Selection of optimal Flax Fiber Reinforced Components for Experimental Investigation by using TOPSIS method

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Abstract. Composite materials are gaining more attention for its green house effect along with other properties such as light weight with high strength for specific applications by which more number of new scholars researching on developing new natural composite materials to replace the regular manufacturing materials. Natural fiber composites offers high strength to Weight ratio, along with exceptional properties such as high durability, stiffness, damping property etc... By which natural composite materials find various applications in different fields of manufacturing industries. Natural reinforced composites show higher variability of properties which provides the necessity of investigating different properties. Flax fibers are finding an important place in non-traditional reinforcement material for technically advancing products. They are attracting many researchers, because of the scope for improving their properties. Moisture content plays a vital role on impact of mechanical properties & addition of nano-particles to flax fibers reinforce composites also has a promising effect on improvement of properties of composites. In this paper an investigation has been carried out on specimens prepared from various wt% of Flax Fiber to analyze the effect of the wetness on the percentage variation of graphene nano particles on some of the mechanical properties and selecting the best composition of natural reinforced composite by using TOPSIS method, from which it is observed that 1 % of graphene in flax fiber as given the best ranking by utilizing this novel method in natural reinforced material.

1. Introduction

Composites materials can be produce by combination of two or more macroscopically identical structural defers by microscopic to achieve significant properties which cannot be obtain when they are acting alone. The behavior of a natural fiber composite depends on fiber strength, chemical stability, matrix to enable stress transfer & modulus. Flax fiber along with a number of other natural fibers is being considered as eco-friendly and alternative of regular synthetic polymer composites. The main feature of natural fibers is a much higher variability of mechanical properties which makes necessitates study of methods for its determination. Over the few decades natural fibers are playing a major role to replace the traditional reinforced materials in order to overcome the shortage of traditional materials and to safe guard the environment from pollution in different aspects [1, 2]. As per the advanced technology in various industries and to minimize the efforts in manufacturing usage of nontraditional reinforcement resources reduces the CO₂ percentage along with ecological benefits directly or indirectly in various fields like automobiles, construction, biomedical etc[3-6]. Natural reinforced fibers with low cost, biodegradability, recyclability and adequate strength makes the automobiles 50% & 40% lighter Weight compare to steel sized bodies and aluminum metal bodies respectively which made Audi company cars make use of flax fiber reinforced materials in door panels and Toyota in RAUM model cars. [7, 8].

Flax reinforced fibers can be used in many applications by replacing other fibers, the mechanical properties of flax fibers can be improved by proper chemical treatment [9]. In Flax reinforced materials thermal stability is less [10], by mixing nano tubes improves the thermal stability and also decreases the capacity of water absorption by the material [11-13]. Glass and carbon epoxy composites increased their
flexural properties by adding the graphene oxide [14, 15]. By considering the enhancement of properties in other epoxy composite materials, the effect of graphene in flax reinforced materials is investigated by comparing it with the properties of pure flax fiber composites which are prepared by hand layup method. Decision made on multi criteria and analysis for material selection & where friendly environmental parameters has major impact along with cost factors, this TOPSIS will be effectively utilized [16-18]. TOPSIS approach is suitable when selection of maximum tensile strength of materials and performance of precise rating comes in to consideration [19-21].

2. Composition of material selected for study
This experiment focuses on development of the composites material and their characterization.
   a. Natural reinforced woven flax fiber structural composition of cellulose 71 weight %, Hemi-cellulose of around 18.6 to 20.6 weight %, lignin of around 2 weight % and moisture contain around 10 weight %
   b. Specific Epoxy was selected for its unique property of excellent bonding and dimensionally stable for chemical reactions which also provides superior mechanical and electrical properties at high temperature. All these advantages epoxy-556 and hardener-951 were selected and procured directly from the market. Based on the data provided by the manufacturer, viscosity and density of resin are 11500Mpa and 1.5g/cm3 respectively, where as hardener posses 15Mpa and 0.95g/cm3 of viscosity and density respectively.
   c. Nano filler material grapheme was used to produce composites with varying weight %of 0 to 0.15 with an increment step of 0.05 by weight %.

   From the literature review, it is observed that flax fiber with Wt% 35 had given the best mechanical properties compare to other wt%, so the specimens were prepared with a constant Flax fiber weight % of 35, varying grapheme weight % with an increment 0.05 and the remaining epoxy weight %. The specimens were prepared with hand layup by compression molding of size 240mm*180mm and 0.48mm average thickness. The table1 below refers composition of specimens for investigation.

| Specimen | Graphene (Wt %) | Flax Fiber (Wt%) | Epoxy (Wt%) |
|----------|-----------------|-----------------|------------|
| S1       | 0               | 35              | 65         |
| S2       | 0.05            | 35              | 64.95      |
| S3       | 0.1             | 35              | 64.9       |
| S4       | 0.15            | 35              | 64.85      |

3. Water Absorption Test
To study the behavior of Flax fiber under water absorption test was carried out. Initially fiber specimen samples are heated at 50 degree during 24 hours and then they were cooled at room temperature. The test was carried out by immersion specimens prepared under International Standard ASTM 570 in to
water bath at room temperature. Samples were removed at regular intervals and weighted immediately after wrapping away from the surface and a precise balance was used to find out the content of water absorbed. The weight percentage gained by flax fiber was measured and it was observed that without weight percentage of graphene, the absorption of moisture is more and by increasing the weight % of graphene, the absorption of moisture was decreasing due to the presence of nano particles, which are acting as an obstacle for absorbing the moisture in the specimen as shown in table 2 and figure 2 represents the graphical water absorption test values of the specimens. The results suggest that swelling of flax fibers due to water absorption can have positive effects on mechanical properties of the composite materials.

**Table 2. Wt% gained by the Specimens during Water absorption test**

| Specimen | Wt of specimen before immersion (gm) | Wt of specimen after Immersion (gm) | % of Wt. Gain |
|----------|-------------------------------------|-----------------------------------|---------------|
| S1       | 7.1                                 | 7.54                              | 6.23          |
| S2       | 6.9                                 | 7.3                               | 5.67          |
| S3       | 6.81                                | 7.15                              | 5.18          |
| S4       | 6.12                                | 6.4                               | 4.43          |

**Figure 2.** Represents the Specimens Water Absorption Test values

### 4. Mechanical properties of the specimens

The test specimens were undergone mechanical tests to know the mechanical characteristics such as Tensile, flexural, impact and hardness.

#### 4.1 Tensile strength

It is observed that with Zero weight % of graphene, the tensile strength of specimen is 38.26 Mpa while adding the graphene with an increment of 0.05 the tensile strength was increased 21% and at 0.1 weight% of graphene the increment in tensile strength was 35%. Further increase in Weight % of graphene, the tensile strength was reduced, may be due to higher % of nano particles might reduce the stress transmission in specimen.

#### 4.2 Flexural Strength

By the addition of weight % of graphene from 0 to 0.1 with an increment 0.05, the flexural strength was increased by 67%, latter by the addition of graphene the flexural strength was reduced.

#### 4.3 Impact Strength

It can be defined as capability of reinforced flax fiber material to withstand the sudden force. Impact test values of different wt. % of composite specimens were noted, it is observed that by adding the filler nano materials the capability of specimens are increased compare to 0 Wt% graphene in flax fiber. With 0.1 Wt% of graphene in flax fiber composition the maximum value was observed, this is due to the filler which made the composite less ductile.
4.4 Hardness

It is plastic deformation resistance of materials induced by indentation. The Wt% of graphene increases, the hardness of the specimens increases. The graphene Wt% with 0.1% flax fiber shows the maximum resistance to the localized deformation by mechanical penetration in to specimen. Whereas 0.15 Wt% of graphene contain in specimen shows reduced resistance compare to 0.1% graphene. Table 3 shows the mechanical properties of the specimens.

The mechanical properties indicates that the Wt% of graphene increases from 0 to 0.1 with an increment of 0.05, the increase in tensile strength was 35%, flexural strength was 67%, the impact load was almost double and the increase in hardness was 205. But for the Wt 5 of graphene 0.15%, there was a reduction in all mechanical properties. From the experimental analysis, we conclude that 0.1 Wt% of graphene with flax fiber gives the best performance

Table 3. Mechanical properties of specimens

| Specimen | Tensile strength (MPa) | Flexural Strength (MPa) | Impact load (KJ/m²) | Hardness |
|----------|------------------------|-------------------------|---------------------|----------|
| S1       | 38.26                  | 44.26                   | 20.86               | 49       |
| S2       | 46.52                  | 62.71                   | 38.15               | 53       |
| S3       | 51.79                  | 73.81                   | 42.72               | 59       |
| S4       | 49.11                  | 71.01                   | 40.15               | 56       |

5. Validating the Best Performance Score of material by using TOPSIS METHOD

The TOPSIS (Technique for order performance by similarity to ideal solution) was first developed by Yoon and Hwang in 1981. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method is a multi criteria decision making analysis by providing realistic modeling than non compensatory methods. TOPSIS compares alternative set of aggregates by identifying the importance of each criteria, normalizes the score of each criteria and identifies the ideal positive solution of composite material which is selected as best performance and where as negative solutions from the criteria to obtain the worst performance values [22, 23].

Steps to be followed:

Step: 1 In this step Decision making matrix is developed which consist of alternatives and criteria which is given $X_{ij}$ and final matrix is given $(X_{ij})_{mxn}$.

Table 4. Decision Making Matrix

| Specimen | Wt of specimen (gm) | Tensile strength (MPa) | Flexural Strength (MPa) | Impact load (KJ/m²) | Hardness |
|----------|---------------------|------------------------|-------------------------|---------------------|----------|
| S1       | 7.54                | 38.26                  | 44.26                   | 20.86               | 49       |
| S2       | 7.3                 | 46.52                  | 62.71                   | 38.15               | 53       |
| S3       | 7.15                | 51.79                  | 73.81                   | 42.72               | 59       |
| S4       | 6.4                 | 49.11                  | 71.01                   | 40.15               | 56       |

Step: 2 Now the above matrix is used to calculate the normalized decision matrix by using following method

$$X'_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}^2}$$

(1)
Step: 3 from the matrix formed in step 2, weighted normalized matrix should be evaluated by using

\[ V_{ij} = W_i \times V_{ij} \quad \text{where} \quad i = 1,2,3,\ldots,n \; \text{and} \; j = 1,2,3,\ldots,m \]  

(2)

| Specimen | Flax fiber wt. % | Graphene wt. % | Normalized matrix |
|-----------|-----------------|----------------|------------------|
| S1        | 35              | 0              | 0.530218516     |
| S2        | 35              | 0.05           | 0.513341535     |
| S3        | 35              | 0.1            | 0.502793421     |
| S4        | 35              | 0.15           | 0.450052852     |

Table 5. Normalized Matrixes

Step: 4 from weighted normalized matrix, ideal best value and ideal worst value as to been identified.

\[ V^+ = \{ (\max V_{ij} \mid j \in C_b)(\min V_{ij} \mid j \in C_c) \} \]

\[ V^- = \{ (\min V_{ij} \mid j \in C_b)(\max V_{ij} \mid j \in C_c) \} \]  

(3)

| Specimen | Flax fiber wt. % | Graphene wt. % | Weighted Normalized Matrix |
|-----------|-----------------|----------------|---------------------------|
| S1        | 35              | 0              | 34.46420357               |
| S2        | 35              | 0.05           | 33.34153267               |
| S3        | 35              | 0.1            | 32.63129301               |
| S4        | 35              | 0.15           | 29.18592746               |

Table 6. Weighted Normalized Matrix

Step: 5 now using Euclidean distance find the separation measurement from best ideal value and worst ideal value.

Separation distance from ideal best value: \[ S^+_i = \left[ \sum_{j=1}^{m} (V_{ij} - V^+) \right]^{0.5} \]  

(4)

Separation distance from ideal worst value: \[ S^-_i = \left[ \sum_{j=1}^{m} (V_{ij} - V^-) \right]^{0.5} \]  

(5)

| Specimen | Flax fiber wt. % | Graphene wt. % | Si+       | Si-       |
|-----------|-----------------|----------------|-----------|-----------|
| S1        | 35              | 0              | 27.39962  | 0         |
| S2        | 35              | 0.05           | 9.531541  | 19.05859  |
| S3        | 35              | 0.1            | 3.445366  | 26.94881  |
| S4        | 35              | 0.15           | 3.782706  | 23.9818   |

Table 7. Calculating Ideal Best and Worst Values

Table 8. Calculating Euclidean distance from the Ideal Best & Ideal Worst Value
Step: 6 Performance score is to be calculated from Euclidean Distance values and ranking is given based on the score obtained.

\[ P_i = \frac{S_i}{(S_i^+ + S_i^-)} \]  \hspace{1cm} (6)

Table 9. Calculating Performance Score

| Specimen | Flax fiber wt. % | Graphene wt. % | Pi | Rank |
|----------|-----------------|----------------|----|------|
| S1       | 35              | 0              | 0  | 4    |
| S2       | 35              | 0.05           | 0.666614 | 3    |
| S3       | 35              | 0.1            | 0.886644 | 1    |
| S4       | 35              | 0.15           | 0.863757 | 2    |

Methodology for final order preference to ideal solution is used to evaluate best material composition based on its multi criteria parameters, the order preference technique has suggested to select the composite material with graphene 0.1Wt% with flax fiber 35% (specimen 3) as the most optimal value compare to other specimens of different graphene percentages.

6. Conclusion

Mechanical properties of composite material are compared with and without graphene percentage. By adding the graphene the mechanical properties shown the positive result compare to normal flax fiber properties. The strength properties of composites increase with increase in Wt% of graphene up to 0.1% and then reduced. Therefore, the optimum Wt% of graphene is found to be 0.1Wt% for better mechanical properties. However, the decrease in strength with high graphene content can be attributed to the following two effects: - Non-uniform dispersion of the graphene in higher loading systems, acoustic cavitations is one parameter for graphene dispersion under low content. Voids might also have decreased the strength. Choi et al. also reported that few voids were produced during the fabrication process and that voids increased with higher nano particle content. Validating the above experimental work is carried out by ideal decision making process TOPSIS Method given the best optimal performance as been evaluated for the different wt % of graphene used in Flax fiber from several attributes, combination like mechanical properties and wt. % from which it is observed that 1 % of graphene in flax fiber as given the best ranking by utilizing this novel method in natural reinforced material.

7. References

[1] Sathish kumar Naveen 2014Glass fiber-reinforced polymer composites – a review., J Reinf Plast Compos 33(13), 1258–1275.
[2] A.Netravali Huang and Mizuta.K 2007 Advanced green composites, Advanced Composite Materials, 15(4), 269–282.
[3] Schmehl Mussig U. Schonfeld and Von Buttlar 2008, Life Cycle Assessment on a Bus Body Component Based on Hemp Fiber and PTP, Poly Environment, 16(8), 51–60.
[4] K Amarnath P Sureshendharn V Kumar 2019 Experimental Investigation to optimize process parameters in Drilling Operation for Composite Materials, Lecture Notes in Mechanical Engineering, 978-981-15-1124-0, 343-352.
[5] Pickering Aruan Efendya Lea TM 2016 A review of recent developments in natural fibre composites and their mechanical performance, Compo Part A, 83, 98–112.
[6] K.Mohanty M. Misra L.Dr zal S.Selke B.Harte Hinrichsen 2005 Natural fibers, biopolymers, and biocomposites: introduction Natural fibers biopolymer, and biocomposites , Taylor & Francis, 1–36.
[7] Suddell Evans 2005 Natural fiber composites in automotive applications, Natural fiber,
biopolymer, and biocomposite, 978-084-93-1741-5, 1–89.
[8] Ochi 2008 Mechanical properties of kenaf fibers and kenaf PLA materials, Mechanics of Materials, 40, 446–452.
[9] Fiore, Scalici and Valenza 2017 Effect of sodium bicarbonate treatment on mechanical properties of flax-reinforced epoxy composite materials, J Compos Mater., 52, 1061–1072.
[10] Muralidhar A 2013 Study of flax hybrid preforms reinforced epoxy composites., Master Des., 52, 835-840.
[11] M.Kabir Wang K.Lau and F. Cardona 2012 Chemical treatment on plant-based natural fibre reinforced polymer composite: overview, Composites Part B: Engineering, 43(7), 2883–2892.
[12] H. Wang G. Xian H 2015 Grafting of nano-TiO2 on flax fibers and enhancement of the mechanical properties of the flax fiber and flax fiber/epoxy composite, Composites: Part A, 76, 172–180.
[13] Seshanandan Ravindran and Sornakumar 2016 Mechanical properties of nano titanium oxide particles – hybrid jute-glass FRP composites, Mechanics Today: Proceedings, 3, 1383–1388.
[14] G. Rajesh A.Prasad 2014 Tensile properties of alkali treatment short jute PLA composite, Procedia materials science, 5, 2188-2196.
[15] H.Singh Kumar 2012 Selection of Material for Bicycle Chain in Indian Scenario using MADM Approach, Proceedings of the World Congress on Engineering, 3.
[16] Balasubramaniyan S and Selvaraj T 2017 Application of integrated Taguchi and TOPSIS method for optimization of process parameters for dimensional accuracy in turning of EN25 steel. Journal of the Chinese Institute of Engineers, 40(4), 267-274.
[17] Khoshidi Hassan Honarbakhsh 2013 Selection of an optimal refinement condition to achieve maximum tensile properties of Al-15% Al–15%Mg2Si composite based on TOPSIS method, Materials & Design, 42, 444-450.
[18] Divya C Raju, L S. and Singaravel B 2021 Application of MCDM Methods for Process Parameter Optimization in Turning Process—A Review. Recent Trends in Mechanical Engineering, 199-207.
[19] Chakladar and Chakraborty 2008 A combined TOPSIS-AHP-method-based approach for non-traditional machining processes selection, Journal of Engineering Manufacture, 222(12), 1613-1623.
[20] H. Dhakal and O.Richardson 2007 Effect of water absorption on the mechanical properties of hemp fibre unsaturated polyester composites, Composites Science and Technology, 67(7), 1674–1683.
[21] Miyagawa A.Mohanty Misra and Drzal 2004 Thermo physical and impact properties of epoxy containing epoxidized linseed oil, Macromolecular Materials and Engineering, 289(7), 636–641.
[22] Zhu K. Chandrashekhara Flanagan and Kapila 2004 Curing and mechanical characterization of a soy-based epoxy resin system, Journal of Applied Polymer Science, 91(6), 3513–3518.
[23] Choi Sugimoto SM. Song Y. Gotoh Y and M. Endo 2005 Mechanical and physical properties of epoxy composites reinforced by vapor grown carbon nanofibers, Carbon, 43(10), 2199–2208.