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Effect of Fibre Orientation and Volume on the Thermo-Acoustic Properties of Jute Polyester Composite

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Abstract
This study investigates the effect of fibre orientation and volume on thermal and sound-absorbing performance of composite material. Automotive noise control is one such area; it is important to prevent the noise as it is not desirable inside the vehicle. Thermal insulating and sound-absorbing composite material made from different jute fibres percentage, treated and polyester unsaturated resin was produced using hand lay-up method. The results showed that the composite of 25% fibre volume fraction and randomly oriented fibre composite gives the best thermal and acoustic properties. The composite with random orientation and 25% fibre volume fraction has shown the highest sound absorption coefficient of 0.46. The composite with 25% fibre volume fraction with parallel orientation gives the least conductivity at 1.2 W/m.K. The composite sample possesses better thermal characteristics and stability over 100% polyester sheet; hence, it finds good scope of application in the refrigerator body parts, interior panels for automobiles, etc.
Key Words: Jute, Polyester Resin, Sound Absorption, Thermal conductivity

I. INTRODUCTION

Noise control in automobiles can be achieved by using acoustic materials. The sound absorption characteristics of materials are studied using ASTM E-1050 and ISO-10534. The sound absorption coefficient is measured as a characteristic of the material. However, one of the leading challenges in the application of acoustic materials is that one single material is not available that covers the entire frequency range of 200 Hz to 6.4 kHz. Hence, characterization of these materials plays an important part in their selection and appropriate application. Use of the best method for analysing the material's acoustic properties would help for industrial applications. The methods provide material acoustic properties like characteristic impedance, random incidence absorption coefficient and propagation constant. The temperature not only degrades the structure, but also affects most properties of the natural fibre composites. A complete understanding of these effects requires understanding of the composites' basic thermo-gravimetric analysis i.e., weight loss and its degradation characteristics with increasing temperature characterization, thermal conductivity and deflection temperature for the composites. In this study, we have developed novel composite material using jute fibre reinforced with unsaturated polyester. This paper discusses all the above mentioned properties of jute polyester composites.

II. MATERIALS AND METHODS

2.1 Materials

Processed jute fibre was obtained from Institute of Jute & Fiber Technology, Kolkata, India. Properties of jute fibre are given in Table 1.

Table 1: Properties of Jute Fibre

Property	Specification
Fineness	1.4 Tex
Tenacity	45gf / Tex
Elongation at break	1.80%

Figure 1: Raw Jute Fibre

The unsaturated polyester resin of the grade ECMALON 4411 was purchased from Nazmi Chemicals Pvt. Ltd. Akola, Maharashtra, India. The properties of the resin are listed in Table 2.

Table 2: Properties of Unsaturated Polyester Resin

Property	Specification
Density	1205Kg/m^3
Viscosity	500 cps at 25^{o}C
Monomer content	33%

2.2 Methods

2.2.1 Fibre Treatment

The raw jute fibres are pre-washed with distilled water to remove the surface dirt present in the fibres and then put in an oven at 100°c for drying until it gains constant weight. The mercerization or alkali treatment is carried out by immersing the washed jute fibres in 5% sodium hydroxide aqueous solution for 3 hours at room temperature. It should be stirred occasionally; the fibres are then taken out and washed in order to remove any absorbed alkali.

2.2.2 Preparation of Composite

In this study, hand lay-up technique was used to formulate the composite samples. The samples were prepared in 30 × 30 CM. Glass sheets and wooden strips were used for a mould for laying the composites. For a good surface finish and easy de-moulding, very light layer of PVA and wax was applied. A primary layer of resin was poured in the mould, fibres were laid and the remaining resin was poured uniformly over fibres. The wet composite was then lightly compressed to squeeze out the excessive resin and air. Another glass sheet greased with PVA and wax is placed on the top and pressed with a pressure of 2 bars. Composites were allowed to cure for 24 hours. Finally, after complete drying, the composites were separated off from the moulds. The samples are then trimmed for finishing. The samples are prepared with a variation of fibre volume percent and fibre length. 2% catalyst and accelerator were used on volume fraction of each resin. The composites are prepared with 15%, 20% and 25% fibre volume fraction and plain UPR sheet as reference with treated and untreated jute fibres.

CTR- Composite with Treated jute fibre as reinforcement with random orientation

CUR- Composite with Untreated jute fibre as reinforcement with random orientation

The composite samples were tested for thermal properties to understand the thermal behaviour and sound absorption coefficient of the composite is also tested by using two microphone impedance tubes. The results were analysed by using MATLAB for interpretation of the results.

2.2.3 Thermal Conductivity

Thermal conductivity values are used to measure heat flow through a material. It is the measure of resistance of materials for heat transmission. Thermal insulation is the reciprocal of conductivity. A composite with lower thermal conductivity means good insulation property. Thermal conductivity of the samples is measured using guarded heat flow test method as per ASTM E1530 specifications. Unitherm Model 2022 was used to measure the thermal conductive property of the composite samples.

2.2.4 Thermograviemetric analysis

Thermograviemetric analysis or thermal gravimetric analysis (TGA) is a method of thermal analysis in which the mass of a sample is measured over time as the temperature changes. This measurement provides information about physical phenomena, such as phase transitions, absorption and desorption as well as chemical phenomena including chemisorptions, thermal decomposition and solid-gas reactions. The samples are tested according to ASTM E1131 standards.

2.2.5 Heat Deflection Temperature

The deflection temperature is the temperature at which a test bar, loaded to the specified bending stress, deflects by 0.010 inch (0.25 mm). The deflection temperature is a measure of a polymer's ability to bear a given load at elevated temperatures. The deflection temperature is also known as the 'deflection temperature under load (DTUL), heat deflection temperature or 'heat distortion temperature' (HDT). The two common loads used are 0.46 M Pa (66 psi) and 1.8 M Pa (264 psi), although tests performed at higher loads such as 5.0 M Pa (725 psi) or 8.0 M Pa (1160 psi) are occasionally encountered. The common ASTM test is ASTM D 648 while the analogous ISO test is ISO 75. The test using a 1.8 M Pa load is performed under ISO 75 Method A while the test using a 0.46 M Pa load is performed under ISO 75 Method B. In this study, we have used Method B for testing the deflection temperature of the composite samples.

2.2.6 Sound Absorption

The ability of the composite material to absorb unwanted noise is based on dissipation of the sound wave energy upon passing through the material and being directed by the fibres, and also on conversion of some of the energy into heat. The amount of original energy less the remaining unabsorbed energy compared to the original energy lead to the measurement referred to as the absorption coefficient (α). The sound absorption coefficient can be measured with the help of an impedance tube tester as per the ASTM standard E 1050. The impedance tube testing method is implemented by the generation of plane wave in a tube by a sound source and then the sound pressures are measured in a microphone position in proximity of the sample.

III. RESULTS AND DISCUSSION

3.1 Thermal conductivity

The composite samples are tested for thermal conductivity at 50^{o} C using guarded heat flow test method as per ASTM E1530 specifications. Unitherm Model 2022 was used to measure the thermal conductive property of the composite samples. The graph below represents the heat flow through the surface of the composite samples.

The heat transfer through sample is given by

$$\kappa = K\,(S1 * S2)A/_{D}$$

Where

K	thermal conductivity W/m.K
S_1	temperature of bottom slab ºC
S_2	temperature of Top slab ºC
A	Area of cross section of sample cm^2
D	thickness of sample cm

From Table 3, it is very clear that with increase in the fibre volume fraction in the composite, the thermal conductivity of the composite is reducing for both random as well as parallel orientation of the jute fibres in the composite. The thermal conductivity is least for composite with maximum of 25% fibre volume fraction as 1.22 W/m.K for random and 1.19 W/m.K for parallel orientated composites. The natural thermal insulation characteristic of the jute fibre is preventing the heat transfer. The introduction of the fibres in the composite also reduces the density of the composite. The R^2 values for both the composite samples suggest that there is a strong correlation between fibre volume fraction and thermal conductivity. From the ANOVA analysis, we find that there is no significant difference in thermal conductivity between the samples for fibre orientation. The equation $\boldsymbol{\kappa = -0.035x + 2.114}$ can be used to predict the thermal conductivity of the composite with desired fibre volume fraction in the composite.

Where, κ - Thermal Conductivity
x - Fibre Volume Fraction

Table 3: Thermal Conductivity of Composite Samples

Sample	Thermal Conductivity W/m.K	
	CTR	CTP
0	2.1	2.1
15	1.63	1.6
20	1.4	1.3
25	1.22	1.19

3.2 Heat Deflection Temperature

Table 4 reflects the heat deflection/distortion temperature of the composite samples. The result clearly shows that the heat deflection temperature of the composite sample is increasing with increasing fibre volume fraction. The composite sample with random fibre orientation and 25% fibre volume fraction exhibited the maximum deflection temperature of 146.8 ^{o}C which is almost 150% higher as compared to plain polyester resin sheet.

Table 4: Heat Deflection Temperature of Composite Samples

Sample	Heat Deflection Temperature °C	
	CTR	CTP
0	58	58
15	96.9	97.7
20	117.9	115.5
25	146.8	144.3

The improvement in the heat deflection temperature of the composite is due to reinforcement of the fibre in the resin and good interfacial bonding between fibres and resin. The distortion temperature is much more sensitive to the presence of reinforcement than the resin. The deflection temperature may increase even by many tens of degrees. If the change is identified as due to interaction between fibre and polymer molecules (particle-particle friction could also be a factor), then it would appear that there is a restriction in the mobility of the slowly moving segments of the polymer, possibly identifiable with an adsorbed layer on the fibre surface, while the rest of the polymer is unaffected. Thus, the glass transition is hardly changed, but the overall mobility is reduced so that the normal mechanical response to deformation as in the heat distortion test will be delayed, giving rise therefore, to an enhanced heat distortion temperature, or, alternatively, softening point. For a crystalline polymer, in which there is already some restriction of chain movement, the reinforcement produces further restrictions. The plausible cause for increase is the fact that incorporation of fibres result in restricted mobility, which increases with increase in fibre volume fraction. The $R^2 = 0.96$ values for both the composite samples suggest that there is strong correlation between fibre volume fraction and heat deflection temperature. From the ANOVA analysis, we find that there is a significant difference in heat deflection temperature between the samples for fibre treatment. The following equation can be used to predict the heat deflection temperature of the composite with desired fibre volume fraction in the composite.

$$\mathbf{Y = 3.07x + 54.45}$$

Where, Y - Heat Deflection Temperature
X - Fibre volume fraction

3.3 Thermograviemetric analysis

TGA curves for unsaturated polyester resin and jute fibre reinforced polyester composites for random and parallel orientation are given in Figure 3(a), 3(b) and 3(c) respectively. From the TGA curves, we can compare the thermal behaviour of UPR with jute reinforced polyester composites. There is an initial peak in the curve at approximately 100^{o}C indicating the removal of moisture from the samples whereas there is a steep drop in the UPR TGA curve around 50-60^{o}C signifying that there is very little moisture. The thermal decomposition in the curve initiates at around 350^{o}C and continues up to almost 400^{o}C for all samples. The loss of 77.39%, 50.38% and 48.35% for UPR, CR 25% and CP 25% was observed from the curve. The more important aspect of the TGA analysis is the weight loss during the decomposition of the composites; lower the weight loss better the thermal stability of the composite. Thus, the jute fibre polyester composite had higher thermal stability as compared to the UPR sheet. If serious degradation of natural fibre occurs at the melt processing temperature, the mechanical reinforcement effect of the fibre is decreased. Thus, TGA analysis was used to determine the high temperature degradation behaviour of the composites under air and nitrogen atmospheres.

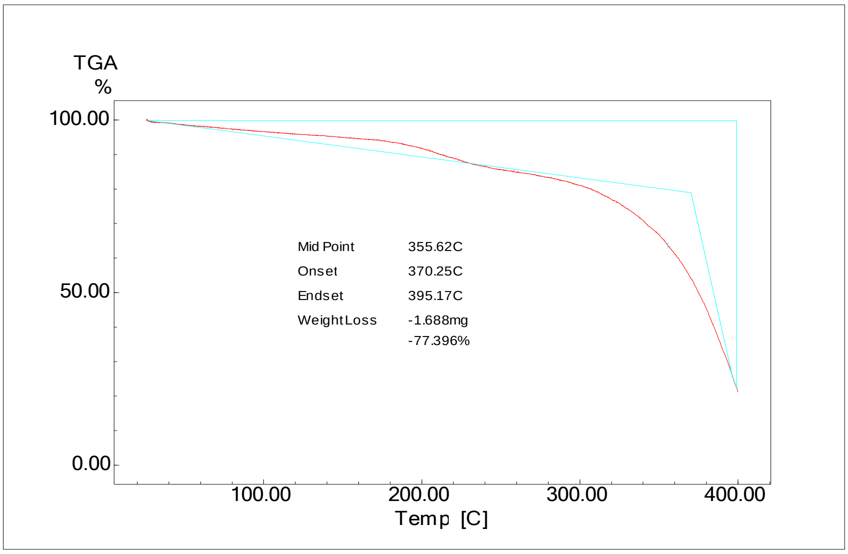

Figure 1(a): TGA Curve of UPR Sheet

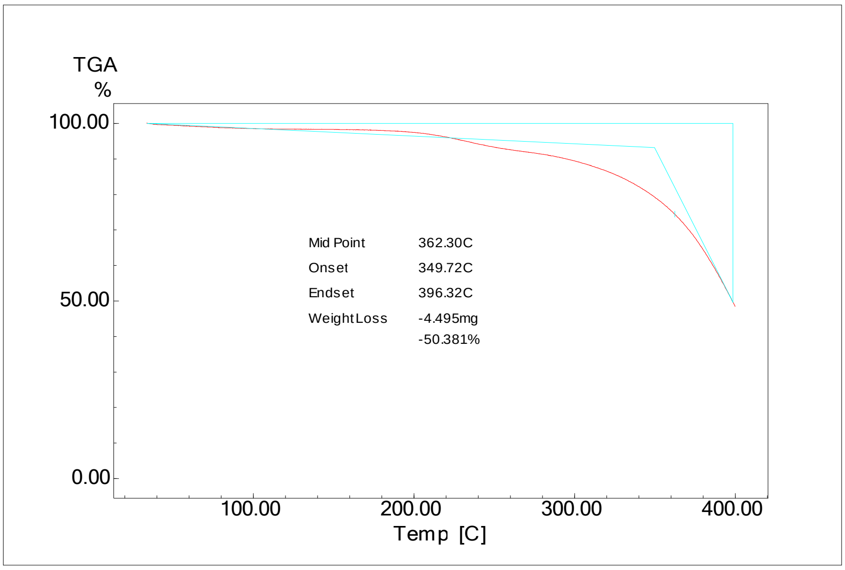

Figure 1(b): TGA Curve of composite CTP-25%

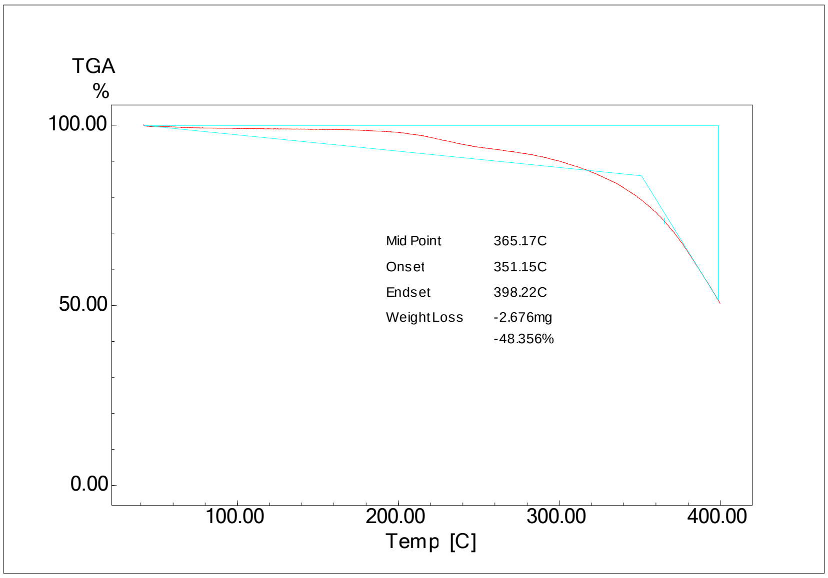

Figure 1(c): TGA Curve of composite CTR-25%

3.4 Sound Absorption Coefficient

Sound absorption is a very important property of a material which helps to control the noise level in specific conditions like in automotives, reduces echo effects in theatre and auditoriums.

Table 5: Sound Absorption coefficient of all samples

Freq. (Hz)	Sound Absorption Coefficient		
	UPR	CTR	CTP
250.00	0.036	0.063	0.058
500.00	0.038	0.069	0.064
1000.00	0.046	0.131	0.126
2000.00	0.082	0.143	0.138
2500.00	0.094	0.141	0.136
4000.00	0.135	0.316	0.311
5000.00	0.151	0.295	0.290
6300.00	0.163	0.457	0.452

In a certain range of thickness of materials, a larger density means a denser structure. The internal surface area is small; the friction and viscous resistance between the vibrating air particle and fibre increases the sound absorption coefficient. Hence, the sound absorption property of unsaturated polyester resin sheet having 0% fibre is poor due to its higher density. In addition, when the density of the sample is increased, the sound absorption coefficient decreases and acoustic energy is reflected at the surface rather than transmission. However, the flow resistivity had only a small effect on the peak location of the absorption coefficient. With reference to the scale, the sound absorption coefficient for jute fibre reinforced composite is moderate-to-average. Maybe with higher fibre volume fraction of the composite, the sound absorption coefficient might improve. There is very marginal difference in the composites with random and parallel orientation of jute fibre in the composite, but we found a very high significant difference between both composite and UPR sheet sound absorption coefficient. The approximate sound absorption coefficient for composites with desired fibre volume fraction can be predicted using the equation

$$\eta = 6E\text{-}05x + 0.052$$

Where, η - Sound Absorption Coefficient
X - Fibre Volume Fraction

The sound absorption coefficient of unsaturated polyester sheet is very poor as compared to jute reinforced composite. The sound absorption coefficient for jute reinforced composite is almost 3 times higher than UPR sheet.

IV. CONCLUSION

From the results and analysis of the investigation, the following conclusions are drawn:

- The thermal stability of the jute reinforced composites has improved as against plain UPR sheet, which can easily replace the pure polymer sheets for the application like refrigerator bodies.
- Thermal conductivity of the composite is reducing with increase in fibre volume fraction of the composite. We can use these composites for the dashboard and interior door panels, which will give good insulation and improve comfort in automobiles.
- The composites with improved heat deflection temperature can sustain higher working temperature without undergoing appreciable deformation and finds scope to be used in manufacturing of body for iron and ceiling/table fans.
- The reduction in weight loss of the composite due to incorporation of jute fibre compared to UPR sheet makes it suitable for industrial applications.
- Both random and parallel oriented jute fibre reinforced composite have given moderate-to-average sound absorption whereas UPR sheet has very poor sound absorption coefficient at the maximum frequency of 6.3 KHz. Hence, jute reinforced composite finds place to be used in looms, sheds, automobiles, cinema theatres and auditoriums.

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