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Manufacturing and Product Analysis of Non-Woven and Paper Based Epoxy Composites

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Abstract

Fiber-reinforced polymer composites are used in a wide variety of applications due to their many advantages, such as relatively low production costs, ease of fabrication, and superior strength compared to pure polymer resins. Polymer reinforcement can be either synthetic or natural. Synthetic fibers such as carbon have high specific strength, but their application fields are limited due to their high manufacturing cost. Recently, interest in recycled fiber-based composites has increased due to their many advantages. In this context, research has been carried out to better utilize non-woven and paper-based materials to make value-added products. The aim of the current research work is to compare the mechanical performance of non-woven and paper-based reinforced epoxy composites manufactured by the VARTM process. Mechanical properties such as tensile strength, flexural strength (using three-point bending), impact strength, hardness strength, and water absorption were measured. A multi-criteria decision approach called TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) was used to select the best alternative from the investigated materials.

Keywords

Recycled Fibers, Nonwovens and Papers, VARTM, Mechanical Properties, TOPSIS

1. Introduction

Today's environmental consciousness drives researchers across the globe to study natural fiber reinforced polymer composites as a more affordable alternative to synthetic fiber reinforced composites. Researchers have been enticed by the accessibility of natural fibers and the simplicity of manufacturing to experiment with inexpensive locally available fibers, study their feasibility for use as reinforcement, and determine how well they meet the requirements of high-quality reinforced polymer composite for various applications. Natural fibers are a good renewable and biodegradable alternative to the most widely used synthetic reinforcement, glass fiber, due to their low cost and high specific mechanical qualities. The use of natural fibers is restricted to non-bearing applications despite their interest and environmental appeal since they are less strong than synthetic fiber reinforced polymer composites. By using improved structural configurations and arranging the fibers for maximum strength performance, it is possible to address the stiffness and strength deficiencies of bio composites. Accordingly, in-depth investigations on the creation and characteristics of polymer matrix composites (PMC) using natural fibers, like jute, sisal, pineapple, bamboo, kenaf, and biogases in place of synthetic fiber were conducted. These plant fibers are renewable, environmentally friendly, inexpensive, lightweight, and offer higher specific mechanical performance than glass or carbon fibers [1]. Paper based reinforced composites are a new field in polymer science. These natural reinforcements have low costs, a low density, and excellent specific qualities. They are non-abrasive and biodegradable. These natural based composites offer specific properties comparable to those of conventional fiber composites. However, while manufacturing these composites, the incompatibility of the reinforcements and their weak moisture resistance frequently limit their potential.

Kumar N, Das D work deals with fibrous biocomposites prepared by using nettle and poly (lactic acid) fibers and employing carding and compression-molding processes. The tensile, bending and impact properties of the biocomposites were found to increase initially with the increase of nettle fiber content till 50 wt% and decrease afterwards. The dynamic mechanical analysis showed that the biocomposites exhibited high storage modulus, low loss modulus, and low damping factor. Further, the biocomposites exhibited excellent biodegradability and their biodegradability increased with the increase of nettle fiber content. Overall, the biocomposite prepared with equal weight proportion of nettle and poly(lactic acid) showed high potential for automotive dashboard panel application [2]. Recycled newspaper (NP) shows excellent potential as a reinforcement for polymer composites. Herein, high-strength laminated composites were prepared by using NP laminas as reinforcement and high-density polyethylene (HDPE) films as matrix. Physical and mechanical properties of the laminated composites were measured by B. Zheng, Chuanshuang Hu, L. Guan, J. Gu, Huizhang Guo, Weiwei Zhang [3]. A study on "Effects of Fiber Angle on the Tensile Properties of Partially Delignified and Densified Wood" was conducted by Matthias Jakob, Jakob Gaugeler and Wolfgang Gindl-Altmutter [4]. The use of wood fibers as a reinforcement in composites was presented by L. M. Matuana, *et al.* [5]. In order to increase the rigidity of plastics, Medupin R.O., Abubakre O.K. noticed that effects of wood fibre loading vary from 20% to 60% mass fraction on the properties of wood polymer composites (WPCs) and assessment of the resulting composite for suitability for use in the construction industry. Using compression moulding technique, virgin low density polyethylene (matrix) was reinforced with sawdust from akpontu. Sodium hydroxide binder was used. Upon examination of the test specimens manufactured, 40% was found to be the optimum reinforcement loading. Increasing fiber load of akpontu improves the strength and stiffness of the composites but decreases impact strength. It was found out that water uptake increases with increasing fiber content in agreement with similar work by other researchers. The result however suggests that water absorption rate of WPCs is high in the first few hours. For akpontu reinforcement, 50 wt% fraction showed the least absorption in the first 100 hours. WPC with 40 wt% reinforcement has the highest overall water absorption [6]. Investigation of unsaturated polyester composites reinforced by aspen high yield pulp fibers were explained by Y. Du, N. Yan, and M. Kortschot [7]. Y. Du, *et al.* demonstrated how composites were made using two different types of thermoset polymers and four different types of pulp fibers which were Whatman cellulose fibers, Kraft pulp, and Hardwood, and Softwood high-yield pulp (HYP). Unsaturated polyester (UP) and Vinyl-ester (VE) were the two polymers. Results from FTIR and TGA demonstrated the chemical distinctions between the four pulp fibers and verified the presence of lignin on HYP pulp fibers. According to the tensile qualities, the two HYP fibers were more compatible with the UPE resin. In contrary, the Kraft and Whatman cellulose fibers were more compatible with the VE resin. The two HYP fibers lignin served as a natural coupling agent between the more hydrophobic UP resin and the natural fiber. When the VE resin was utilized, the two cellulose-rich pulp fibers performed better. Comparing the composite storage moduli to those of the neat UP and VE resins revealed a substantial improvement. Glass transition temperature of the composites has been slightly increased [8]. A. Endres, *et al.* described both a hardwood and a softwood pulp underwent the standard fractionating and refining processes used in papermaking. To create sheets for epoxy-resin reinforcement, treated pulps were used. The influence of several fiber treatments on composite properties was assessed. These treatments allowed a significant increase in fiber volume content and composite strength. In addition, a model based on fiber, paper, and thermoset properties was used to predict the strength of paper-based thermoset composites over a broad range of pulps and fiber volume fractions [9].

One of the well-known multi-criteria decision making (MCDM) techniques is TOPSIS, which is an approach for ordering performance by assessing the proximity to the ideal solution. This is the process of finding the best option from all of feasible alternatives. TOPSIS, created by Hwang & Yoon in 1981 is a multiple criteria method that uses the simultaneous minimizing of the distance from the Positive Ideal Solution (PIS) and the longest distance from the Negative Ideal Solution (NIS) to identify solutions from a finite collection of alternatives. Although TOPSIS has been used for a variety of purposes, very little information has been written about the material selection demonstrated by Singh H & Kumar [10]. In order to choose materials for ecologically friendly design, Huang *et al.* researched the multi-criteria decision-making process and uncertainty analysis. Entropy technique presents designers or decision-makers preferences on cost or environmental impact and successfully demonstrates the uncertainties of their weights. It has been stated that TOPSIS method exhibits a reasonable performance in producing a solution [11].

2. Experiment

2.1. Materials

2.1.1. Flax Fiber Spun Lace

The main fraction of flax fiber consists of cellulose, mucilage gums, and lignin, which can be classified as either dietary fiber or functional fiber. Flax fiber is a soft, lustrous and flexible, stronger than other natural fibers but less elastic and available at reasonable prices. This fiber has characteristics such as high strength, strong moisture absorption, good luster, light weight, small elongation, easy degradation and many more. It has an apparent density of 1.50 g/cm^3. The thickness of each sheet is 1.20 mm. It has been ordered from Easy Composites EU, Netherlands.

2.1.2. Specialty (Kraft Paper)

Specialty paper is mostly used for the laminate manufacturing. Specialty paper is referred for heavy paper-based products. The preparation can range from a thick paper termed as paperboard to corrugated fiberboard which is made of multiple layers of material. Natural Specialty Paper can range from grey to light brown. Most types of Specialty papers are recyclable for industrial or domestic use. Clean Specialty papers (*i.e.*, paper that has not been subjected to chemical coatings) is usually worth recovering and the key qualities of this include high strength, absorption power, insulation qualities (heat, sound, vibration), air permeability and shape stability. It has apparent density of 0.78 g/cm^3, thickness of each sheet is 0.40 mm.

2.1.3. Newspaper

Newspaper is a slender sheet and a non-coated paper material produced by mechanically or chemically processing cellulose fibers extracted from wood, rags, grasses, or other plant materials. Some mechanical properties of this include high toughness, high tensile strength which measures inter fiber bonding and total network strength and minor stretching. This fibre is available for free of cost, high strength to weight ratio, quick moisture absorption and release, and rapid degradation. The Newspaper sheet that took into consideration of the experiment has the apparent density of 0.69 g/cm^3 thickness of each sheet is 0.30 mm.

2.1.4. Epoxy Resin

Epoxy resin L-285 has greater thermal as well as mechanical properties when compared with other types of resins. The L-285 epoxy resin system exhibits low viscosity, free of solvents and fillers, resistant to most alkalis and acids, resistant to stress cracking, maintains stiffness and flexibility, low water absorption. It has been purchased from Schweighofer, Deutschland.

It is easy to incorporate epoxy resin (density: 1.23 g/cm^3) into composite laminates because of their high density and high adhesion between fibers when compared to other resins like vinyl ester resin (density: 1.4 g/cm^3), polyethylene resin (density: 0.9 g/cm^3) and polypropylene (density: 0.92 g/cm^3).

Mixing Ratios L-285: H-285.

Parts by Weight 100: 40 (±2).

Parts by Volume 100: 51 (±2).

The specified mixing ratios have to be observed carefully; therefore weighing the resin and hardener precisely using accurate scales. Adding more or less hardener will not result in a faster or slower reaction, but in an incomplete curing which cannot be corrected in any way. Mix the resin and hardener thoroughly until they are homogeneously mixed, paying special attention to the walls and the bottom of the mixing container.

2.2. VARTM Process

Vacuum Assisted Resin Transfer Molding (VARTM) is open mold, out of autoclave (OOA) composite manufacturing process, with its distinguishing characteristic being the replacement of the top layer of a mold tool with a vacuum bag and also peel ply, distribution media are arranged in a sequence manner and the use of a vacuum to assist in resin flow. The process involves the use of a vacuum to facilitate resin flow into a fiber layup that has been arranged within a mold tool covered by a vacuum bag. After the impregnation occurred the composite part is allowed to cure at room temperature with an optional post cure sometimes carried out.

In general, all VARTM processes can be divided into three processing steps including material and tooling preparation, the infusion step and the post-infusion step (**Figure 1**). Each process step will influence final material quality in particular the fiber volume fraction and void content distribution. Capital and infrastructural requirements are less as compared to other methods.

2.3. Methodology

The methodology consists of two steps:

Step 1: Surface treatment of fibers

Fibers were treated with NaOH alkali solution ordered from N_2O_3, Deutschland to reduce the inter-fibrillar region of the fiber by removing hemicellulose and lignin and further to reduce the cementing force between fibrils. This led to a more homogenous dispersion of the bio fiber in the matrix as well as increase in the aspect ratio of the fiber in the composite, resulting in an improvement in fiber reinforcement efficiency. For 30 minutes, the required amount of

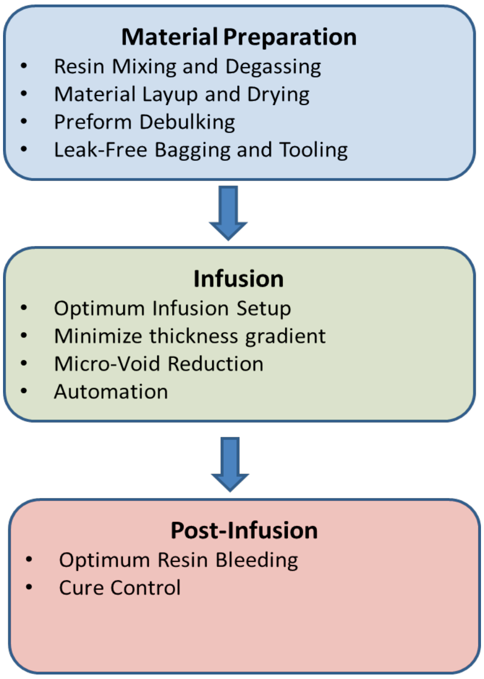

Figure 1. VARTM processing step.

fibers were treated with a 2 wt-% NaOH solution. The excess NaOH was then thoroughly washed from the fibers with water. The fibers were then allowed to cure for 24 hours at room temperature before being reinforced.

Step 2: Sample Preparation

The low temperature curing epoxy resin and corresponding hardener are mixed in a ratio of 100:40 by weight. A mold with the dimension 330 mm × 330 mm was used for casting the composite slabs. Table 1 shows the compositions that are varied for the Six (6) different specimens.

In the preparation step, the cutting of reinforcement fibers, flow media, peel ply, and the vacuum bag was carried out. The mold was prepared according to the required dimensions with the sealant tape. The fiber reinforcements were arranged with a stacking sequence. Peel ply was placed on both sides of the fibers. To ensure the fast and even distribution of resin over the fibers, the flow media was placed on top of the peel ply. This is followed by placing the entire setup in a vacuum bag as shown in Figure 2 and Figure 3.

The processing step entails adjusting the pressure in the vacuum bag as well as initiating a chemical reaction by adding a hardener to the resin that causes the resin to cure. For VARTM to create high quality composite parts it is crucial that air leakages are avoided. Air leakages can cause resin to improperly flow through the mold and also lead to the formation of air bubbles.

The main process of impregnating the fibers with resin occurs with the aid of a vacuum in the infusion step. The Specimen was cured for 24 h at room temperature followed by warm curing for 8 h at 60˚C.

After Post Curing, The Specimen slabs which are initially fabricated are cut down according to the test standards. The thickness of the composites

Table 1. Compositions for different specimens.

Specimen	Epoxy Resin [wt.-%]	Flax [wt.-%]	Specialty [Kraft] paper [wt.-%]	News-paper [wt.-%]
S01	60	40	-	-
S02	70	30	-	-
S11	60	-	40	-
S12	70	-	30	-
S21	60	-	-	40
S22	70	-	-	30

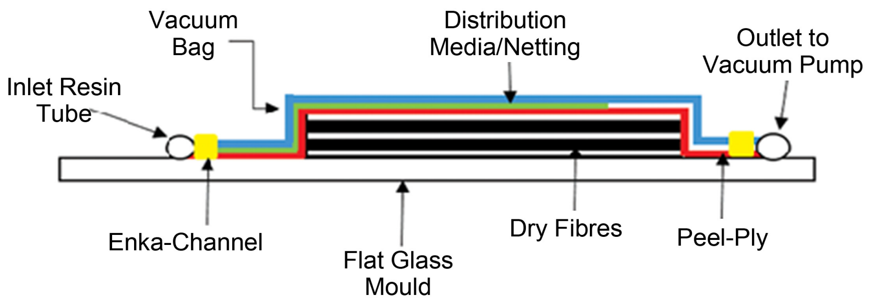

Figure 2. Schematic diagram of VARTM Process.

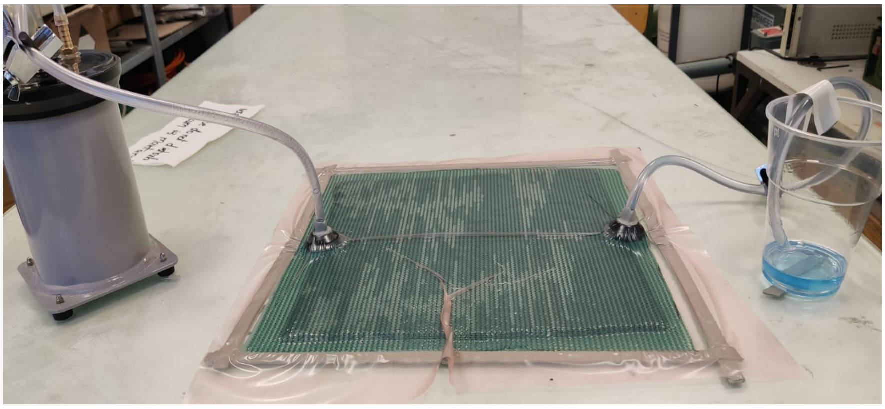

Figure 3. Experimental Setup-VARTM Process.

should be around 2.4 mm to match the requirements of the "Test conditions for fiber-reinforced plastic composites". In order to achieve this thickness, the number of sheets was varied from 2 sheets for Flax specimen to 6 and 8 sheets for the Specialty Paper and Newspaper specimens respectively.

2.4. Property Measurements

2.4.1. Flexural Tests

Flexural tests were carried out in the accordance with DIN EN ISO 178. It measures the force required to bend a sample under three-point loading conditions. The specimen was supported by a span and a load was applied at the center, causing three-point bending at a test speed of 5 mm/min and the flexural modulus was measured. This test was carried out on samples measuring 80 × 20 × 2.4 mm.

2.4.2. Tensile Tests

Tensile tests were carried out in accordance with DIN EN ISO 527. The top and bottom grips of the tensile testing machine held the test samples. The grips were moved apart at a constant test speed of 5 mm/min. The force and displacement of the specimen were continuously measured. Young's modulus was measured between 0.05% and 0.25% strain. This test was carried out on samples measuring 120 × 20 × 2.4 mm.

2.4.3. Impact Tests

Charpy impact tests were carried out in accordance with DIN EN ISO 179. It is a single-point test that measures the resistance of a material to an impact from a pendulum hammer with a velocity of 2.9 m/s, a hammer weight of 0.9510 kg and an impact energy of 4 joules. Toughness is determined by the amount of force required to fracture the material with a swinging pendulum. The specimen was supported horizontally and unclamped at both ends. The impact strength in kJ/m^2 was calculated. This test was carried out on unnotched samples measuring 80 × 20 × 2.4 mm.

2.4.4. Hardness Tests

Shore hardness is a measure of a material's resistance to needle penetration under a defined spring force. It is expressed as a number ranging from 0 to 100 on the A or D scales. The harder the material, the higher the number. The main difference between Shore A and Shore D is that Shore A is used to measure flexible rubbers, whereas Shore D is used to measure harder, rigid materials. Shore A using a cone with a truncate tip is valid from 10 to 90 Shore A. Shore D using a cone with a tip is valid from 30 to 100 Shore D. Shore D was used to measure the hardness of the samples. After needle penetration, hardness values were noted after waiting for a period of 10 s.

2.4.5. Water Absorption Tests

Water absorption tests are carried out with samples that are kept in water at 15˚C for 48 h. The samples are weighed before immersion and later on after immersion.

$$W = \frac{W_0 - W_i}{W_0} \times 100 \text{ in } [\%] \tag{1}$$

with w_0—weight of the sample before immersion and w_i—weight of the sample after immersion.

2.5. TOPSIS

From m options (alternatives) A_i, each of which depends on n parameters (criteria) x_j whose values are expressed with positive real numbers x_{ij}. The best option should be selected.

Initially, the parameter values x_{ij} should be balanced according to the procedure of normalization. Suppose that A_{ij} (or) a_{ij} are the normalized parameter values. Then each option A_i is expressed as the point A_i ($a_{i1},\cdots,a_{in}\in R$). Selecting the most optimal value $a_j^*\in\left\{a_{1j},\cdots,a_{mj}\right\}$ for every parameter x_j, we determine the positive ideal solution $A^*=\left(a_i^*,\cdots,a_n^*\right)$. The opposite is the negative ideal solution $A^{\mathrm{o}}=\left(a_i^{\mathrm{o}},\cdots,a_n^{\mathrm{o}}\right)$. The positive and negative ideal solution are also denoted by A^+ and A^-. The decision on the order of options is made respecting the order of numbers.

Based upon the weights, the equation for the Weight Normalization Decision Matrix is given by

$$A_{ij}\left(\mathrm{or}\right)a_{ij}=w_j\frac{x_{ij}}{\sqrt{\sum_{x=1}^{6}x_{ij}^2}} \tag{2}$$

where w_j—Weight of the criteria and x_{ij}—Parameter(Property) values.

The positive ideal solution A^+ (or) A^* contains the largest numbers of the first, second and third column of *A*, and the smallest numbers of the fourth and fifth column of *A*.

The negative ideal solution A^- (or) A^{o} contains the smallest numbers of the first, second and third column of *A*, and the greatest numbers of the fourth and fifth column of *A*. The positive and negative separation measure is calculated by using the formulas.

$$s_i^+=\sqrt{\sum_{j=1}^{n}\left(A_{ij}-A_j^*\left(\mathrm{or}\right)A_j^+\right)^2} \tag{3}$$

$$s_i^-=\sqrt{\sum_{j=1}^{n}\left(A_{ij}-A_j^0\left(\mathrm{or}\right)A_j^-\right)^2} \tag{4}$$

where A_{ij}—Normalized parameter values, A^+ (or) A^*—Positive ideal solution and A^- (or) A^{o}—Negative ideal solution.

Relative Closeness Factor decides the best and worst solutions from the set of alternatives. The equation to calculate this given by

$$C_i=\frac{s_i^-}{s_i^++s_i^-} \tag{5}$$

where, s_i^+ —Positive Separation measure and s_i^- —Negative Separation measure.

Finally, the ranking of attribute is given by highest closeness factor value to the lowest closeness factor.

3. Results and Discussion

3.1. Flexural Tests

As shown in **Figure 4** and **Table 2**, the flexural strength and modulus increased with an increase in the weight percentage of fiber. As **Figure 4** depicts the values of flexural strength, clearly composite of paper reinforcement with 40% fiber content has the highest values *i.e.*, 174 MPa for S11 and 154 MPa for S21 respectively, when compared to the flax-composites with same composition. As the fiber content has been reduced to 30%, the percentage difference of flexural

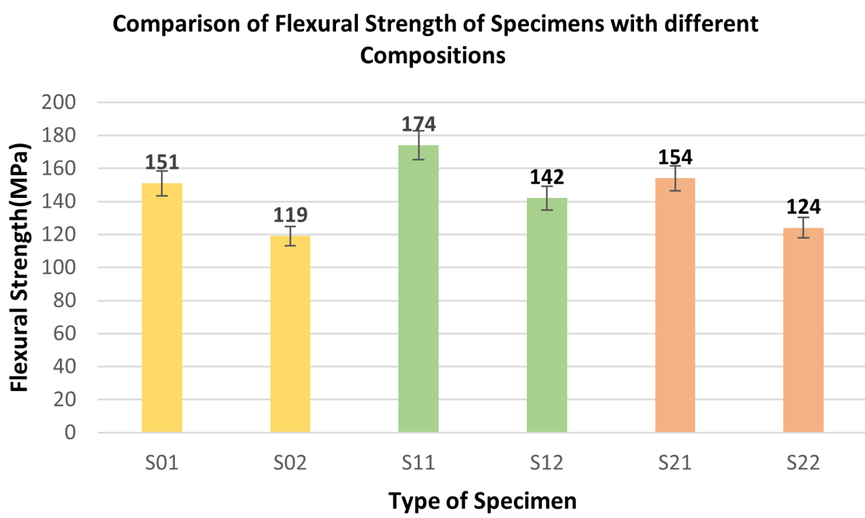

Figure 4. Results of flexural strength measurements.

Table 2. Results of flexural modulus and strength measurements.

Specimen	S01	S02	S11	S12	S21	S22
E_f [MPa]	3730	2130	6860	5640	5960	4600
σ_{FM} [MPa]	151	119	174	142	154	124

strength between S12 and S02 is 19.32% and S22 and S02 is 4.20% accordingly.

3.2. Tensile Tests

The results of tensile test are presented in **Figure 5** and **Table 3**. In compared to other samples, the tensile strength of Specialty Paper with 40% fiber content was quite high. Tensile strength improved by 16.82% when compared to, according to the test findings. The yield strength defines the maximum load that a sample can bear. In comparison to Flax S02 (30% Fiber), Specialty paper S12 improved yield strength by 20%. There is not much difference in Tensile Strength between S21 (40% fiber) to S01 and S22 (30% fiber) to S02. The tensile strength was 125 MPa for S11, 120 MPa for S12, 108 MPa for S21, 107 MPa for S01, 100 MPa for S02 and 99 MPa for S22. The percentage of increase in tensile strength is due to the uniform dispersion of resin between the fibers by holding them together.

3.3. Impact Strength

Figure 6 depicts impact strength. The energy absorption rate increased as the fiber content decreased. As a result, the energy absorbing capability of the paper composite is increased, enhancing the composite's toughness. Specimen S22, possessing the highest impact strength. It absorbed 40.6 kJ/m^2 of energy which is 4.90% more than the energy absorbed by S02 with 70% of resin content. Whereas, S21 (60% resin) absorbed 0.5% of more energy than S01 which is the lowest of all. The difference in Impact strength between S12 (70% resin) and S02 is

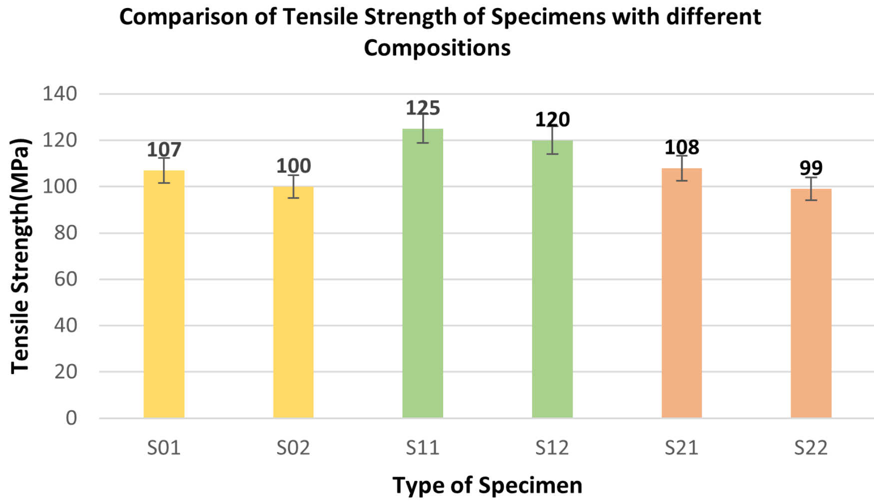

Figure 5. Results of tensile strength measurements.

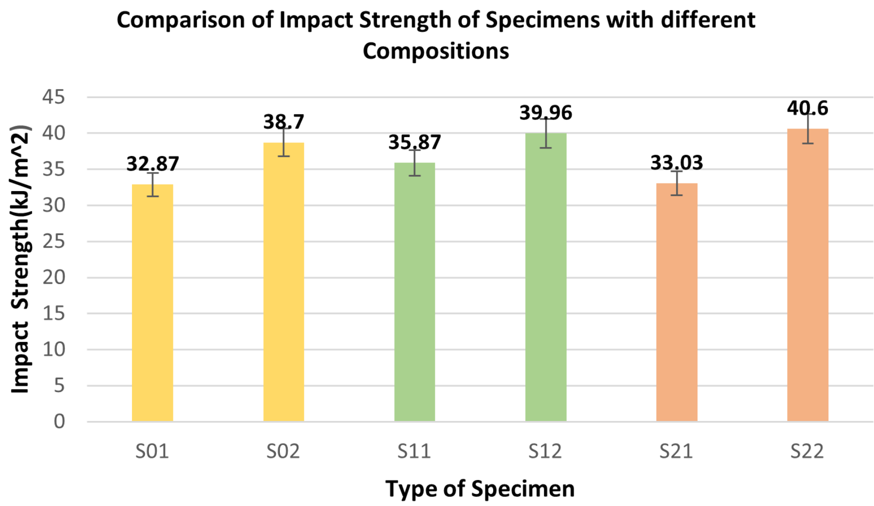

Figure 6. Results of impact strength measurements.

Table 3. Results of tensile tests.

Specimen	E_t [MPa]	σ_y [MPa]	ε [%]	σ_M [MPa]
S01	6920	107	2.3	107
S02	5420	100	3.3	100
S11	7980	125	4.7	125
S12	6840	120	4.2	120
S21	6970	108	2.6	108
S22	5335	99	1.9	99

3.25% and that of S11 (60% resin) and S01 is 9.12% respectively.

3.4. Shore D Hardness

As seen in **Figure 7**, specimen S12 with 70% resin content possessed the highest

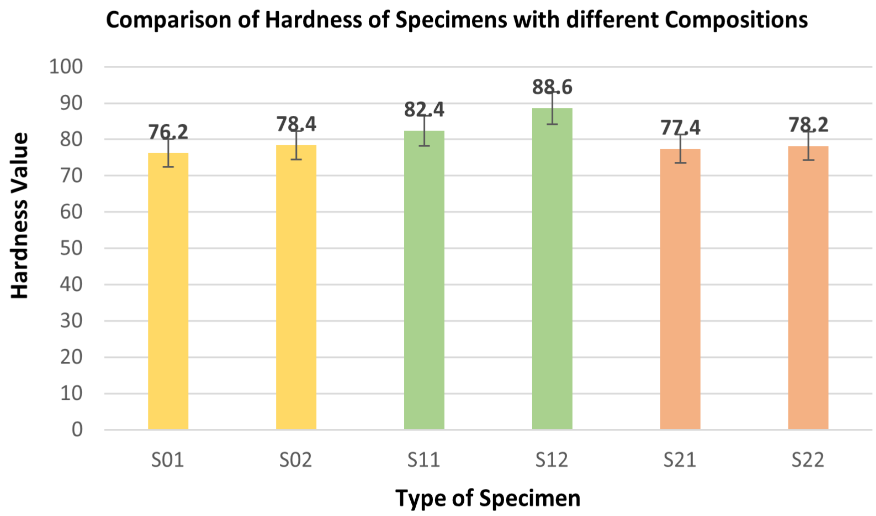

Figure 7. Results of hardness value measurements.

shore hardness value of 88.6 Shore. As the matrix content has been increased, the hardness of the composites has been raised. The specimen with high matrix content showed the highest hardness values. The noticeable hardness difference can be observed from S11 to S01 as 8.13%, There was not that much difference in shore hardness values of composites with 60% resin content *i.e.*, In comparison, specimens S21 to S01 and S22 to S02 difference of 1.57% and 2.62% was observed respectively. The improvement in this property is particularly due to the incorporation of resin to fiber.

3.5. Moisture Content

Figure 8 depicts that the fiber content is more. The moisture content has been the highest. Specimen S01 has the highest moisture content with 31.39%. Whereas, the Specimens S21 and S22 has 18.75% and 2.04% moisture than S01 and S02 respectively. When the moisture is present in any composite it affects the mechanical properties due to degradation of the interfacial bond between the fiber and the matrix, so here the same happened with flax reinforced composites they achieved less mechanical properties when compared to paper reinforced composites.

3.6. TOPSIS

According to this, the best alternative would be the one that is closest to the positive-ideal solution and farthest from the negative ideal solution. TOPSIS main aim is to selecting the top ranked alternative and comparing it with all ranks in this set of simulations. In **Figure 9**, all the composite materials are compared based on the TOPSIS method and ranking has been done. The Decision Matrix, Weight Normalized Decision Matrix, Ideal Positive and Ideal Negative Solution, Separation Measure, Relative Closeness Value and Ranking are tabulated in **Tables 4-8**.

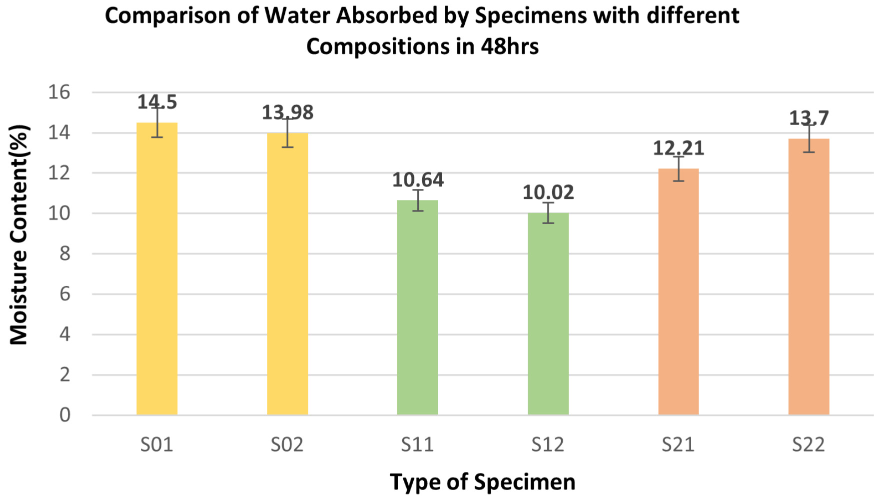

Figure 8. Results of moisture content Measurements.

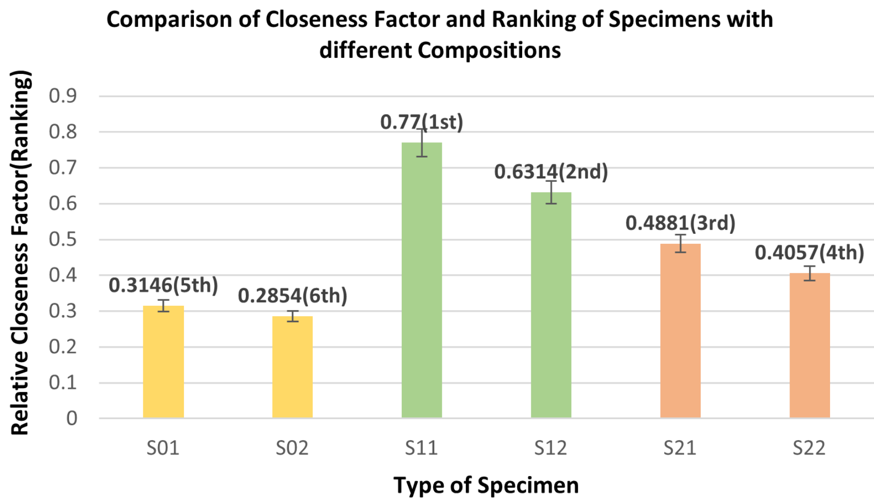

Figure 9. Results of relative closeness factor and ranking measurements.

Table 4. Decision matrix.

Specimen	Tensile strength [MPa]	Flexural strength [MPa]	Impact strength [kJ/m^2]	Hardness Shore D	Moisture content [%]
S01	107	151	32.87	76.2	14.5
S02	100	119	38.70	78.4	13.98
S11	125	174	35.87	82.4	10.64
S12	120	142	39.96	88.6	10.02
S21	108	154	33.03	77.4	12.21
S22	99	124	40.60	78.2	13.7

In the above Table 4, all the properties that have been achieved were accumulated and named as Decision Matrix. To achieve the Weight Normalized Decision Matrix, the weight percentage is distributed equally among all the properties

Table 5. Weight normalized decision matrix.

Specimen	Tensile strength [MPa]	Flexural strength [MPa]	Impact strength [kJ/m^2]	Hardness Shore D	Moisture content [%]
S01	0.0789	0.0865	0.0725	0.0774	0.0937
S02	0.0737	0.0709	0.0854	0.0797	0.0904
S11	0.0921	0.1036	0.0792	0.0837	0.0688
S12	0.0884	0.0846	0.0882	0.0900	0.0648
S21	0.0803	0.0899	0.0729	0.0786	0.0789
S22	0.0744	0.0738	0.0896	0.0795	0.0886

Table 6. Ideal positive and ideal negative solution.

Solution	Tensile strength [MPa]	Flexural strength [MPa]	Impact strength [kJ/m^2]	Hardness Shore D	Moisture content [%]
A^+ (or) A^* Positive Ideal Solution	0.0921	0.1036	0.0896	0.0774	0.0648
A^- (or) A^o Negative Ideal Solution	0.0737	0.0709	0.0725	0.0900	0.0937

Table 7. Separation measure.

Specimen	S01	S02	S11	S12	S21	S22
S_i^+	0.0440	0.0433	0.0128	0.0223	0.0280	0.0353
S_i^-	0.0202	0.0172	0.042	0.0358	0.0250	0.0241

Table 8. Relative closeness value and ranking.

Specimen	S01	S02	S11	S12	S21	S22
Relative Closeness Factor	0.3146	0.2854	0.7700	0.6314	0.4881	0.4057
Ranking	5th	6th	1st	2nd	3rd	4th

i.e., $w_j = 1/5$ and x_{ij} refers to value of each property that has been achieved. The values w_j and x_{ij} are substituted in Formula (2) to get Table 5.

The positive ideal solution A^+ (or) A^* contains the largest numbers of the first, second and third column of A, and the smallest numbers of the fourth and fifth column of A. The negative ideal solution A^- (or) A^o contains the smallest numbers of the first, second and third column of A, and the greatest numbers of the fourth and fifth column of A (refer Table 6).

TOPSIS originally used Euclidean distances or Separation measure (**Table 7**) to compare alternatives with their PIS (Positive Ideal Solution) and NIS (Negative Ideal Solution), with the selected option having the smallest distance from the PIS and the greatest distance from the NIS. To achieve this, use Formula (3) and Formula (4). Here A_{ij} represents weight normalized decision matrix value of individual property (refer **Table 5**) and A^{+} (or) A, A^{-} (or) A^{o} has been presented in **Table 6**.

Relative Closeness values **Table 8** can be achieved by substituting the positive and negative separation measure values in Formula (5). Based upon the relative closeness factor values, ranking has been done accordingly from highest to lowest.

3.7. Discussion of Results

The results can be summarized as follows:

- From the samples with different compositions, the specialty paper composite with epoxy resin has a very high Young's modulus of 7980 MPa.
- The flexural modulus was more in specialty and newspaper reinforced epoxy composites with 6860 MPa and 5960 MPa respectively.
- The composites with newspaper and epoxy resin have higher impact strength with a value of 40.6 kJ/m^2 and flax composite has least impact strength with a value of 32.87 kJ/m^2
- The specimens with high matrix content showed the optimal hardness values.
- The composites with flax and epoxy resin have the high moisture content with 14.5% and 13.98%.
- Based on TOPSIS, Ranking of the Composites are S11 (1st rank), S12 (2nd rank), S21 (3rd rank), S22 (4th rank), S01 (5th rank), S02 (6th rank).

4. Conclusions

In this work, flax and paper reinforced composites using epoxy resin were produced with by the VARTM-process with two different compositions for better results. This method of fabrication was very simple and cost-effective. Their mechanical properties like tensile and flexural strength, strain, young's modulus, flexural modulus, and impact energy, hardness and moisture content were investigated. The mechanical properties of the paper composites were also compared with the flax reinforced composites. The fiber fraction plays a major role in the mechanical properties of paper composites.

The results showed that paper with resin had a substantial impact on the mechanical characteristics when compared with flax with resin. Fiber hybridization with resin aided in the improvement of mechanical qualities. Paper composites have a different reinforcing efficiency than flax fibers, which is connected to the performance of a non-woven fiber and is responsible for the biggest increases. The matrix attributed an effective transfer of load to fiber. This mechanism, in turn, improved the load-carrying capability of the paper composite during tensile and flexural loading when compared flax composite. Because of uniform dispersion of resin between the fibers, the tensile characteristics of the samples were higher. As a result, the energy absorbing capability of the paper composite increased, enhancing the composite's toughness. The specimen with high matrix content showed the better hardness values. When the moisture is present in any composite, it affects the mechanical properties due to degradation of the interfacial bond between the fiber and the matrix, so here the same happened with flax reinforced composites they achieved less mechanical properties when compared to paper reinforced composites. According to TOPSIS, the best alternative would be the one that is closest to the positive-ideal solution and farthest from the negative ideal solution has been finalized.

5. Future Scope

Engineers might expect extremely good outcomes in the future if they continue their study by utilizing different kinds of recyclable papers. This work may be expanded to investigate in fabricating hybrid composites with the use of different kind of resins and the evaluation of their mechanical and physical behaviors.

Automobile manufacturers can utilize these materials that they are light enough to improve fuel efficiency. Using such bio-composites in automotive parts not only assists in reducing the component's mass, but also cuts the amount of energy that is required for manufacturing.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Agarwal, A. and Thombre, M. (2013) Preparation and Characterization of Polymer Matrix Composite Using Natural Fiber Lantana-Camera. *IOSR Journal of Mechanical and Civil Engineering* (*IOSR-JMCE*), **217**, 161. https://www.semanticscholar.org/paper/Preparation-and-characterization-of-polymer-matrix-Agarwal-Thombre/7f2c67cdd273a4a2cf483fd93426946cf333b6a8

[2] Kumar, N. and Das, D. (2017) Fibrous Biocomposites from Nettle (*Girardinia diversifolia*) and Poly (Lactic Acid) Fibers for Automotive Dashboard Panel Applications. *Composites Part B*, **130**, 54-63. https://www.researchgate.net/publication/318769639_Fibrous_biocomposites_from_nettle_Girardinia_diversifolia_and_polylactic_acid_fibers_for_automotive_dashboard_panel_application https://doi.org/10.1016/j.compositesb.2017.07.059

[3] Zheng, B., Hu, C.S., Guan, L., Gu, J., Guo, H.Z. and Zhang, W.W. (2019) Strength Laminated Composites from Recycled Newspaper and HDPE.

https://www.semanticscholar.org/paper/Structural-Characterization-and-Analysis-of-from-Zheng-Hu/cae1a561cebba5fd63523322c0b82b5e2c58ddac

[4] Jakob, M., Gaugeler, J. and Gindl-Altmutter, W. (2020) Effects of Fiber Angle on the Tensile Properties of Partially Delignified and Densified Wood. *Materials*, **13**, 5405. https://www.mdpi.com/1996-1944/13/23/5405/htm https://doi.org/10.3390/ma13235405

[5] Matuana, L.M. and Stark, N.M. (2015) The Use of Wood Fibres as Reinforcement in Composites. *Biofiber Reinforcements in Composite Materials,* 648-688. https://www.researchgate.net/publication/282482692_The_use_of_wood_fibers_as_reinforcements_in_composites. https://doi.org/10.1533/9781782421276.5.648

[6] Medupin, R.O. and Abubakre, O.K. (2015) Effect of Wood Fibre Characteristics on the Properties of Wood Polymer Composites. *Journal of Multidisciplinary Engineering Science and Technology* (*JMEST*), **2**, 101-105. https://www.researchgate.net/publication/331773316_Effect_of_Wood_Fibre_Characteristics_on_the_Properties_of_Wood_Polymer_Composites

[7] Du, Y., Yan, N. and Kortschot, M. (2012) Investigation of Unsaturated Polyester Composites Reinforced by Aspen High Yield Pulp Fibers. *Polymer Composites*, **33**, 169-177. https://www.semanticscholar.org/paper/Pulp-fiber-reinforced-thermoset-polymer-composites%3A-Du-Wu/4a0cca0c1ab7ae57baeecdf156d5852821942747 https://doi.org/10.1002/pc.21255

[8] Du, Y., Wu, T., Yan, N., Kortschot, M. and Farnood, R. (2013) Pulp Fiber-Reinforced Thermoset Polymer Composites: Effects of the Pulp Fibers and Polymer. *Composites Part B*: *Engineering*, **48**, 10-17. https://www.sciencedirect.com/science/article/abs/pii/S1359836812007810 https://doi.org/10.1016/j.compositesb.2012.12.003

[9] Kroeling, H., Mehlhase, S., Fleckenstein, J., Nubbo, N., Endres, A., Schabel, S. and Miletzky, F. (2013) Engineering and Modeling of Tensile Strength of Paper-Thermoset Composites. 19*th International Conference on Composite Materials*, 5280-5292. https://www.researchgate.net/publication/260674915_engineering_and_modelling_of_the_tensile_strength_of_paper-thermoset_composites

[10] Singh, H. (2012) Selection of Material for Bicycle Chain in Indian Scenario using MADM Approach. *Proceedings of the World Congress on Engineering*, **3**. https://www.semanticscholar.org/paper/Selection-of-Material-for-Bicycle-Chain-in-Indian-Singh/27a889e430f70fec16d260f3d8019abe07667077

[11] Huang, H., Zhang, L., Liu, Z. and Sutherland, J.W. (2011) Multi-Criteria Decision Making and Uncertainty Analysis for Materials Selection in Environmentally Conscious Design. *The International Journal of Advanced Manufacturing Technology*, **52**, 421-432. https://link.springer.com/article/10.1007/s00170-010-2745-9 https://doi.org/10.1007/s00170-010-2745-9