CHAPTER 7

COMPARATIVE STUDY ON THREE DIFFERENT LIGNOCELLULOSIC FIBRE BASED BIOCOMPOSITES AND THEIR ACOUSTIC PROPERTIES

7.1 INTRODUCTION

In the present study, our attention has been given on physical and morphological structures of banana, coir and sisal fibres. Apart from this, the effects of physical and morphological structures on acoustic properties have been also presented. The regression model and ANOVA have been used for analysing the acoustic properties of the three different lignocellulosic fibre reinforced biocomposites.

7.2 JUSTIFICATION FOR THE SELECTED LIGNOCELLULOSIC FIBRES (Banana, Coir and Sisal)

Tests of the sound absorption behavior of natural fibres have shown that their cell-lumens allow them to embrace more diversified modes to attenuate sound wave energy. The banana fibres have flat and ribbon like multi-cellular structure. Coir is a hard and tough multi-cellular fibre with a central portion called “lacuna”. It is found (Yang & Li 2012) that a single sisal fibre is made up of a bundle of hollow sub fibres that have lumen within them with many connected air cavities, and those air cavities might be the major contributors of sound energy absorption. The cell wall of a sub-fibre is made up of millions of nanofibres (Bahrambeygi et al. 2013). In the presence of nanofibres, fine morphology involving more cells with smaller size can be
achieved. Due to the presence of this fine morphology, more paths for passing sound waves are created and also higher absorption of sound energy, because of higher friction between sound waves and internal cell walls (Xiaodong et al. 1965). On the other hand, the nano-sized fibres would also lead to the extra vibrations, which result in more dissipation of sound energy (Yang & Li 2012 & Bahrambeygi et al. 2013).

Recent reports (Lou and Chou 1992, Pilato and Michno 1994, TIFAC 2014, Gupta 1998, Faruk et al. 2010, Peters 1998, Agarwal an Broutman 1990, Pigott 1980, IPMA 2014, Bledzki & Gassan 1999, Joshi et al. 2004, Bruijn 2000, Leão 1998 & Xiaodong et al. 2014) indicate that plant-based natural fibres can very well be used as reinforcement in polymer composites, replacing to some extent, more expensive and non-renewable synthetic fibres such as glass, asbestos and glass wool. The properties of some of the natural fibres are compared in table 2.4 (Chapter-2). As in synthetic fibre composites, the mechanical properties of the final product depend on the individual properties of the matrix, fibre and the nature of the interface between them. Where the fibre is an agricultural one, it is possible to tailor the end properties of the composite by selection of fibres with a given chemical or morphological composition. Several studies of fibre composition and morphology have found that cellulose content and microfibril angle tend to control the mechanical properties of cellulosic fibres. Higher cellulose content and lower microfibril angle result in higher work of fracture in impact testing.

Sisal and banana fibres show better reinforcing efficiency than coir and the specific strength properties of the composites are comparable to those of glass fibre reinforced plastics (GRP) (TIFAC 2014). On the other hand, coir fibre, despite having low strength and modulus, improves the impact resistance due to its large strain energy absorption (TIFAC 2014). The experimental procedure for fibre selection has given in chapter-3.
7.3 PHYSICAL, MORPHOLOGICAL AND MECHANICAL PROPERTIES OF THREE DIFFERENT LIGNOCELLULOSIC FIBRES

Banana, coir and sisal, the major source of natural fibres, are grown in many parts of India. Some of them have aspect ratios (ratio of length to diameter) > 1000 and can be woven easily. Sisal and banana fibres are cellulose-rich (> 65%) and show tensile strength, modulus and failure strain comparable with the lignin-rich (> 40%) coir fibre is relatively weak and possess high failure strain (table 7.1). The banana fibres have a flat and ribbon like structure with individual fibre diameters in the range from 20-30 µm. The combination of cellulose and hemicelluloses are called hollow-cellulose and usually accounts for 60-70 percentage of the plant dry weight. When compared to other lignocellulosic plants, banana pseudo-stem has higher cellulose content probably due to the higher amount of fruit they support (Satyanarayana et al 1990 & Mukherjee and Satyanarayana 1984).

Table 7.1 Physical, morphological and mechanical properties of banana, coir and sisal fibres (Satyanarayana et al 1990 & Mukherjee and Satyanarayana 1984)

<table>
<thead>
<tr>
<th>Fibre type</th>
<th>Diameter (µm)</th>
<th>Density (kg/m³)</th>
<th>Cellulose (%)</th>
<th>Lignin (%)</th>
<th>Microfibrillar angle (degree)</th>
<th>Elastic modulus (GN/m²)</th>
<th>Tenacity (MN/m²)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana</td>
<td>20-30</td>
<td>1350</td>
<td>67</td>
<td>5</td>
<td>11-12</td>
<td>8-20</td>
<td>529-754</td>
<td>1-3.5</td>
</tr>
<tr>
<td>Coir</td>
<td>10-50</td>
<td>1460</td>
<td>43</td>
<td>45</td>
<td>30-45</td>
<td>4-6</td>
<td>131-175</td>
<td>15-40</td>
</tr>
<tr>
<td>Sisal</td>
<td>8-50</td>
<td>1450</td>
<td>65</td>
<td>12</td>
<td>10-22</td>
<td>9-16</td>
<td>568-640</td>
<td>3-7</td>
</tr>
</tbody>
</table>

Coir is a hard and tough multicellular fibre with individual fibre diameter in the range from 10-50 µm and contains highest lignin content
among the selected fibres (TIFAC 2014). Moreover, it can be realized that natural fibre possesses a multi-scale structure, as shown in Figure 2.4. In the previous studies (Sun et al. 1993, Koizumi et al. 2002 & Lee and Joo 2003) on the various parameters that influence the sound absorption properties of fibrous material, fibre size was shown to be an important parameter that changes the sound absorption significantly. This behavior can be attributed to the fact of the changes of two basic material properties; tortuosity and flow resistivity with the change of fibre size as addressed from the previous works (Sun et al. 1993 & Lee & Joo 2003). In general, flow resistivity of porous material is inversely proportional to the fibre diameter for a given porosity (Ingard 1994), whereas tortuosity of the porous material is an indicator of how much tortuous the transmission path of sound wave within the absorbent (Cox et al. 2009). These results indicate that fibre size plays an important role for sound absorption behavior of banana and coir fibre based materials.

7.4 EFFECT OF PHYSICAL AND MORPHOLOGICAL STRUCTURES ON ACOUSTIC PROPERTIES OF THE MATERIALS

Figure 7.1 (a), (b) and (c) represents the cross-sections of single banana, coir and sisal fibre (which can be a typical representative of the cross-sections of natural fibres). It is found out that a single natural fibre is made up of a bundle of hollow sub fibres that have lumen inside. It is confirmed that the natural fibres are porous and contain many connected open air cavities and those air cavities might be the major contributors of sound energy absorbed. It also observed that there are many micro pores and continuous bubbles in the porous structure of natural fibres. When the sound wave is incident to the surface of the porous fibre structure, the air motion and compression in micro pores caused by sound wave vibration might cause the friction with the micro pore wall and so that the air that is close to the micro pore wall cannot move
easily. Because of the viscous and friction forces, considerable parts of the sound energy are absorbed (Chen et al. 2010). The sound energy absorbed is also due to the heat loss caused by heat exchange between the micro pore wall and the air in the micro pores. The cell wall of a fibre is made up of millions of nano-fibrils. The nano-sized fibrils would also lead to the extra vibration, which caused more sound energy absorption (Li et al. 2010). From figure 7.1 (d), the random distributions of natural fibres in the recycled paper pulp matrix biocomposites can allow most of the sound waves to hit the micro pores of the fibre bundle and support the sound absorption effect. These special structures and the fibre spreading are the main reason for the sound absorption in natural fibre based biocomposites (Chen et al. 2010). The voids between the fibres and matrix would also facilitate sound absorption (Reddy & Yang 2011).

Figure 7.1 SEM (200 µm) photomicrographs of (a) Banana fibre; (b) Coir fibre; (c) Sisal fibre showing their cross-sectional features and (d) Recycled paper pulp/sisal fibre biocomposite
7.4.1 Effect of banana, coir and sisal fibre physical and morphological structures on NRC

In this section, effect of banana, coir and sisal fibre physical and morphological structure (Table 7.1) on sound absorption is discussed and the results are shown in Table 7.2. The results based on the average of 15 samples in each case, indicate that coir fibre reinforced biocomposite shows slightly higher NRC (0.47) compared to banana fibre reinforced biocomposites as shown in table 7.2. The above statement agrees with previous research that stated that sound absorption of porous material is directly proportional to the fibre diameter for a given porosity (Koizumi et al 2002 & Lee and Joo 2003). The coir fibre reinforced biocomposites have slightly higher NRC due to their highest fibre diameter range (10-50 µm) and multi-cellular structures among the selected fibres. Banana fibres have flat and ribbon like multi-cellular structure and has slightly lower NRC (0.46) because of its lower range of diameters (20-30 µm). Hence coir fibre reinforced biocomposites may be more efficient as a raw material for sound absorption materials.

Sisal fibre reinforced biocomposites have the highest NRC (0.50) among these three different fibre reinforced biocomposites due to their fine hollow morphological structure and also diameter range (8-50 µm), causing them to absorbed more sound energy than banana and coir fibre based biocomposites. In the presence of hollow structure, fine morphology and size involving more cells with smaller size can be achieved. Due to the presence of this fine morphology, more paths for passing sound waves are created leading to higher absorption of sound energy, because of higher friction between sound waves and internal cell walls (Xiaodong et al. 1965).
<table>
<thead>
<tr>
<th>Sample code</th>
<th>Average cut length, cm ($X_1$)</th>
<th>Composite Thickness, cm ($X_2$)</th>
<th>Fibre volume fraction, $V_f$ ($X_3$)</th>
<th>Made of banana fibres</th>
<th>Made of coir fibres</th>
<th>Made of sisal fibres</th>
<th>Made of banana fibres</th>
<th>Made of coir fibres</th>
<th>Made of sisal fibres</th>
<th>Made of banana fibres</th>
<th>Made of coir fibres</th>
<th>Made of sisal fibres</th>
<th>Density</th>
</tr>
</thead>
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<tr>
<td>S1</td>
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<td>2</td>
<td>0.20</td>
<td>0.38</td>
<td>0.40</td>
<td>0.42</td>
<td>0.82</td>
<td>0.81</td>
<td>0.80</td>
<td>150</td>
<td>150</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>1.5</td>
<td>6</td>
<td>0.20</td>
<td>0.46</td>
<td>0.47</td>
<td>0.52</td>
<td>0.79</td>
<td>0.80</td>
<td>0.76</td>
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<td>161</td>
<td>190</td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>3.5</td>
<td>2</td>
<td>0.20</td>
<td>0.46</td>
<td>0.46</td>
<td>0.49</td>
<td>0.80</td>
<td>0.81</td>
<td>0.78</td>
<td>153</td>
<td>151</td>
<td>176</td>
<td></td>
</tr>
<tr>
<td>S4</td>
<td>3.5</td>
<td>6</td>
<td>0.20</td>
<td>0.55</td>
<td>0.56</td>
<td>0.58</td>
<td>0.80</td>
<td>0.80</td>
<td>0.79</td>
<td>154</td>
<td>160</td>
<td>171</td>
<td></td>
</tr>
<tr>
<td>S5</td>
<td>1.5</td>
<td>4</td>
<td>0.15</td>
<td>0.43</td>
<td>0.45</td>
<td>0.47</td>
<td>0.79</td>
<td>0.80</td>
<td>0.78</td>
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<td>156</td>
<td>197</td>
<td></td>
</tr>
<tr>
<td>S6</td>
<td>1.5</td>
<td>4</td>
<td>0.25</td>
<td>0.45</td>
<td>0.46</td>
<td>0.48</td>
<td>0.83</td>
<td>0.81</td>
<td>0.78</td>
<td>140</td>
<td>162</td>
<td>184</td>
<td></td>
</tr>
<tr>
<td>S7</td>
<td>3.5</td>
<td>4</td>
<td>0.15</td>
<td>0.51</td>
<td>0.50</td>
<td>0.54</td>
<td>0.76</td>
<td>0.79</td>
<td>0.80</td>
<td>180</td>
<td>157</td>
<td>164</td>
<td></td>
</tr>
<tr>
<td>S8</td>
<td>3.5</td>
<td>4</td>
<td>0.25</td>
<td>0.50</td>
<td>0.49</td>
<td>0.56</td>
<td>0.75</td>
<td>0.80</td>
<td>0.78</td>
<td>200</td>
<td>164</td>
<td>189</td>
<td></td>
</tr>
<tr>
<td>S9</td>
<td>2.5</td>
<td>2</td>
<td>0.15</td>
<td>0.44</td>
<td>0.43</td>
<td>0.45</td>
<td>0.81</td>
<td>0.81</td>
<td>0.78</td>
<td>140</td>
<td>145</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>S10</td>
<td>2.5</td>
<td>2</td>
<td>0.25</td>
<td>0.42</td>
<td>0.44</td>
<td>0.46</td>
<td>0.82</td>
<td>0.82</td>
<td>0.85</td>
<td>150</td>
<td>152</td>
<td>122</td>
<td></td>
</tr>
<tr>
<td>S11</td>
<td>2.5</td>
<td>6</td>
<td>0.15</td>
<td>0.52</td>
<td>0.51</td>
<td>0.54</td>
<td>0.81</td>
<td>0.79</td>
<td>0.74</td>
<td>140</td>
<td>158</td>
<td>210</td>
<td></td>
</tr>
<tr>
<td>S12</td>
<td>2.5</td>
<td>6</td>
<td>0.25</td>
<td>0.51</td>
<td>0.53</td>
<td>0.56</td>
<td>0.83</td>
<td>0.80</td>
<td>0.75</td>
<td>140</td>
<td>164</td>
<td>210</td>
<td></td>
</tr>
<tr>
<td>S13</td>
<td>2.5</td>
<td>4</td>
<td>0.20</td>
<td>0.46</td>
<td>0.48</td>
<td>0.50</td>
<td>0.81</td>
<td>0.81</td>
<td>0.86</td>
<td>153</td>
<td>156</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>S14</td>
<td>2.5</td>
<td>4</td>
<td>0.20</td>
<td>0.48</td>
<td>0.47</td>
<td>0.51</td>
<td>0.84</td>
<td>0.81</td>
<td>0.81</td>
<td>130</td>
<td>154</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>S15</td>
<td>2.5</td>
<td>4</td>
<td>0.20</td>
<td>0.46</td>
<td>0.49</td>
<td>0.49</td>
<td>0.81</td>
<td>0.81</td>
<td>0.78</td>
<td>150</td>
<td>156</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.46</strong></td>
<td><strong>0.47</strong></td>
<td><strong>0.50</strong></td>
<td><strong>0.80</strong></td>
<td><strong>0.80</strong></td>
<td><strong>0.78</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
7.5 COMPARISON OF NRC FOR THREE DIFFERENT LIGNOCELLULOSIC FIBRE REINFORCED BIOCOMPOSITES

Figure 7.2 shows Noise Reduction Coefficient (NRC) against frequency for fifteen different combinations with three different fibre reinforced composites (totally 45 samples). It is evident that type of fibre influences the sound absorption coefficients. All the samples exhibited similar pattern of sound absorption at all frequencies. For all the samples, when the frequency increased, sound absorption coefficient also increased. Tested value shows not much significant differences between fibre (banana, coir and sisal) reinforced composites on sound absorption coefficient, while there is significant difference between selected parameters as shown in table 7.2. The specimens made of sisal fibre reinforced biocomposite show higher NRC (Average: 0.50) in average of 15 different combinations compared to the specimens made of banana (Average: 0.468) and coir (Average: 0.476) as shown in Table 7.2. These biocomposites show the same reaction against sound waves over a wide frequency ranges (125-4000 Hz).

The NRC of sisal fibre reinforced biocomposites is in the range of 0.42–0.58. All the sisal fibre reinforced biocomposites showed a higher NRC than specimens made of banana and coir are 0.38-0.55 and 0.40-0.56 respectively. NRC values, 0.38–0.58, of these fibre reinforced composites were higher than conventional and micro-fibre fabrics, which give the NRC values 0.15-0.25 and 0.20-0.25, respectively (Young et al 2007).

However, the average NRC of the three different fibres reinforced biocomposites show only a slight difference as the fibres physical and morphological structures are close to each other. The above statement is evidenced in previous studies (Xiaodong et al 1965, Koizumi et al 2002, Lee and Joo 2003 and Bahrambeygi et al. 2013). However within and between
selected parameter combinations of these fibres showed significant difference in NRC, thus validating the premise that the selected parameter have a significant effect on the sound absorption coefficient and NRC. According to this study, as the fibre cut length, fibre volume and biocomposite thickness increases, NRC increased linearly up to 3.5 cm, 0.20 and 6 cm respectively for all the fibres chosen.

Figure 7.2 Comparison of experimental results of different fibre reinforced biocomposites for NRC

7.6 REGRESSION ANALYSIS FOR THREE DIFFERENT FIBRE BASED BIOCOMPOSITE

To establish the relationships between the independent and dependent variables, regression analysis is done. The regression coefficients ($\beta_0$, $\beta_1$, $\beta_2$ and $\beta_3$) are used in the equation (3.7) for the determination of predicted response values. The correlation coefficients between the observed values and predicted values by proposed model show a very good correlation. The correlation coefficient values are 0.95, 0.93 and 0.97 for banana, coir
and sisal fibre reinforced biocomposites respectively. It indicates that observed values of fibre reinforced paper pulp biocomposite has a real degree of association with the predicted values of the three different fibre reinforced biocomposite blocks.

If the regression equations of 4.1, 5.1 and 6.1 for the three fibre reinforced biocomposites are considered, one would find that the values of correlation coefficients are similar for the three different fibre based biocomposites. The physical and morphological properties of banana, coir and sisal fibres again are similar, except lignin content in the case of coir. Among the various properties, fibre diameter and density are the most dominant properties for sound absorption of the materials. However, the values show a negative correlation between fibre volume fraction and NRC for banana fibre based composites.

\[
\text{NRC (y)} = 0.300 + (0.0375 \times X_1) + (0.0213 \times X_2) - (0.0500 \times X_3) \quad (4.1)
\]

\[
\text{NRC (y)} = 0.304 + (0.0288 \times X_1) + (0.0212 \times X_2) + (0.0750 \times X_3) \quad (5.1)
\]

\[
\text{NRC (y)} = 0.292 + (0.0350 \times X_1) + (0.0238 \times X_2) + (0.150 \times X_3) \quad (6.1)
\]

According to table 7.2, the samples of S6, S10 and S12 show lower NRC for banana fibre based biocomposites at 0.25 fibre volume fractions, whereas it is higher for coir and sisal fibre based biocomposites at same fibre volume fraction. It is indicative that when the value of fibre volume fraction increases, the value of the response variable (NRC) decreases even at the highest thickness (6 cm) of the biocomposites. The highest fibre volume fraction of 0.25 provides lower NRC for banana fibre based biocomposites because of lower fibre diameter range (20-30 µm) and density (1350 kg/m³) of banana fibre than coir and sisal fibres as shown in table 7.1. Besides,
positive correlation for coir and sisal fibre based biocomposites due to their fibre diameter and density (table 7.1), are relatively same.

The dependent variable of NRC can be predicted from a linear combination of the independent variables (fibre cut length, composite thickness and fibre volume fraction). However, not all of the independent variables appear necessary (or the multiple linear models may be underspecified). The following appear to account for the ability to predict, NRC (p < 0.05): fibre cut length and composite thickness except fibre volume fraction for banana fibre based biocomposites. The volume fractions of the fibres are more dependent on diameter and density of the fibres and materials. The banana fibre diameter range (20–30 µm) and density (1350 kg/m$^3$) are low compared to coir and sisal fibres (table 7.1). Due to the presence of this lower fibre diameter, lower paths for passing sound waves are created and also lower absorption of sound energy, because of lower friction between sound waves and internal cell walls (Xiaodong et al. 1965).

The volume fraction, cut length and composite thickness increased (0.25, 3.5cm and 6cm respectively) in the biocomposites, porosity and density also increased linearly. According to table 7.2 the NRC decreased below and above the porosity of 0.80 and density of 154 kg/m$^3$ due to higher sound flow resistivity with lower sound absorption coefficient. This means, there are not enough pores on the surface of the material for sound to pass through and get damped. The above reason may explain the negative correlation between NRC and fibre volume fraction for banana fibre based biocomposites. The regression coefficients have a value either positive or negative and accordingly have an effect on the experimental results. For a variable to have a significant effect, its coefficient must be greater than twice the standard error (Standard Error of Estimate of 0.011, 0.011 and 0.008 for banana, coir and sisal fibre based biocomposites respectively). However, the non-
significant coefficients should not be eliminated altogether (Surajit Sengupta 2010).

According to table 7.2 the NRC is slightly higher for coir and sisal fibre compared to banana fibre based biocomposites at 0.25 fibre volume fraction. However, the coir and sisal fibre are relatively same diameter and density as well as higher than that of banana fibres. Because of the presence of this higher fibre diameter, higher paths for passing sound waves are created and also slightly high absorption of sound energy, due to high friction between sound waves and internal cell walls (Xiaodong et al. 1965). The above said reason might explain the positive correlation seen between NRC and all the selected variables for coir and sisal fibre based biocomposites.

7.7 ANALYSIS OF VARIANCE (ANOVA) ON THREE DIFFERENT FIBRE BASED BIOCOMPOSITES

F Test: The critical value is the number that the test statistic must exceed to reject the test. In this $F_{\text{crit}}(14, 2) = 3.74$ at $\alpha = 0.05$. Since $F = 44.890 > 3.74$, the results are significant at the 5% significance level. One would reject the null hypothesis, concluding that there is strong evidence that the expected values in the three groups differ. The p-value for this test is $p < 0.001$.

From the table 7.3, p-value of the test is less than 0.05. Therefore, at 5% level of significance, we reject the null hypothesis and conclude that the explanatory variables have significant linear relationship with response and the fitted linear model is valid. According to ‘p’ value (table 7.4), the following independent variables are appearing to account for the ability to predict NRC ($p < 0.05$): fibre cut length and composite thickness, except fibre volume fraction for banana and coir fibre based biocomposites. According to table 7.2, the sample of S6, S8, S10 & S12 show lower NRC for banana and
coir fibre based biocomposites at 0.25 fibre volume fractions, whereas it is higher for sisal fibre based biocomposites. The NRC increases linearly up to 0.20 fibre volume fractions for banana and coir fibre based biocomposites, then decreases at 0.25 fibre volume fractions (sample S6, S8, S10 & S12).

Table 7.3  Analysis of Variance on Ranks for NRC of three different fibre reinforced biocomposites

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF*</th>
<th>SS*</th>
<th>MS*</th>
<th>F*</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>14</td>
<td>0.0759</td>
<td>0.00542</td>
<td>44.890</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Between Treatments</td>
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<td>0.0101</td>
<td>0.00507</td>
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<tr>
<td>Residual</td>
<td>28</td>
<td>0.00316</td>
<td>0.000113</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>0.0892</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DF* - Degrees of Freedom; SS*- Sum of Square; MS* - Mean sum of Square; F* – Variance Ratio

The above stated reasons are not applicable to fibre volume fraction which is one of the independent variables not appearing to contribute for predicting NRC (p<0.05) for banana and coir fibre reinforced biocomposites. However, the overall correlation is approximately same for all the fibre reinforced biocomposites. Besides, the non-significant coefficients should not be eliminated altogether as the coefficients are greater than twice the standard error for three different fibre based biocomposites (Surajit Sengupta 2010). However, in the sisal fibre based biocomposites, all the independent variables appear to contribute for predicting NRC (p<0.05): Fibre cut length, composite thickness and fibre volume fraction. According to sample S6, S8, S10 & S12 at 0.25 fibre volume fractions provide higher NRC for sisal fibre based biocomposites whereas lower for banana and coir based biocomposites. The above stated reasons applicable to all the independent variables appear to contribute for predicting NRC (p<0.05) for sisal fibre reinforced biocomposites.
The results of analysis of variance (ANOVA) for various combinations of the biocomposites are listed in Table 7.4. It shows that the effects of selected fibres, fibre length, fibre volume fraction and composite thickness have significant effects on NRC in terms of bulk density and porosity.

Table 7.4 p-value for three different fibre and variable based biocomposites

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Selected independent Variables</th>
<th>P &lt; 0.05</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Banana fibre based biocomposites</td>
<td>Coir fibre based biocomposites</td>
</tr>
<tr>
<td>1</td>
<td>Fibre cut length, (X1)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2</td>
<td>Composite thickness, (X2)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>3</td>
<td>Fibre volume fraction, (X3)</td>
<td>0.516</td>
<td>0.365</td>
</tr>
</tbody>
</table>

The mean values according to Least Significant Difference (LSD) with pair wise comparisons of the biocomposites are given in Table 7.5. From the table 7.5, p-value of the test is less than 0.05 for all the fibre combination based biocomposites. Therefore, at 5% level of significance, we reject the null hypothesis and conclude that the selected three different fibres, variables and their combinations have significant linear relationship with response and the fitted linear model is valid.
Table 7.5  The mean value of NRC of various biocomposites: Pair wise comparisons on NRC for different fibre reinforced biocomposites (Fisher Least Significant Difference Method-LSD)

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Difference of Means</th>
<th>LSD(α=0.050)</th>
<th>P</th>
<th>Diff. &gt; = LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sisal based biocomposites Vs. Banana based biocomposites</td>
<td>0.0351</td>
<td>0.00795</td>
<td>&lt;0.001</td>
<td>Yes</td>
</tr>
<tr>
<td>Sisal based biocomposites Vs. Coir based biocomposites</td>
<td>0.0270</td>
<td>0.00795</td>
<td>&lt;0.001</td>
<td>Yes</td>
</tr>
<tr>
<td>Coir based biocomposites Vs. banana based biocomposites</td>
<td>0.00806</td>
<td>0.00795</td>
<td>0.047</td>
<td>Yes</td>
</tr>
</tbody>
</table>

7.8 CONCLUSION

The outcomes indicate that biocomposites with banana, coir and sisal fibres reinforcement provide better NRC throughout the range of frequencies 125-4000 Hz compared to conventional fibre based materials. It is concluded that, biocomposite blocks with optimum fibre length of 3.5 cm, 0.20 fibre volume fraction at 6 cm thickness has given highest NRC throughout, when considering the three different fibre reinforced biocomposites. In addition, the multiple linear regression models and ANOVA can be used successfully for predicting and analyzing the acoustic properties of three different biocomposite blocks respectively. The
regression model indicates that, the NRC of coir and sisal fibre based biocomposites give positive correlation for all the selected variables. However the NRC of banana fibre based biocomposites give positive correlation for fibre cut length and composite thickness while negative correlation for fibre volume fraction.