Low velocity impact, compression after impact and morphological studies on flax fiber reinforced with basalt powder filled composites

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Abstract

The objective of this research is to examine the low velocity impact (LVI) and effect of compression after impact (CAI) properties on flax fiber and basalt powder reinforced polyester composites. For this study the 10 layers of flax fiber, basalt powder by varying from 5% to 30% the composites were prepared. In the LVI analysis composite (10 layers of basalt/10% of basalt powder) shows better results about 1755 N of force and for CAI also same composite B experienced with less deformation and more residual energy to absorbing the force of about 2250 N. The addition of filler material up to certain limit will support the reinforcing fiber to achieve some enhanced property. The morphological changes and their properties were assessed using Fourier Transform Infrared Spectroscopy (FTIR) and x-ray diffraction Analysis (XRD) studies for particulate basalt powder. The presence of Pyroxene group of rocks in basalt powder responsible for stability in high temperatures seen using XRD analysis. The band width around 3390–3425 cm\(^{-1}\) shows the presence of hydroxyl group (OH) in the basalt powder. This proved that the materials are Polar Hydrophilic in nature examined with FTIR spectroscopy.

Introduction

Flax fiber is one of the strongest natural fibers with cellulose which is widely used for engineering applications. It is extracted from the flax plant by means of retting process in which the fibers are removed from the epidermis. This flax fiber application is extended up to manufacturing of furniture’s as a replacement of wood. Basalt is one of the continuous synthetic fibers which are extracted from the dense volcanic rocks mainly used for construction and engineering purposes. The hard basalt rocks are crushed in to fine particles to enhance the property of the powder for various applications. One of the well-known applications is usage of basalt powder as a reinforcing material with cement for constructions. Basalt powder contains so many minerals in that the structure of the minerals were important, if there is any changes in the structure of minerals which in term affect the property of the powder these changes are easily identified with the XRD and FTIR analysis [1]. Powder formed basalt shows an improved property when mixed with the raw natural fiber in terms of tensile, flexural strength and dynamic mechanical performance and morphological investigations [2]. FTIR and x-ray diffraction helps to study about the various patterns of organic structure and mineral composition of the composite, the presence of rich calorified minerals in the natural fibers will produce good strength blended with basalt powder [3]. However basalt fiber used as the reinforcement material for polymers, the usage of powdered basalt produce a better surface modifier to achieve good mechanical properties [4]. XRD and FTIR were performed to evaluate the surface modification of chemically treated and un-treated basalt fibers, these result shows that maximum pristine layer of basalt fiber with less changes in the surfaces when it is amorphous, but the
Table 1. Composite Descriptions.

| Composite ID | Name of the combinations                |
|--------------|----------------------------------------|
| A            | Flax-10 layers /5% basalt powder        |
| B            | Flax-10 layers /10% basalt powder       |
| C            | Flax-10 layers /15% basalt powder       |
| D            | Flax-10 layers /20% basalt powder       |
| E            | Flax-10 layers /25% basalt powder       |
| F            | Flax-10 layers /30% basalt powder       |
| G            | Flax-10 layers                          |
| H            | Basalt-10 layers                         |

crystallinity nature of the fiber exhibits more chemical and physical surface changes [5]. The tensile strength and fracture properties of basalt fiber/epoxy composites shows that the treated fiber exhibits more deterioration and good bonding on the interface than the untreated fiber and these modifications are studied with the help of XRD, TEM and FTIR analysis [6, 7]. Functional groups and crystalline structure of the fiber responsible for the modification happens in the properties of the composite structure, while seeing flax fiber which has natural crystallinity would produce good mechanical properties [8]. Geopolymers in the form of slag which has greater ability to resist corrosion with the same basalt used as geopolymers shows better performance in their mechanical properties with raw natural fibers and these process and changes are studied with the help of XRD and Fourier transforms infrared spectroscopy [9, 10]. Flax fiber reinforced with particulate composite, especially synthetic powders will results with good mechanical properties and absorb less perforation in the time drop weight force applying in the composites [11, 12]. Normally hybrid composites are good for low velocity impact (LVI) related applications in that CAI (compression after impact) helps to study about the impact damage responses and residual strength of the composite after impact [13]. The impact damage threshold resistance was more for flax fiber and also good interlaminar resistance towards delamination, the damage development on the surface of the composite was also very less while adding some powdered synthetic materials [14–16]. Flax fiber and basalt powder combination has excellent displacement towards failure and also they shows a better performance with less damages, to study about the damages on internal surfaces and morphological changes with the help of FTIR and XRD analysis further understanding about failures and its causes [17–19]. The energy absorption and impact resistance are the good properties of composites which undergone LVI and CAI responses, the composites which has flax as reinforcement and basalt powder as a filler material will produce some better properties [20]. The addition of filler materials were responsible for the changes happened in the mechanical properties and these changes are helps to evaluate the failure studies of the composite [21]. Impact energy damages are purely depends upon the impact surface characteristics of the composites, the composites have basalt fiber in the impacted face experienced with low impact energy absorption [22]. Combination of basalt/flax fiber composite showed a good impact resistance, during the application of sudden impact loading conditions [23]. Therefore from the overall observation, this study characterized the low velocity impact, compression after impact, XRD and FTIR studies of woven flax/basalt powder polyester composite.

Materials and methods

Woven flax fiber used as reinforcement material which is purchased from Vruksha composites & Services Chennai and basalt powder (40 mesh x down and 150 mesh by down) with the particle size of 1 to 20 μm imported from Austria. General purpose polyester resin used as matrix material, it is purchased from vasavi bala resins Chennai. Methyl ethyl ketone peroxide (MEKP) used as accelerator and cobalt naphthenate as catalyst. The fabrication of composites done by compression molding technique. The size of the mold is about 150X130X3mm and the flax mat is cut according to the given size of the mold for composite preparation.

In the fabrication of composite ten layers of woven flax fiber taken as constant addition of filler material (basalt powder) varying with 5% to 30% in the increment of 5 grams for each composite and these combinations shown in the table 1. With this combination six composite plates were fabricated in same methodology discussed above, after fabrication the composite plates are undergone for LVI, CAI and morphological studies as per the standards.

Result and discussion

X-ray diffraction (XRD) analysis

X-ray diffraction pattern is an intensity plot of x-rays scattered in different angles in the particles present in the powder. And this helps to distinct the material whether amorphous or crystalline with chemically arrangement
of atoms in the chosen sample. The amorphous material doesn’t produce any sharp peaks, because the atoms are identical and arranged in different phase. But the crystalline materials we see the sharp peaks in the graphs, this is due to the arrangement of different atoms in the mixture phase. The x-ray intensity always recorded as count per second with the detector position of 2θ. The instrument which is used to characterize the basalt powder was brucker D8 advance eco XRD analyzer with a room temperature of 25°C. Figure 1 represents the XRD pattern for pure basalt powder. The minerals present in the powder were noted in the graph and the nomenclature with chemical formula is shown in the table 2.

The surface morphology of pure basalt powder is used for synthesis purposes. The size of the basalt powder is about 2–4 μm. Crystal structure of this powder with seven materials at various intensity and angles are plotted in figure 1. The presence of Plagioclase with continuous solid solution series gives color less appearance for the basalt. In this presence of some secondary minerals such as calcite, chlorite, and zeolites are seen in the XRD spectra. Pyroxene mostly seen in the grouping of rocks which has more amount of calcium, magnesium and iron provide the stability at high temperatures. Olivine was abundant in these basalt powder and quartz are typical forms of mafic they are green in color, often found in lava. Synthesis of mineralogical information hornblende was observed which is seen in metamorphic and igneous rocks. Another mineral is nepheline which is widely used for providing the geographical information about minerals extraction in the Earth crust. Orthopyroxene is one of the mineral from silicate family with thin plated igneous rocks. Therefore, the XRD synthesis helps to observe the percentage of minerals present and their properties in the basalt samples. Pore size is estimated about 4 Å, the average crystal size was calculated about 800 nm [24]. The constituents of minerals in the samples decided the property of the materials.

Fourier transform infrared spectroscopy (FTIR) analysis
It is the technique used to obtain the electromagnetic spectrum wave of absorption or emission of the materials whether, it can be a solid, liquid or gas to find their molecular component and structures. The monochromatic infrared (IR) is pass on the sample, it will absorb the light with some wavelength to be noted. Similarly the same
amount of light is absorbed by another material present in the sample in a different wavelength. This analytical technique is used to identify the organic and inorganic materials present in the sample by drawing the graph between transmittance of light and their wavelength’s identified. And also the infrared spectrum identifies the chemical bonding of samples for qualitative and quantitative analysis.

FTIR analysis is done with Shimadzu IR-tracer 100 which is fully automated with high sensitivity and high resolution. Figure 2 shows the FTIR spectra for basalt powder X-axis represents wave number and Y-axis represents absorbance of light. Low IR reflect ability shows the occurrence of materials. The higher IR (infrared ray) reflect represent the calibration fault or there is full transmittance of infrared ray on the material. Wave number interval between 4000–500 cm⁻¹ with the resolution of 2 cm⁻¹. The spectra obtained in air with same intervals of time. The band width around 3390–3425 cm⁻¹ shows the presence of hydroxyl group (OH) in the material. This proved that the materials are Polar Hydrophilic in nature [25]. Symmetric stretching oscillations from 2985–1160 cm⁻¹ there is the deformation due to vibrations and bending. The chain stretching in between the regions, proved the presence of CH₃ (methyl) and CH₂ (methylene) in the basalt powder. The formation of this carbon chain was responsible for the strength and morphology of any of the materials.

Low velocity impact response on flax fiber/basalt powder composite
The low velocity impact test carried out for composites to determine the material deformation under higher speed. During the happening of the impact event, the composite absorbs the energy otherwise the scattering of energy inside the layers. It is depending upon the strength of the material which responds for impact loading conditions. Low velocity impact test was done on IMATEK IM10 drop weight impact testing machine as shown in the figure 3. Energy scale of 12 J as constant energy source for throughout the happening of impact event from the height of 0.24 m. The shape of the impactor is hemispherical shape with the mass of 5 Kg and a piezo electric sensor was connected to record the event. The low velocity impact test was done as per ASTM D7136 standard with the specimen size of 150 mm × 100 mm. The information’s related to the events are validated with the help of LABVIEW software.

In this section the combination flax layers with various percentage of basalt powdered composite, force versus time relationship for low velocity responses were discussed and presented in the figure 4. The x-axis symbolizes the time and y-axis with force, this comparison will helps to study about the low velocity responses of these combinations.

More addition of filler material with the fiber reduces the stiffness of the composite [26]. Especially basalt powder with flax fiber exhibits good absorbing behavior for low velocity applications [26]. Figure A represents 10 layers of flax fibers with 5% of basalt power composite while seeing the figure, energy absorption was more and also energy with standing ability also good for composite A. It can with stand a force up to 1750 N at 1.5 s after the application of load. The adhesion between the flax fiber and polyester resin was more after the addition of basalt fiber filler.

The combination of flax fiber with the basalt powder provides a support for the composite in the time of application of sudden load. Figure B represents with 10 layers of flax fiber with 10 grams of basalt fiber was added for the composite B. The peak of the curve clearly defines that more amount of energy is absorbed and it doesn’t allow the impactor to penetrate inside the composite. The presence of filler basalt powder provides additional strength to the flax fiber in the time of application of impact force about of 1755 N. The improved interfacial
bonding between the basalt powder and the polyester resin will exhibit this kind of responses in the time of sudden load applications \[27\]. In figure C severe damages were noted for the composite C and the peak of the curve clearly indicates that the composite does not absorb the application of load. In composite C the 10 layers of flax with 15 grams of basalt powder was added as filler. The hybrid architecture of the fiber will produce a counter attack on the application of sudden load. The low transverse strength of the flax fiber with polyester resin exhibits more perforation on the surface of the composite was seen about 1600 N of applied force. The addition of basalt powder as filler material increases the strength of the composite. Responses with sustainable drop in the load by loss of elastic energy towards subsequent fiber breakage with perforations were noted \[28\]. From this influences of filler material with the reinforcement fiber was less. But increasing the quantity of the filler material in composite leads to severe damages on low velocity related sudden load applications. In figure D the peak of the curve with more fluctuations seen in the absorbed energy. The absorbed energy was more than the applied energy, than the energy is scattered inside the material with more amount of penetration by the impactor \[29\]. Addition of basalt powder as filler material about 20%, 25% and 30% for the composite E, F and G with the 10 layers of flax fibers. The effect of low velocity responses of these composites were seen in the figure E, F and G. Peak of these curve represents the excessive damages on the surface of the composite, due to the application of sudden load. Elastic response of the flax fiber composite was weak in the addition of more amount of filler material in the composite. In the same case complete damages on the composite was noted. With the full penetration of the impactor on the surface of the composite, does not absorb the force of about 1500 N to restrict the deformation comparing to other composites. There are two types of the curve we must notice to speak about the impact performance of the material. Open and closed type curves, both the curve depends upon the amount of energy applied, absorbed and released. The curve is open so, less absorption of energy with small perforation noticed in figure G of 10 layers of flax composite G. Figure H of composite H with 10 layers of basalt fiber, closed type curve is noticed and peak of the curve experienced with some re-bounding of impactor.

**Compression after impact (CAI) response on flax fiber/basalt powder composite**

Compression after impact test is use to find out the damage resistance of the composite after the impact event happened on the composite specimen. The result of this test indicates a severe damage on external surface of the composite. CAI test helps to measure the residual strength of the material during the time of compression. Compression after impact test was carried out on Zwick Roell hydraulic testing machine, with a speed rate of 1.20 mm min\(^{-1}\). ASTM D7137 standard for compression test was followed to study about the compression behavior of the composite. In figure 5 the CAI setup with mold were shown. The fixture was prepared with the dimension of 150 mm \(\times\) 100 mm to hold the specimen from buckling during the time of applying of compressive load.
Figure 4. Force versus time (composite A, composite B, composite C, composite D, composite E, composite F, composite G, composite H).
The absorbed energy and damage resistance of the flax fiber/basalt powder composite highly influence the residual strength of the composite [29]. Figure 6, the graph shows the CAI responses of flax fiber/basalt powder composite. The x-axis indicates the composite code and y-axis indicates the compression force applied after the impact event. The maximum residual strength noted on pure basalt composite of composite H is about 2400 N. The basalt fiber polyester composite shows a superior peak load performance by absorbing more amount of energy as residuals than the flax fiber polyester composite. It is clearly, proved on composite G pure flax fiber polyester composite has with stand only around 1450 N, while seeing the specimen it was heavily damaged internally and externally due to the scattering of energy.

Deformation is less and more residuals of energy absorbed for the composite B about 2250 N which has 10 grams of basalt powder. Absorbed energy and magnitude of damaged area were influenced by the addition of filler material in the composite. This filler material supports the composite to exhibit some of residual energy after the happening of the impact event. The presence of filler basalt powder produces a stiff bond between the sackings of flax fiber and polyester resin [30]. The thickness of the flax laminates and the required amount of filler basalt powder supports the composite to produce better residual strength after the impact event. In the addition of more amount of basalt powder as filler material, does not show better CAI response. Because the
residual strength of the composite material depends on the thickness and orientation of the fiber. If the filler material was added into the composite, it also affects the residual strength of the composite. While seeing the composite A, C, D, E and F the difference in the filler basalt powder affects the CAI response of the composite. Hence, it is proved with the CAI results of these composites about 1985 N, 1879 N, 1622 N, 1609 N and 1519 N.

Conclusion

In this paper, the low velocity impact and compression after impact properties of 10 layers of flax and varying amount of basalt powder added as a filler material were examined. The summaries of results are as follows,

- In XRD analysis, the presence of Plagioclase responsible for formation of secondary minerals like calcite, chlorite, and zeolites were seen in the XRD spectra. Pyroxene mostly seen in the grouping of rocks which has more amount of calcium, magnesium and iron provide the stability at high temperatures for the basalt powder. Olivine was abundant and quartz responsible for the hardness strength of the basalt powder.

- Symmetric stretching oscillations from 2985–1160 cm⁻¹ causes deformation due to vibrations and bending. The stretching in between the regions proved the presence of CH₃ and CH₂ in the basalt powder. Formation of this carbon chain was responsible for the strength and decides the morphological stability at high temperature which was identified through FTIR analysis.

- In low velocity impact test, the 10 layers of flax fiber with 10 grams of basalt powder (composite B) has more amount of energy is absorbed were noted, it doesn’t allow the impactor to penetrate inside the composite. The presence of filler basalt powder provides additional strength to the flax fiber in the time of application of impact force about 1755 N.

- Deformation is less and more residuals of energy absorbed for the about 2250 N which has 10 grams of basalt powder with 10 layers of flax fibers (composite B). The absorbed energy and magnitude of damaged area were influenced by the addition of filler material in the composite. This filler material supports the composite to exhibit some of residual energy after the happening of the impact event. The presence of 10 g basalt powder produces a stiff bond between the sackings of flax fiber and polyester resin was observed from CAI test.

- From the overall observation for both CAI and LVI tests, the lesser amount of filler material about 10 g helps to absorb the energy before and after the happening of the event noted in composite B. Addition of required amount of filler material in the composite will increases the strength of the composite and help for various mechanical related applications.

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