



# Fabrication and Mechanical Characterization of VARTM Epoxy Composites

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## Abstract

Vacuum-assisted resin transfer molding (VARTM) offers potential advantages for producing large-scale composite structures, including relatively low-cost processing and the ability to achieve high fiber volume fractions. However, for many aircraft applications, VARTM currently faces challenges in providing consistent repeatability and controlling process variability. Understanding and minimizing the sources of this variability is essential to reliably produce aircraft-quality parts. Models have been developed to capture the underlying process physics and have been validated through experiments. In this study, hybrid composites were manufactured using a combination of glass and flax fibers reinforced with an epoxy resin system containing a hardener and synthetic fillers. The VARTM process was employed to fabricate these composites, which provided a balance of high strength and stiffness from the glass fibers and good damping properties from the flax fibers. Specimens were prepared in both warp and weft directions according to DIN 521 standards and were tested for tensile, bending, and Charpy impact properties using a universal testing machine. The resulting mechanical properties of the hybrid composites are presented in tabular form.

## Subject Areas

Materials Engineering

## Keywords

VARTM, U.T.M., Molding, Tensile, Bending and Charpy Test

## 1. Introduction

Composites materials produce combination properties of two or more materials that cannot be achieved by either fiber or matrix when they are acting alone. Fiber-

reinforced composites were successfully used for many decades for all engineering applications. The mechanical behavior of a fiber-reinforced composite basically depends on the fiber strength and modulus, the chemical stability, matrix strength and the interface bonding between the fiber/matrix to enable stress transfer [1].

Compares natural and glass fibers are clearly showing areas where the former has distinct advantages over the latter. Carbon dioxide neutrality of natural fibers is particularly significant. The burning of a substance derived from petroleum products releases enormous amounts of carbon dioxide into the atmosphere. This phenomenon is believed to be the major cause of the greenhouse effect and consequently, the world climatic changes.

Flax is probably the oldest textile fiber known to mankind. It has been used since ancient times to produce cloth which is better known to us by linen. Flax fibers have high strength and durability. The increasing application of natural fiber-reinforcement has advantages in cost, availability, and degradability. The cost of flax fibers is nearly three times cheaper than that of glass fibers that are often used in the composites industries. It has a low density compared to those of glass fibers. For the use of automotive industry, weight reduction is always an issue, and this is the main reason that more and more automobile parts use flax fibers. Another reason for selecting flax fiber, which has damping and load absorption properties.

In the present generation, almost all the structural materials are made using the glass fiber composites. Glass fiber reinforced composites were first made to use in the 20th century for aerospace application. Cost of the glass fiber is less, and it is less brittle fibers than other fibers. Glass fiber (GF) composites was most commonly used in the manufacture of composites materials. The functional characteristics of GF composites are used in the marine industry and piping industries because of good environmental resistance, better damage tolerance for impact loading was equal to steel, had a higher stiffness than aluminium. The glass fiber widely used in the aircraft, automobile, aerospace, and defence. The main drawback of the glass material is the rigidity, because of the lack of flexibility, the installation becomes more difficult.

## **2. Materials and Methods**

### **2.1. Apparatus Used**

- Fiber material (glass fiber and flax fiber)
- Resin and hardener
- Talcom filler
- Vacuum bag
- Pre-ply
- Distribution media
- Vacuum pump - 1.8bars pressure
- Pipes
- Seal tab

- Realize agent
- Base setup (preform)
- Laminate configuration and processing details

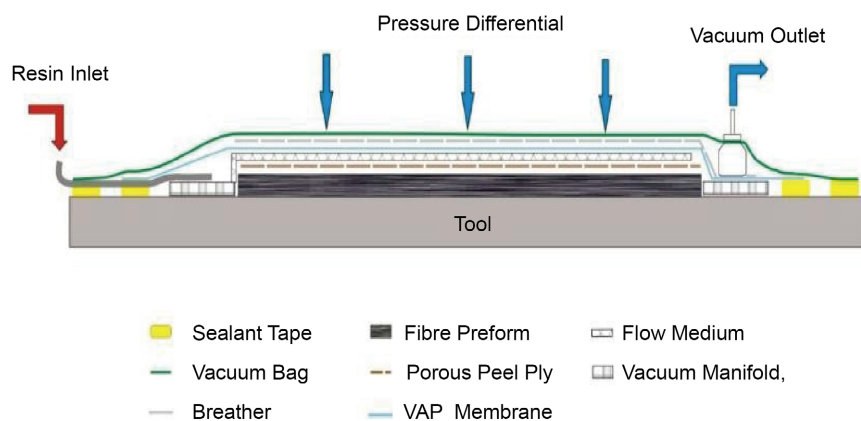
The composite laminates were prepared using a hybrid arrangement of glass and flax fibers in the sequence [G/G/F/F/G]. Both types of fibers were arranged in a bidirectional woven form with orientations of  $0^\circ$  and  $90^\circ$ , which helps provide balanced in-plane properties. The glass fiber had an approximate areal density of  $600 \text{ g/m}^2$ , while the flax fiber had a lower areal density of about  $300 \text{ g/m}^2$ . A total of five layers were used, resulting in a laminate thickness of around 3 to 4 mm.

The matrix consisted of an epoxy resin system mixed with a hardener in a ratio of 100:40 by weight. Talc filler was introduced into the resin at three different concentrations: 2 wt%, 5 wt%, and 7 wt%. Before the infusion process, the resin mixture was carefully degassed to remove any trapped air, which could otherwise lead to voids in the final composite.

The VARTM process was carried out under a vacuum pressure of approximately  $-0.8 \text{ bar}$ . A peel ply and distribution medium were used to ensure uniform resin flow across the laminate. After infusion, the setup was left undisturbed and allowed to cure at room temperature (approximately  $25^\circ\text{C}$ ) for 24 hours.

## 2.2. Experimental Plan

The Resin transfer molding (RTM) process is a cost-effective fabrication method for the manufacture of polymer composites. In a traditional RTM process, the catalyzed thermosetting resin is injected into an enclosed metal mold containing a previously positioned reinforcement preform. The preform is compacted to the specified fiber volume fraction when the matched metal mold is closed. The resin wets out the fiber until the mold is filled, and the part is then cured inside the mold. **Figure 1** explains the process of the RTM [2].



**Figure 1.** A schematic diagram of the process.

### Material

- **Flax Fiber:** The use of Flax fiber for the reinforcement of composites has lately received increasing attention, both by the academic and by the industry. Flax

fiber which originates from renewable resources is a noteworthy alternative to the mineral fibers. Their low cost, low density, sustainable and has excellent vibration damping properties, improving shock absorption and environmental impact and has been showing to work well when combined with glass fiber in hybrid composites structures.

- **Glass Fiber:** The manufacturing process has the great effect on the properties of glass fiber reinforced epoxy resin composites. Glass fibers have as excessive physical properties such as high strength, easy to handle and lightweight. The main advantage of glass fibers is used for the thermal and electrical insulation, heat and corrosion resistance fabrics.

### 2.3. Resin, Hardener and Filler

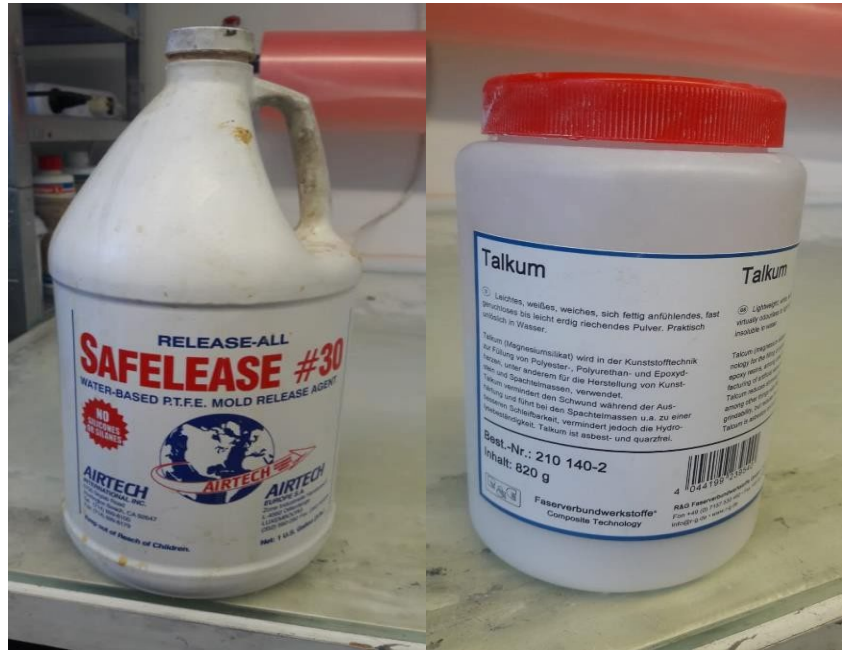
- Some steps should be followed while mixing the resin with hardener and filler.
- The two components (Resin and Hardener) should be a mix in cure temperature and cure time. This may take a couple of minutes.
- Resin and hardener should be mixed in the ratio of (100:40) with 2, 5, and 7% of talcum filler.
- Do not attempt to make the resin cure quicker, or become hardener, by adding more of the hardener component it does not work.
- The two components should be mixed properly, and it should be clear with the air bubbles and stirring lines.
- The mixing time should be less or else it becomes hard and very hot.
- After mixing the resin and hardener, filler (talcum) is added to the component with respective percentages.
- While mixing the resin safety instructions should be followed [3].

### 2.4. Vartm Procedure

Glass fiber (3 layers) and Flax fiber (2 layers) is used as a reinforcing material, Epoxy resin (latex) and hardener, as shown in **Figure 2**, are used as matrix material, and Talcom is used as a filler material with different weight percentage to increase mechanical properties. Talcom is a low-cost filler used to transform resin into an easily spreadable paste or putty [4]. Talcum increases weight and stiffness. Use to extend resin, reduce shrinkage and sanding effort. Use for a faring compound and to fill voids where weight is not a consideration. Before starting the experiment, the flat stone plate is placed on the table, to make sure that plate is free from dirt. Apply release agent 3 times with an interval of 5 minutes to avoid sticking of the plate to the plastic sheet. The glass fiber and flax fiber are cut at the required size of 270 × 250 mm.

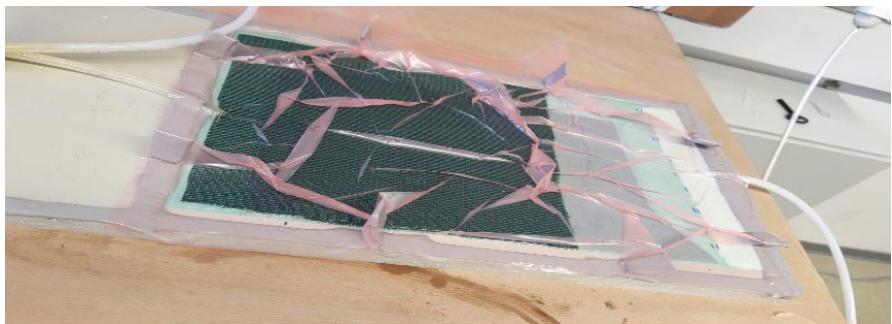
A VARTM process for resin infiltration of stitched foam core preform was developed. The stitched foam core preform was placed on a flat plate. The flat plate was treated with a release agent over the area on which manufacturing took place. A porous peel ply was placed directly on top of the preform. Then, a nylon high-permeable distribution medium was cut to leave approximately 60% of the glass

and flax fiber space between the edge of the medium and the vacuum edge of the preform. A resin distribution tube was placed one for inlet and another for excess amount. The entire assembly was then sealed in a vacuum bag. A vacuum port was centered on the breather materials. The other end of the resin tube was plugged, and a vacuum was applied to expel any air.



**Figure 2.** Epoxy resin (latex), hardener and talcom.

After the vacuum bag is fully fixed on the top of the fibers check there are no leakages for the air. The vacuum bag should be free from air and dust. Start the vacuum pump and the resin gets transfer throughout the vacuum setup as shown in the above **Figure 3**.



**Figure 3.** Vartm setup.

The vacuum setup should not be disturbed till 24 hours and keep it in the room temperature. The experiment was repeated with the 2%, 5% and 7% of fillers. After keeping the composite till 24 hours it demolds and it was lightweight composite material. As shown in **Figure 4** below.



**Figure 4.** Flat epoxy composite.

## 2.5. Preparation and Testing Procedure

All test specimens were cut from the fabricated laminates using a precision cutter to maintain consistent dimensions and avoid edge damage. Care was taken to ensure that all specimens were prepared under identical conditions for fair comparison.

For tensile testing, specimens were prepared according to ISO 527 with dimensions of  $250 \times 25$  mm and a gauge length of 150 mm. The tests were conducted at a crosshead speed of 10 mm/min, and three specimens were tested for each filler percentage.

Flexural testing was performed using the three-point bending method based on ASTM D790. The specimens had approximate dimensions of  $80 \times 10 \times 4$  mm, and five samples were tested for each composition.

Charpy impact testing was carried out following ASTM A370 guidelines (adapted for composites). The specimens measured  $80 \times 10$  mm and included a V-notch with a depth of 2 mm and an angle of  $45^\circ$ . Between three and four specimens were tested for each filler level.

The tests were conducted using a calibrated Universal Testing Machine (UTM). Different tests were conducted, such as the three-point bending test, tensile test and impact test carried (Charpy type) on impact machine [5].

### 2.5.1. Tensile Test

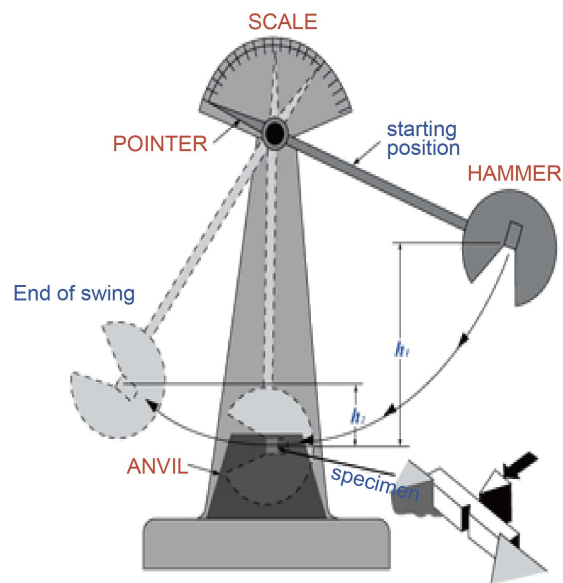
One of the most fundamental mechanical tests that can be performed on a material is the tensile test. Tensile properties indicate how the material will react to forces being applied in tension. A tensile test, as in **Figure 5**, is a fundamental mechanical test where a carefully prepared specimen is loaded in a very controlled manner while measuring the applied load and the elongation of the specimen over some distance. These tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, and reduction in area, tensile strength, yield point, yield strength, and other tensile properties [6].

### 2.5.2. Charpy Test

The Charpy test is measured by allowing a pendulum to strike a grooved machined test piece and measuring the energy absorbed in the break. The Charpy test, as in **Figure 6**, measures the energy absorbed by a standard notched specimen



**Figure 5.** Tensile testing machine.



**Figure 6.** Charpy testing machine.

while breaking under an impact load. This test continues to be used as an economical quality control method to determine the notch sensitivity and impact toughness of engineering materials.

The Charpy test is commonly used on metals, but it is also applied to composites, ceramics, and polymers. It is one of the most commonly used methods to evaluate the relative toughness of a material. This test consists of striking a suitable specimen with a hammer on a pendulum arm while the specimen is held securely at each end. The hammer strikes opposite the notch. The energy absorbed by the specimen is determined by precisely measuring the motion of the pendulum arm [7]. Important factors that affect the toughness of a material include low temperature, high strain rates (by impact or pressurization), and stress concentrators such as notches, cracks, and voids.

### 2.5.3. Flexural Test

Bend test machines are typically universal testing machines specially configured to evaluate material ductility, bend strength, fracture strength, and resistance to fracture. Bend tests tend to be associated with ductile metals and metal products. The most frequently studied bending load in materials testing is the three-point bending test, as shown in **Figure 7**. Using this method, a beam mounted on two supports is studied under a single force applied to the center. The bending test demonstrates the relationship between a load of a bending beam and its elastic deformation. The effects of the modulus of elasticity and the second moment of the area are shown.



**Figure 7.** Bending test machine.

Generally, a bending test is performed on metals or metallic but can also be applied to any substance that can experience plastics deformation, such as polymers and plastics. These materials can take any feasible shape but when used in a bend test most commonly appear in sheets, strips, bars, shells, and pipes [8]. Bend test machines are normally used on materials that have an acceptably high ductility.

## 3. Result and Discussion

### 3.1. Definition of Variables

To maintain clarity and consistency, the following parameters are used throughout the study: In FEM analysis all these variables will be used for demonstration of mechanical performance [9] [10].

$\sigma_{low}$ : Lower yield stress (MPa)

$\sigma_{high}$ : Ultimate tensile stress (MPa)

$E_t$ : Tensile modulus (MPa)

$\sigma_b$ : Tensile strength at break (MPa)

$\epsilon_b$ : Strain at break

$E_f$ : Flexural modulus (MPa)

$\sigma_{fc}$ : Flexural stress at conventional limit (MPa)

$\sigma_{fM}$ : Maximum flexural stress (MPa)

### 3.2. Tensile Test

The tensile test was performed on a computer-controlled universal testing machine according to the guidelines with the dimensions of  $250 \times 25$  mm (ISO DIN 527) and  $180 \times 20$  mm (to compare with standard measurement and can be used to analysis in Siemen-Nastran) [11] [12]. Tensile strength and elongation properties can be measured. Speed is 10 mm/min. For the gripping  $50 \times 25$  mm glass/flax with epoxy resin is adhered to the specimen. Gauge length is 150 mm for the  $250 \times 25$  mm specimen.

The specimens are cut in the required dimensions and ready for the tensile test, as shown in **Figure 8**.



**Figure 8.** Tensile test specimen.

The Tensile test is conducted on the specimen more than 2 times with the same percentage of filler to check the average and later with the 5% and 7%. The values are noted in the computer. **Tables 1-3** represent the results which are conducted by the three different percentage fillers in glass/flax fibers.

**Table 1.** Represents the glass-flax fibers with 2% of synthetic filler—tensile test results.

Glass and flax fiber with 2% synthetic filler											
Specimen	L (mm)	$\sigma_{low}$ (MPa)	$\sigma_{high}$ (MPa)	Et (MPa)	$\sigma_b$ (MPa)	$\epsilon$	b (mm)	H (mm)	Ao (mm <sup>2</sup> )	F (N)	Speed (mm/min)
1	150	43600	65159	10700	180	12	24.1	1.95	47.01	8143	10
2	150	44680	44682	148	207	1.7	24.3	2.11	51.44	8899	10
3	150	—	—	—	195	6.9	23.8	1.92	45.70	7906	10

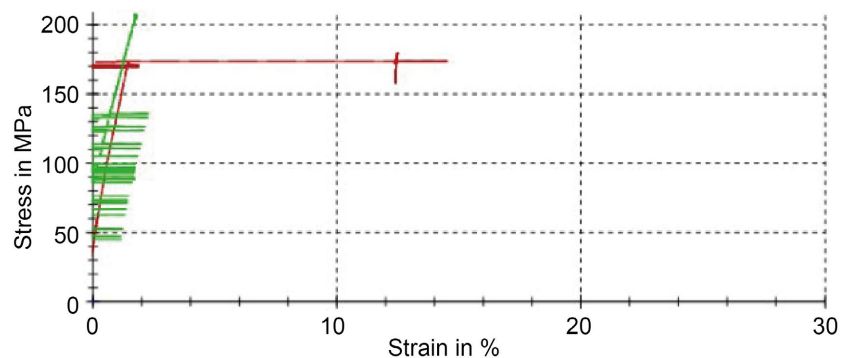
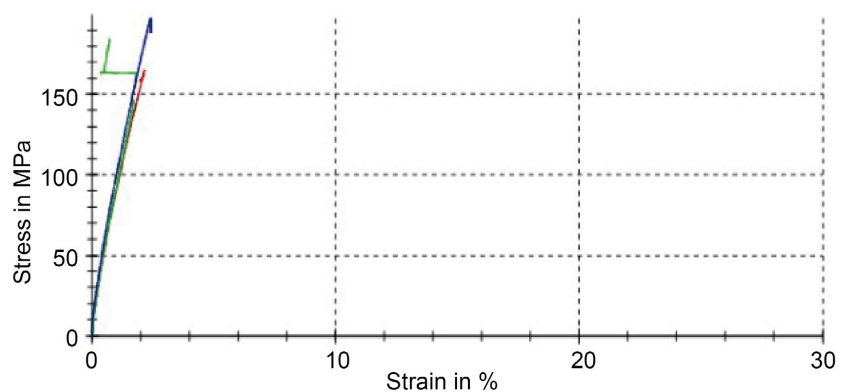
**Table 2.** Represents the glass-flax fibers with 5% of synthetic filler—tensile test results.

Glass and flax fiber with 5% synthetic filler											
Specimen	Length (mm)	$\sigma_{low}$	$\sigma_{high}$	Et	$\sigma_b$	$\epsilon$	b (mm)	H (mm)	Ao (mm <sup>2</sup> )	Force (N)	Speed (mm/min)
1	150	8948	29537	10300	165	2.2	25.3	2.11	53.40	4378	10
2	150	2900	29561	12500	184	0.7	23.7	2.31	54.86	2726	10
3	150	1275	34562	10900	198	2.4	25.7	2.1	54.12	3279	10

**Table 3.** Represents the glass-flax fibers with 7% synthetic filler—tensile test results.

Glass and flax fiber with 7% synthetic filler											
Specimen	Length (mm)	$\sigma_{low}$ (MPa)	$\sigma_{high}$ (MPa)	$E_t$ (MPa)	$\sigma_b$ (MPa)	$\epsilon$	b	H	Ao	Force	Speed
1	150	0046	0184	683	194	3.1	23.0	1.93	44.4	3943	10
2	150	1784	33132	7660	141	2.3	24.9	2	64.7	5761	10
3	150	8754	27228	9010	162	2.0	24.4	1.90	46.51	4651	10

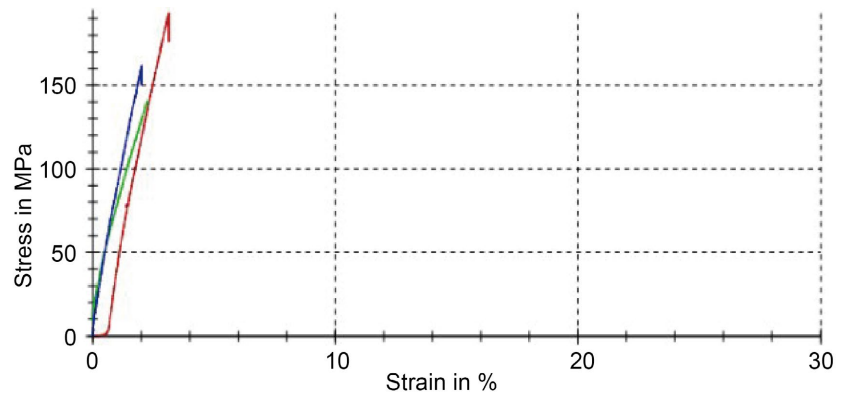
Comparison of the ultimate tensile stress of different percent fillers is tested under tensile test. From **Tables 1-3**, it becomes clear that glass-flax fibers with 2% of synthetic fillers exhibit the highest tensile strength of among other kinds of fibers tested. The graphs are plotted by the tensile test valves which indicate the stress and strain breaking point and represents the young modulus. **Figures 9-11** are glass/flax fibers with epoxy resin respectively 2%, 5%, and 7% of synthetic fillers.

**Figure 9.** Typically stress-strain curve of glass/flax with 2% synthetic filler.**Figure 10.** Typically stress-strain curve of glass/flax with 5% synthetic filler.

### 3.3. Bending Test

Bend test is conducted on the three-point bending test machine to evaluate the bending strength of the material, ductility, and fractural strength [13]. The most

commonly used specimen size for ASTM is  $3.2 \times 12.7 \times 125$  mm and for ISO is  $10 \times 4 \times 80$  mm. The different sizes and shapes can conduct the test easily. The actual dimensions of our specimens are  $28 \times 24$  mm as shown in **Figure 11** below.



**Figure 11.** Typically stress-strain curve of glass/flax with 7% synthetic filler.



**Figure 12.** Bending test specimens.

By testing the specimens as shown in **Figure 12**, on the bending test machine with three different percent fillers on the glass/flax fibers the tensile strength and tensile modulus are noted by the computer as shown in **Table 4-6**.

**Table 4.** Represents the glass-flax fibers with 2% of synthetic filler—flexural test results.

Glass and flax fibers 2% of synthetic fillers						
Specimen	Length (mm)	h (mm)	b (mm)	Ef (MPa)	$\sigma_c$ (MPa)	$\sigma_M$ (MPa)
1	28	1.96	22.3	2550	199	201
2	28	1.96	22.3	2740	211	240
3	28	1.96	22.3	3000	223	251
4	28	1.96	22.3	2350	205	223
5	28	1.93	22.3	2780	204	237

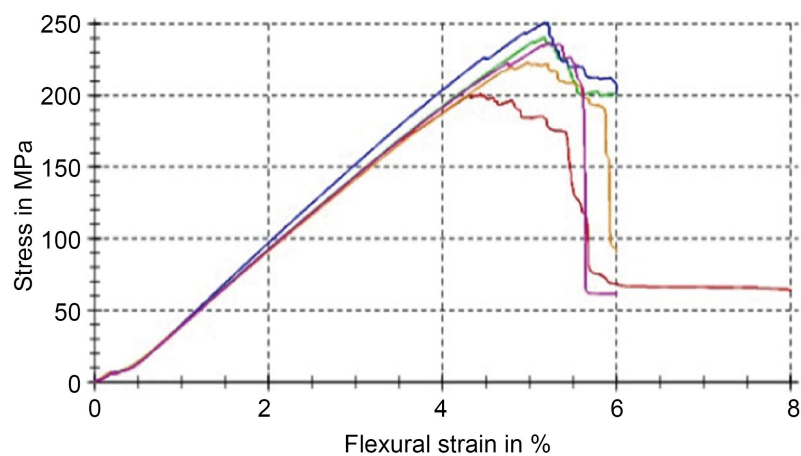
**Table 5.** Represents the glass-flax fibers with 5% of synthetic filler—flexural test results

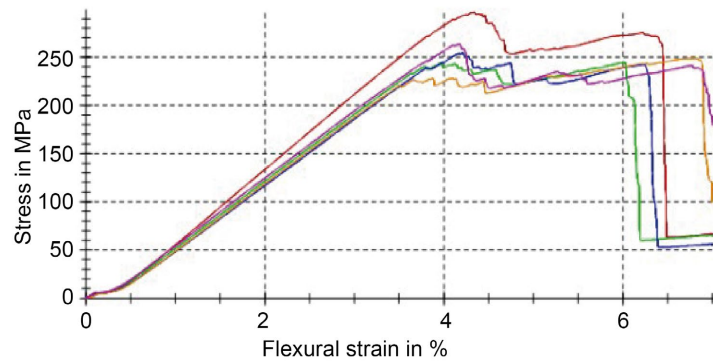
Glass and flax fibers 5% of synthetic fillers						
Specimen	Length (mm)	h (mm)	b (mm)	Ef (MPa)	$\Sigma\sigma_c$ (MPa)	$\sigma_fM$ (MPa)
1	28	2.1	26.06	2020	180	189
2	28	2.0	26.06	2220	188	188
3	28	2.6	26.06	2200	174	178
4	28	2.3	26.06	1400	146	154
5	28	2.0	26.06	1520	132	—

**Table 6.** Represents the glass-flax fibers with 7% of synthetic filler—flexural test results.

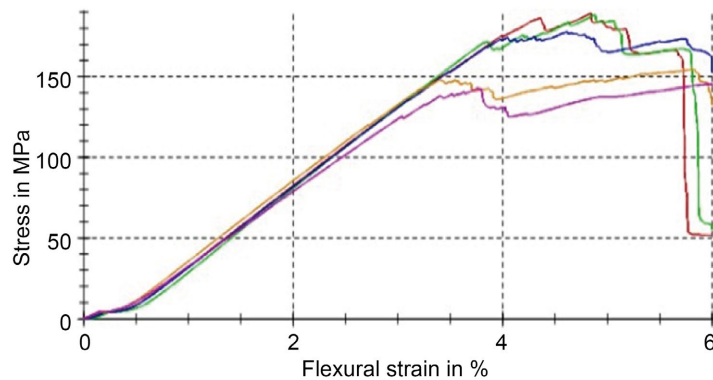
Glass and flax fibers 7% of synthetic fillers						
Specimen	Length (mm)	h (mm)	b (mm)	Ef (MPa)	$\sigma_c$ (MPa)	$\sigma_fM$ (MPa)
1	28	1.8	22.8	1820	265	297
2	28	1.88	22.7	1360	242	244
3	28	1.86	22.6	1740	244	254
4	28	1.86	22.0	2090	224	249
5	28	1.84	21.3	1550	250	264

By comparing the values of the three **Tables 4-6** it clearly shows that the glass/flax with epoxy resin and 2% of synthetic filler have the more flexural strength and flexural modulus with respect to the other two composite fibers. **Figures 13-15** show the result of the bending test machine by using three different percent of fillers which are 2%, 5%, and 7%.

**Figure 13.** Three-point bending graph of glass/flax fibers with 2% of synthetic fillers.



**Figure 14.** Three-point bending graph of glass/flax fibers with 5% of synthetic fillers.



**Figure 15.** Three-point bending graph of glass/flax fibers with 7% of synthetic fillers.

### 3.4. Charpy Test

The Charpy impact test is also known as the Charpy v-notch test, it is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture [14]. According to the ASTM A370, the standard specimen size for Charpy impact testing is  $10 \times 10 \times 55$  mm. The dimensions of the specimen are  $80 \times 10$  mm is used. The Charpy test is conducted on the specimens as shown in **Figure 16**.



**Figure 16.** Charpy test specimens.

The Charpy test is conducted on the specimens, and the results are discussed in the three tables as shown below. **Tables 7-9** represent the amount of energy observed by the specimens in the standard deviation form.

The three tables are glass/flax fibers with 2%, 5%, and 7% of synthetic fillers.

**Table 7.** Represents the glass-flax fibers with 2% of synthetic filler—Charpy impact test results.

No. of tests	004
Mean	0.139 kJ/m
Standard deviation	0.034 kJ/m
Mean	73.29 kJ/m <sup>2</sup>
Standard deviation	18.04 kJ/m <sup>2</sup>
Co-efficient of variation	24.61%

**Table 8.** Represents the glass-flax fibers with 5% of synthetic filler—Charpy impact test results

No. of tests	003
Mean	0.100 kJ/m
Standard deviation	0.023 kJ/m
Mean	54.22 kJ/m <sup>2</sup>
Standard deviation	12.59 kJ/m <sup>2</sup>
Co-efficient of variation	23.23%

**Table 9.** Represents the glass-flax fibers with 7% of synthetic filler—Charpy impact test results.

No. of tests	004
Mean	0.191 kJ/m
Standard deviation	0.065 kJ/m
Mean	101.4 kJ/m <sup>2</sup>
Standard deviation	34.55 kJ/m <sup>2</sup>
Co-efficient of variation	34.05%

From the above three **Tables 7-9**, it was clearly shown that the amount of energy is absorbed in glass/flax fibers with 7% of synthetic filler with compare to the other two composite material. This indicates the amount of energy absorbed by the material during fracture is more in GF fibers with 7% of synthetic filler.

The variation in mechanical performance with filler content can be understood by considering how the filler interacts with the matrix and fibers. At low filler levels (2 wt%), the particles are well distributed, which improves bonding and allows stresses to be transferred more effectively through the composite [15]. At

moderate levels (5 wt%), some particle clustering begins to occur, which weakens the structure slightly. At higher levels (7 wt%), the material becomes better at absorbing energy due to increased internal resistance to crack propagation, although this reduces its strength and stiffness [16].

Overall, the results highlight a trade-off between strength and toughness, which is a common characteristic in particle-filled composites.

#### 4. Conclusions

The study demonstrates that the mechanical properties of hybrid glass/flax epoxy composites are strongly influenced by the amount of talc filler. A filler content of 2 wt% provides the best balance of tensile and flexural properties, while 7 wt% improves impact resistance. These findings suggest that careful control of filler content is essential to achieve the desired balance of mechanical performance in VARTM-fabricated composites.

By observing the results, it can be concluded that glass/flax epoxy composites were prepared with hand lay-up technology. To improve the mechanical properties, mercerization treatment of glass/flax under stretch and the modification of the epoxy resin with synthetic filler were performed. As found, the tensile and bending test properties of glass/flax fibers with 2% of synthetic filler are more than compared to the 5% and 7% of filler. Moreover, in the Charpy test, the amount of energy absorbed during the fracture is high in 7% of filler.

It has been concluded that flax fiber can be used efficiently to reinforce different thermoplastics available. Thermoplastics are plastics that can be remelted. Flax is one of the potential natural fibers with high strength and low density. Glass fibers improve the mechanical properties of the epoxy. It can easily obtain any shape of the desired molding.

VARTM manufactured composites have maximum stiffness, maximum strength and minimum thickness compared to other resin transfer molds. There is a lot of research and projects going on the lightweight technology. This composite can be considered lightweight because of its mechanical properties, degradability and recyclability. There are some news recycling techniques like the depolymerization of thermoset fiber-reinforced epoxy matrix composite.

#### Conflicts of Interest

The authors declare no conflicts of interest.

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