
10	H1	19.558	19.794	19.99	20.041	20.15	20.32	20.332
11	H2	20.01	20.208	20.291	20.334	20.361	20.398	20.424
12	H3	19.967	20.106	20.112	20.125	20.15	20.172	20.19

The percentage weight gain of the samples is measured at different time intervals by using the following equation.

$$\text{Water absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100$$

Where, W1 and W2 are the weight of the dry and wet samples.

Table 4.4 Percentageof Moisture Absorption of composites with Epoxy as the matrix material at every 24 hrs

Sl. No.	Speci-men	% Gain of Water									
		After 24 hrs (Day 1)	After 48 hrs (Day 2)	After 72 hrs (Day 3)	After 96 hrs (Day 4)	After 120 hrs (Day 5)	After 144 hrs (Day 6)	Average of Each Speci-men	Average of Each Compo-site	Range of Each Speci-men	Range of Each Compo-site
1	A1	0.096	0.064	0.072	0.024	0.064	0.072	0.065		0.024-0.096	
2	A2	0.071	0.008	0.032	0.040	0.016	0.055	0.037	0.047	0.015-0.079	0.015-0.096
3	A3	0.083	0.008	0.066	0.025	0.041	0.017	0.040		0.016-0.083	
4	B1	0.607	0.087	0.147	0.074	0.060	0.013	0.165		0.013-0.165	
5	B2	0.175	0.097	0.145	0.054	0.090	0.036	0.099	0.132	0.036-0.175	0.013-0.229
6	B3	0.210	0.229	0.078	0.274	-0.007	0.013	0.133		0.013-0.229	
7	C1	4.995	0.677	0.273	0.385	0.496	0.592	1.236		0.272-4.995	
8	C2	2.398	7.797	1.315	0.541	0.171	-0.019	2.034	1.575	0.17-2.398	0.17-4.995
9	C3	3.399	1.883	0.699	1.842	0.325	0.589	1.456		0.325-3.399	
10	D1	2.958	2.843	0.225	0.082	0.082	0.104	1.049		0.082-2.958	
11	D2	1.778	1.436	0.280	0.459	0.351	0.040	0.724	1.130	0.039-1.778	0.039-5.856
12	D3	5.857	1.290	1.002	0.791	0.459	0.309	1.618		0.309-5.856	

The percentage increase in weight of the composite specimen after immersing it into water at every 24 hrs calculated by using above formula and the values are tabulated separately for human hair reinforced with both epoxy and vinylester matrix. The average values of the composite shows that the percentage moisture gain of the composite increases when the fiber volume in matrix increases. The composite with 15 Percentage volume of human hair shows lower moisture gain or lower increases of Percentage weight when compared to other composites. The higher fiber content composite obtained larger value of Percentage moisture absorption than other composite. The range of moisture absorption from initial day to final day is calculated and it is tabulated in above table. The range values also increases with increasing fiber content.

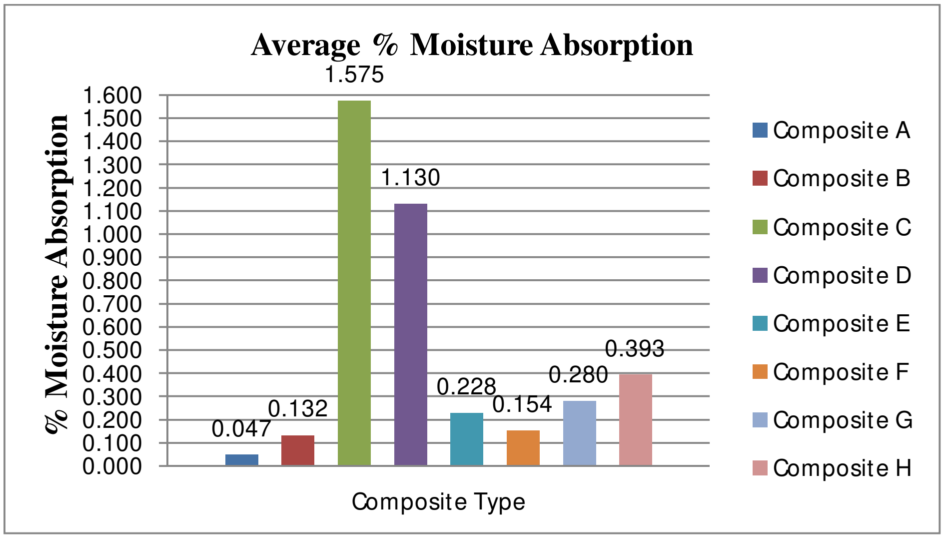

Figure 4.5 Average Percentage Gain of water at every 24 hrs.

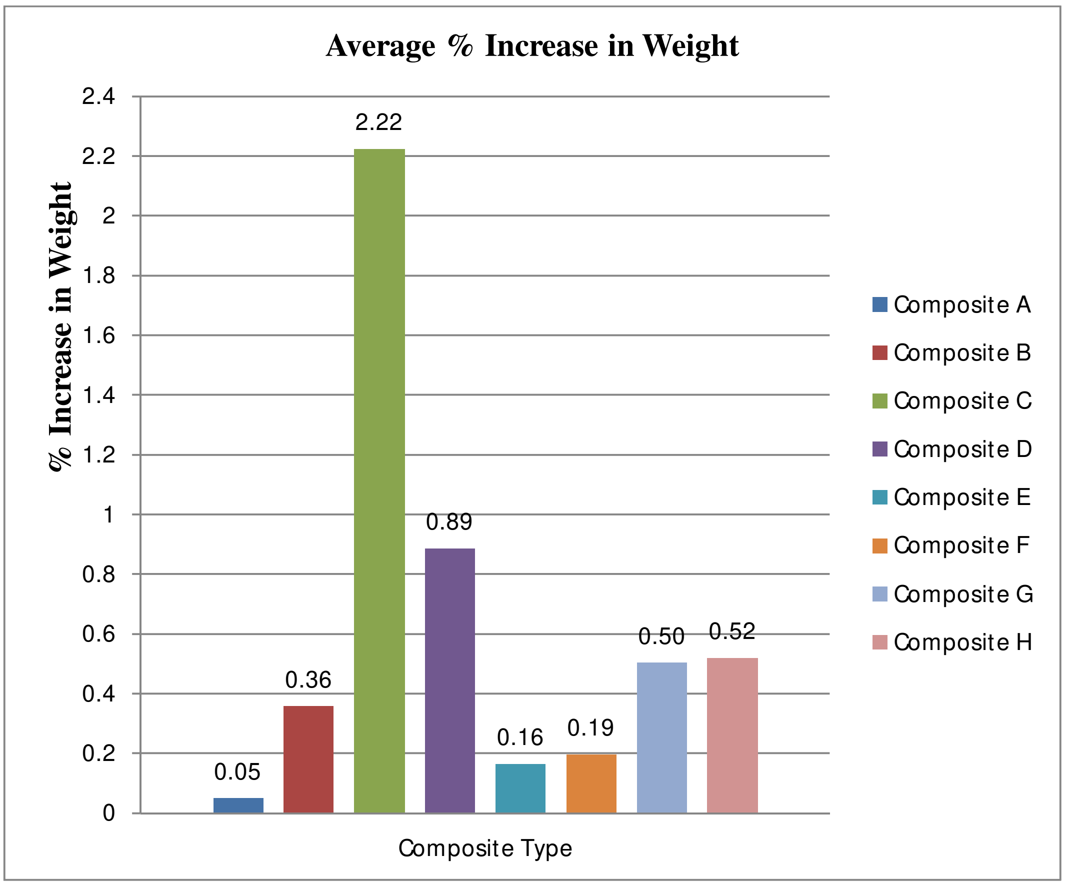

Figure 4.6 Average Percentage Increase in Weight of the Composite after Drying.

The Percentage increase in moisture absorption of the composite with vinylester matrix is shown in below table 4.9. The similar kind of result was obtained as the result obtained for the composite with epoxy matrix. When comparing the composite with epoxy matrix and composite with vinylester matrix, the vinylester matrix composite shows lower Percentage moisture absorption at all fiber volume fraction.

Table 4.5 Percentage of Moisture Absorption of composites with Vinylester as the matrix material at Every24Hrs

Sl. No.	Speci-men	% Gain of Water									
		After 24 hrs (Day 1)	After 48 hrs (Day 2)	After 72 hrs (Day 3)	After 96 hrs (Day 4)	After 120 hrs (Day 5)	After 144 hrs (Day 6)	Average of Each Speci-men	Average of Each Compo-site	Range of Each Speci-men	Range of Each Compo-site
1	E1	0.285	0.160	0.044	0.027	0.009	0.018	0.090	0.228	0.008-0.285	0.008-1.017
2	E2	0.908	0.110	0.178	0.068	0.068	0.101	0.239		0.067-0.907	
3	E3	1.018	0.119	0.345	0.324	0.176	0.137	0.353		0.118-1.017	
4	F1	0.725	0.196	0.092	0.098	0.255	0.097	0.244	0.154	0.092-0.724	0.005-0.724
5	F2	0.341	0.093	0.005	0.137	0.055	0.011	0.107		0.005-0.341	
6	F3	0.488	0.054	0.030	0.048	0.024	0.024	0.111		0.024-0.488	
7	G1	1.146	0.049	0.172	0.068	0.424	0.403	0.377	0.280	0.049-1.145	0.025-1.213
8	G2	1.213	0.106	0.186	0.095	0.135	0.105	0.307		0.095-1.213	
9	G3	0.501	0.113	0.077	0.056	0.169	0.026	0.157		0.025-0.501	
10	H1	1.207	0.990	0.255	0.544	0.844	0.059	0.650	0.393	0.059-1.206	0.059-1.206
11	H2	0.990	0.411	0.212	0.133	0.182	0.127	0.342		0.132-0.989	
12	H3	0.696	0.030	0.065	0.124	0.109	0.089	0.186		0.064-0.696	

The water absorbed specimens were dried at environmental temperature for 4 hrs and weight of the dried specimens were weighed and noted down. The increase in weight of the specimen was calculated from the specimen weight which obtained before immersing it into water. The weight of the specimen before immersing and after drying the specimens was used to calculate the increase in weight of the specimen which is tabulated for both the composite with epoxy matrix and vinylester matrix in below Table 4.10 and Table 4.11respectively. And also the total increase in Percentage moisture absorption is calculated from day 6 values and day 1 values.

Table 4.6 Percentage of increase in weight of composites with Epoxy as the matrix material after fully dried condition.

Sl.No.	Specimen	Mass of the Composite in Gram				
		Before Immersion	After 144 hrs (Day 6)	Fully Dried Condition	% Gain on final day from dry specimen	Increase in Weight %
1	A1	12.51	12.559	12.512	0.392	0.016
2	A2	12.616	12.644	12.62	0.222	0.032
3	A3	12.071	12.1	12.083	0.24	0.099
4	B1	14.819	14.966	14.875	0.992	0.378
5	B2	16.547	16.646	16.6	0.598	0.32
6	B3	15.226	15.348	15.283	0.801	0.374
7	C1	14.213	15.288	14.52	7.563	2.16
8	C2	14.053	15.825	14.458	12.609	2.882
9	C3	15.356	16.742	15.606	9.026	1.628
10	D1	12.608	13.416	12.754	6.409	1.158
11	D2	14.51	15.15	14.573	4.411	0.434
12	D3	12.379	13.616	12.511	9.993	1.066

The result shows that for both epoxy and vinylester composite the Percentage moisture gain increases with increasing fiber content. The composite with 30% volume fraction shows higher value of Percentage moisture absorption than other composites.

Table 4.7 Percentage of increase in weight of composites with Vinylester as the matrix material after fully dried condition.

Sl.No.	Specimen	Mass of the Composite in Gram				
		Before Immersion	After 144 hrs (Day 6)	Fully Dried Condition	% Gain on final day from dry specimen	Increase in Weight %
1	E1	11.217	11.278	11.244	0.544	0.241
2	E2	11.680	11.848	11.699	1.438	0.163
3	E3	10.021	10.235	10.030	2.136	0.090
4	F1	18.212	18.480	18.252	1.472	0.220
5	F2	18.190	18.307	18.206	0.643	0.088
6	F3	16.585	16.696	16.631	0.669	0.277
7	G1	16.060	16.426	16.148	2.279	0.548
8	G2	19.617	19.980	19.755	1.850	0.703
9	G3	19.378	19.561	19.428	0.944	0.258
10	H1	19.558	20.332	19.726	3.957	0.859
11	H2	20.010	20.424	20.094	2.069	0.420
12	H3	19.967	20.190	20.023	1.117	0.280

D. Density Analysis

The actual density (ρc) of the composites were determined using simple water immersion technique experimentally.

Experimental Density

Density = Mass / Volume

Where,

Mass = Weight of Specimen in Gram

Volume = Volume of water rise in Beaker in cm = $\Pi r^2 h$

Radius of Beaker, r = 3.06 cm

Height of water rise in beaker, h (cm)

Theoretical Density

The Theoretical density of the composite material can be calculated by using the following equation,

The density of the composite material in terms of volume fractions, the density of the composite material is written as

$\rho c = \rho f V f + \rho m V m$

Where,

ρf = Density of Fiber

ρm = Density of Matrix

ρc = Density of Composite

Vf = Volume fraction of Fiber

Vm = Volume fraction of Fiber

E. Density Analysis of Various Composites

The density obtained from experimental method shows closer to the theoretical density values. Three specimens for each composite were used for determining experimental density of the composites. Average value of experimental density of each composite is shown in table 4.12 and table 4.13. The result shows that for epoxy composite human hair with 15%, 20 % and 30 % volume content posses slightly higher density than theoretical density. These may be due to the presence of moisture content in the composites. Similarly for the composites with Vinylester as the matrix material shows closer experimental values than theoretical density. And also obtained density is lighter than the conventional materials.

Table 4.8 Calculated Density of composites with epoxy as matrix material

Sl.No.	Composite	Specimen	Density of Composite ρc(g/cm3)	Average Experimental Density of Composite ρc(g/cm3)	Theoretical Density of Composites ρc(g/cm3)
1		A1	1.316		
2	A	A2	1.34		
3		A3	1.172	1.276	1.2605
4		B1	1.1992		
5	B	B2	1.372		
6		B3	1.328	1.3	1.26
7		C1	1.052		
8	C	C2	1.112		
9		C3	1.064	1.076	1.2675
10		D1	1.3		
11	D	D2	1.296		
12		D3	1.62	1.405	1.271

Table 4.9 Calculated Density of composites with epoxy as matrix material

Sl.No.	Composite	Specimen	Density of Composite ρc(g/cm3)	Average Experimental Density of Composite ρc(g/cm3)	Theoretical Density of Composites ρc(g/cm3)
13		E1	1.272		
14	E	E2	1.24		
15		E3	1.176	1.229	1.303
16		F1	1.236		
17		F2	1.26		
18	F	F3	1.128	1.208	1.3
19		G1	1.14		
20		G2	1.136		
21	G	G3	1.116	1.131	1.305
22		H1	1.108		
23		H2	1.096		
24	H	H3	1.132	1.112	1.306

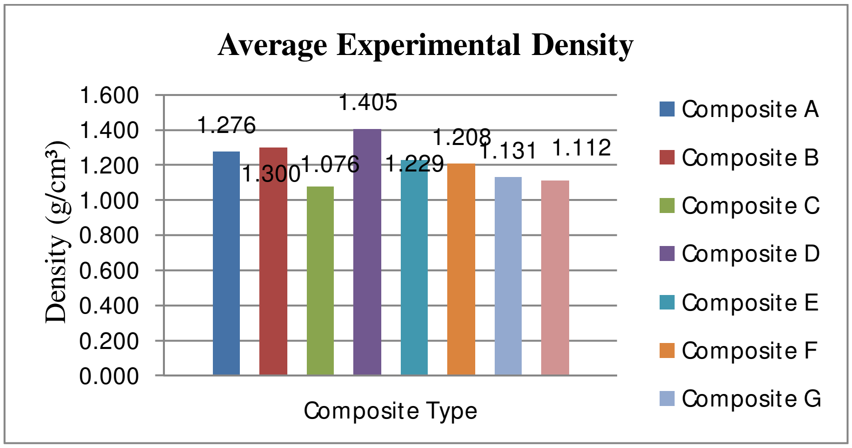

Figure 4.7Average Experimental Density

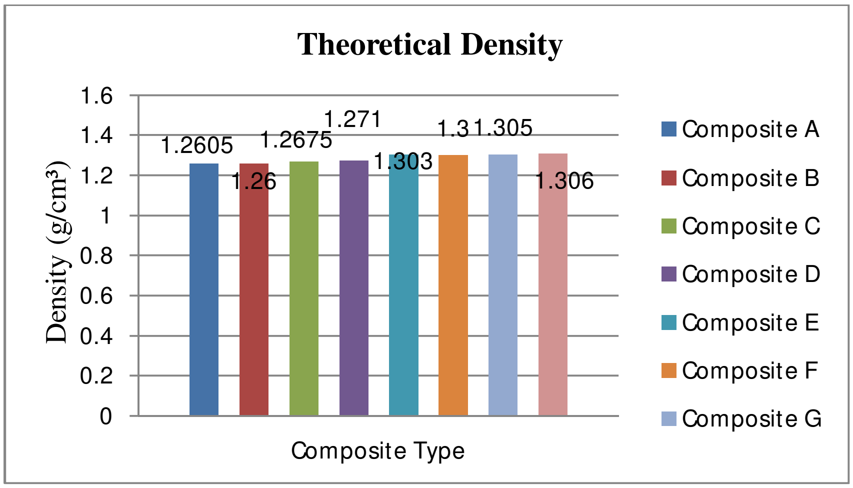

Figure 4.8 Theoretical Density

Figure 4.9 Specimens used for determining Density of Composites

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F. Hardness Test

According to ASTM E 10 standards for composites, the specimens were prepared for Rockwell-B hardness test. The hardness properties of the composites are studied by applying indentation load normal to fibers diameter. The effect of fiber loading time on Rockwell hardness of both dry and wet specimens is illustrated in Figures 8 and 9.Generally, fibers that increase the moduli of composites increase the hardness of the composite. This is because hardness is a function of the relative fiber volume and modulus.

Table 4.10 The Average Value of hardness

Sl.No.	Composite	Dry Specimen			Average RHN	Wet Specimen			Average RHN
		Sample 1	Sample 2	Sample 3		Sample 1	Sample 2	Sample 3	
1	A	50	57	41	49.33	59	55	55	56.33
2	B	78	61	54	64.33	61	58	54	57.67
3	C	53	42	60	51.67	59	58	52	56.33
4	D	57	56	59	57.33	61	69	62	64.00
5	E	80	81	61	74.00	59	60	70	63.00
6	F	58	57	74	63.00	67	74	62	67.67
7	G	79	82	70	77.00	65	73	82	73.33
8	H	92	86	77	85.00	80	68	65	71.00

Specimen Size: (75 x 25 x 5) mm
Test Machine: Rockwell Hardness Machine.
Indenter=1/16’’ ball load=100kg for Polyester Composite.

Figure 4.10 Specimens used for Hardness Test

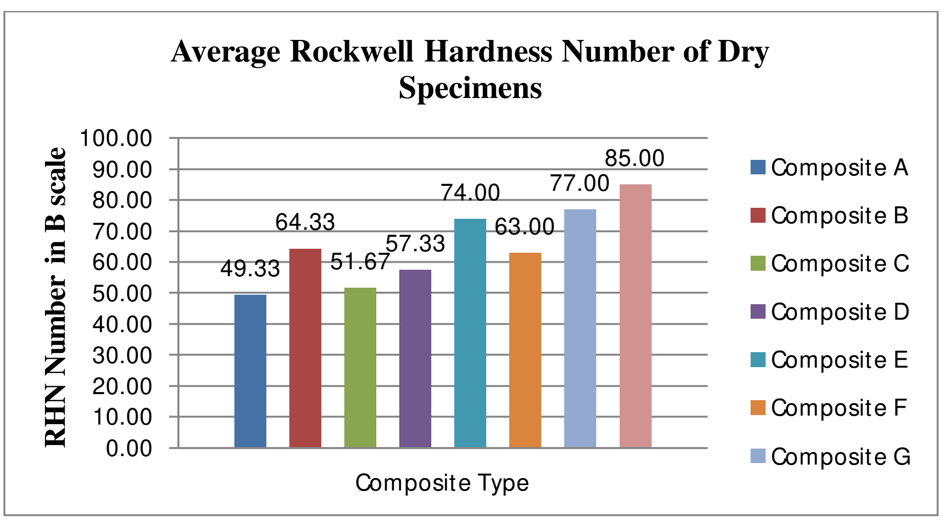

Figure 4.11Average Rockwell Hardness Number of Dry Specimens

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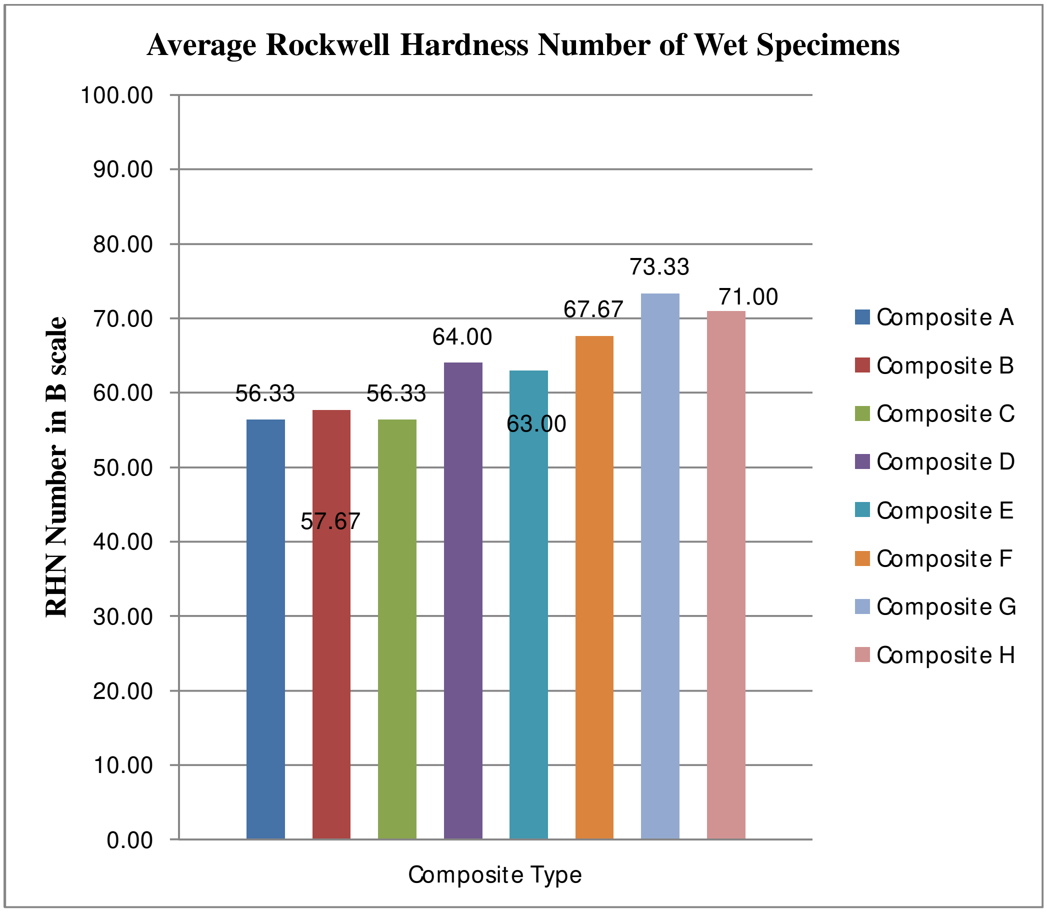

Figure 4.12 Average Rockwell Hardness Number of Dry Specimens

When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number.

From result the obtained hardness values exhibits around 50 to 90. The variations are due to the higher matrix contribution at the interface and voids. The lower hardness number indicates higher resistance of the material against load.

Table 4.11 Average values of Mechanical test result of composites

Composite	Impact Strength (Joul)	Rockwell Hardness Number		Experi-mental Density of Composite ρc(g/cm3)	Theoretical Density of Composites ρc(g/cm3)	% gain of moisture	% Increase in Weight of Composites after drying
		Dry Specimen	Wet Specimen				
A	2.56	49.33	56.33	1.276	1.2605	0.047	0.049
B	3.4	64.33	57.67	1.3	1.26	0.132	0.357
C	3.6	51.67	56.33	1.076	1.2675	1.575	2.223
D	3.9	57.33	64.00	1.405	1.271	1.130	0.886
E	2.7	74.00	63.00	1.229	1.303	0.228	0.164
F	3.4	63.00	67.67	1.208	1.3	0.154	0.194
G	3.9	77.00	73.33	1.131	1.305	0.280	0.503
H	4.1	85.00	71.00	1.112	1.306	0.393	0.519

G. Scanning Electron Microscopy

The microstructure of fractured specimens was analyzed by Scanning Electron Microscope. From Fig. 9 composite D and Fig. 10 composite H the SEM images identified that during the fabrication of composites using hand layup technique presence of vacuum inside the mould creates voids in the composites that decrease quality of properties. Fiber pull out also occurred in composite D which shows lack of adhesion between fiber and matrix during fabrication. It is evident from Fig. 11 Composite A and Fig. 12 composite E clear and uniform distribution of fiber with matrix was achieved.

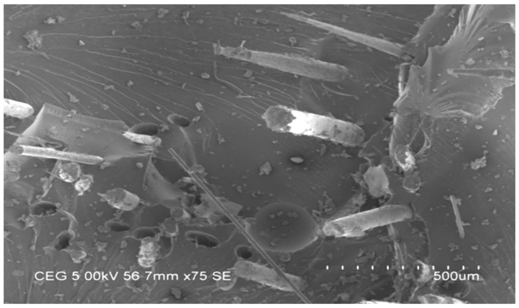

Figure 4.13 Composite with 30 % Human Hair and 70% Epoxy

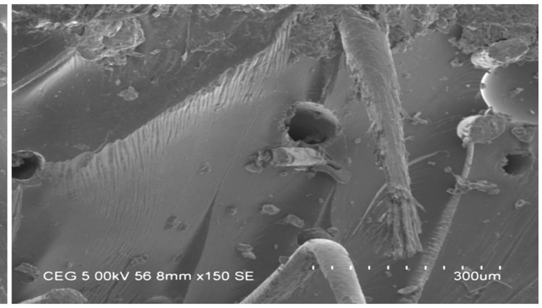

Figure 4.14 Composite with 30% Human Hair and 70% Vinylester

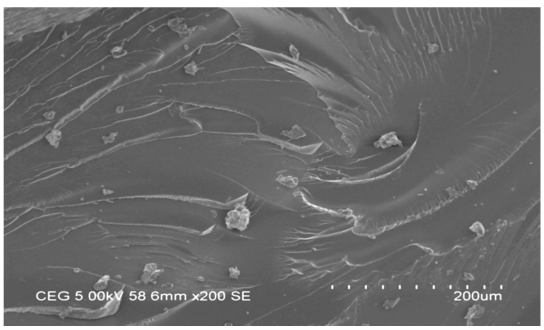

Figure 4.15Composite with 15% Human Hair and 85 % Epoxy

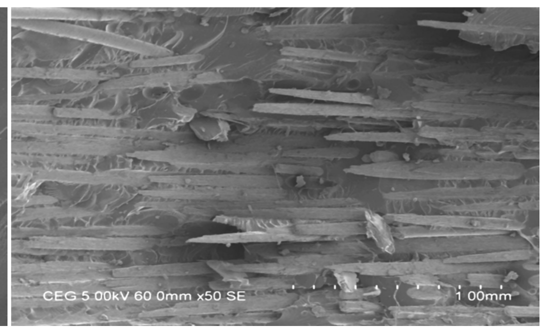

Figure 4.16Composite with 15% Human Hair and 85% Vinylester

H. Summary of Research Findings

From impact properties the 15% of human hair reinforced epoxy composite has lower impact strength than other composites and the 30% human hair reinforced composite has higher value of impact strength than other composite. From these it was decided that impact strength of composite are gradually increased when the volume of human hair content increased. The density obtained from experimental method shows closer to the theoretical density values. And also obtained density is lighter than the conventional materials. Percentage increase in Water absorption in all the composite specimen shows lesser in value when compared to other natural fiber reinforced composites. From Rockwell Hardness Number obtained from hardness test it was concluded that the values exhibits around 50 to 90. The variations are due to the higher matrix contribution at the interface and voids. The lower hardness number indicates higher resistance of the material against load.

V. CONCLUSION

This work shows that successful fabrication of a human hair reinforced epoxy and vinylester composites by simple hand lay-up technique. Fabrication of composites done with four different fiber and matrix volume fraction(15:85, 20:80, 25:75 and 30:70ratio of Human hair/ Epoxy and Human hair/ Vinylester respectively).

Mechanical and physical properties such as Impact, Rockwell Hardness, density and water absorption properties were determined. From impact result, the impact energies were found to increase with increase in human hair content in composite. The percentage moisture gain of composite increases when the human hair volume in composite increases. Composite with 15% and 20 % volume of human hair shows lower moisture gain or lower increases in percentage weight when compared to other composites. This may be due to the hydrophobic behavior of human hair that leads to the lower interaction of human hair and water.

After drying the water absorbed specimens at room temperature the weight of dried composites increases with increasing human hair content in composites. Increase in moisture absorption is lower for vinylester composite when compared to epoxy composites. The density obtained from experimental method shows values closer to the theoretical density values. Percentage error calculated from experimental density and theoretical density shows that the composite with 25 % and 30 % volume of human hair had higher variation. This may be due to the presence of voids in the composites that absorb moisture from air leads to higher variation of weight. Similarly for the composites with Vinylester as the matrix material but result shows lesser than epoxy composites. The Rockwell hardness of human hair reinforced composite exhibits around 50 to 85. The hardness number obtained from the results indicates that the human hair reinforced composites can resist loading. Vinylester composite obtained higher hardness number than epoxy composites. From result, composite with 25% human hair and 30 % human hair (Composite C,D,G &H)shows higher mechanical properties than composite with 15 % human hair and 20 % human hair (Composite A,B,E &F). But physical properties were found to better in 15 % human hair and 20 % human hair composites and SEM image reveals that presences of voids affects inter bonding that decreases physical properties of composites.

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