JEAS

JOURNAL OF ENGINEERING AND APPLIED SCIENCES

Journal of Engineering and Applied Sciences, Volume 17, Number 1, June 2020, 137-151

# Comparative Analysis on Thermal Strength of Coir/Empty Plantain Fruit Bunch and Coir/Pseudo Stem Plantain Hybrid Fibers Reinforced Polyester Matrix Composites

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**Abstract**
This study used volume fraction of the hybrid fiber, coupling agent and coir/plantain fiber ratio as the control factors for determining the optimum thermal properties of coir/plantain hybrid fiber reinforced polyester composites. Taguchi design technique was adopted in preparing the samples, investigating the signal-to-noise ratio (S/N ratio) for the quality characteristic of the control factor levels required to optimize each thermal property of the samples using Minitab 17. Thermal tests were carried out on the samples of coir/plantain empty fruit bunch (CEFB) hybrid and coir/plantain pseudo stem (CPS) hybrid fiber reinforced polyester composite respectively, after determining the volume fraction of the treated hybrid fiber. The thermal optimum values of the control factors were established for CEFB hybrid fiber reinforced polyester composite and CPS hybrid fiber reinforced polyester composite. CEFB hybrid fiber reinforced polyester composite has the optimum thermal conductivity of $0.3016 W/m-K$, optimum linear thermal expansion of $10.6070\, x\, 10^{-5}$ /℃ and optimum specific heat of $2641.51\, J/kg-K$; while CPS hybrid fiber reinforced polyester composite has the optimum thermal conductivity of $0.2791 W/m-K$, linear thermal expansion of $10.395\, x\, 10^{-5}$ /℃, and optimum specific heat of $2633.10\, J/kg-K$. The considered control factors add value to the thermal properties of coir/plantain hybrid fibers reinforced polyester composite. The CEFB hybrid fiber reinforced polyester composite offers better thermal properties than that of CPS hybrid fiber.

**Keywords:** composite, control factor, coir/plantain hybrid fiber, Taguchi, thermal strength.

## 1. Introduction

Fibers of native species are being used in producing clothes, craft parts, buildings and cordage in different climatic zone. The advantages of using natural fibers, compared with synthetic fibers, in composites are their unlimited availability, biodegradability, low cost, low density, recyclability and renewability (Espert et al., 2002; Gassan and Bedzki, 1999; Joseph et al., 2002; Li et al., 2000). The pre-treated process of fiber and the manufacturing process of the composites generally govern the properties of natural fiber reinforced polymer composites. The hybrid fiber reinforced composites can withstand higher load than the single-fiber reinforced composites. The hybrid fiber reinforced composite enhances the damping, mechanical, thermal properties when compared to single-fiber reinforced composite; and the hybrid composites are used for many application and replacing single-fiber reinforced composite material (Sathishkumar et al., 2014).

Thermal strength of coir/plantain hybrid fibers reinforced polyester composites is the maximum stress the materials can withstand when they are subjected to heat. Composites are generally known to be specifically patterned to fit into different specifications that have desirable properties for particular purpose. Composites provide higher strength at a lower weight and have lower life-cycle costs that help in their evolution (Okonkwo et al., 2015; Abdalla et al., 2008). A good combination of different natural fibers as hybrid fibers in any natural hybrid fiber reinforced composites gives rise to better thermal property, and thermal and insulating protection. Many research have been carried out on coir and plantain fibers (Chukwunyelu et al., 2016; Okonkwo et al., 2015; Chukwunyelu et al., 2015; Ihueze et al., 2012; Okafor et al., 2013) as reinforcements for polymeric materials in the manufacturing of cheap, renewable and environmentally friendly composites. Acceptable specific strength, biodegradability, enhanced energy recovery, high toughness, low cost, low density, low weight, and recyclability are the advantages of coir and plantain fiber as well as other natural fibers (Lee et al., 2005; Sastra et al., 2005; Myrtha et al., 2008).

According to the transverse and in-plane thermal conductivities for randomly oriented composites for several volume fractions of fibers in hemp fiber reinforced composites studied by Behzad and Sain (2007), the orientation of fibers was found to have a noteworthy influence on thermal conductivity of composites. Thermal conductivity and thermal diffusivity of oil-palm-fiber-reinforced composites with and without alkali treatment at room temperature were studied by Agrawal et al., (2000) using transient plane source technique. It was discovered that the chemical treatments, saline alkali and acetylation of fibers increased the proposed thermal properties of oil-palm-fiber-reinforced composites. The alkali treatment eliminates impurities and improves the fiber surface adhesion characteristic with the resin, and thereby gives to a superior thermal conductivity. Li et al. (2008) determined the thermal conductivity, thermal diffusivity and specific heat of flax fiber–HDPE biocomposites around 170–200℃ temperature range. The thermal conductivity, thermal diffusivity and specific heat were found to decrease with increased fiber content. However, there is no appreciable change in thermal conductivity as well as thermal diffusivity in the specified temperate range. Conversely, the specific heat of flax fiber–HDPE composites steadily increased with temperature.

Alsina et al. (2005) studied to determine the thermal properties of jute-cotton, sisal-cotton and ramie-cotton hybrid fabric reinforced unsaturated polyester composites. The volume fractions of jute, ramie, and sisal fibers in the fabrics were found to be 0.77, 0.69, and 0.64 respectively. The results showed that the thermal conductivity of sisal-cotton hybrid polyester composites was 0.213-0.25 $W/m-k$ and its specific heat was 1.065-1.236 $J/cm^3$℃; Jute-cotton hybrid polyester composites have thermal conductivity of 0.10-0.237 W/m-k and specific heat of 0.869-1.017 $J/cm^3$℃; Ramie-cotton hybrid polyester composites have thermal conductivity of 0.19-0.22 $W/m-k$ and specific heat of 0.839-0.894 $J/cm^3$℃.

Though the natural hybrid fiber reinforced composites have poor compatibility between hydrophilic natural fiber and hydrophobic polymeric matrix, numerous applications natural fiber reinforced polymer composites are being exploited in automotive sector, building and construction. Going by afore authors' works, there is no comparative analysis on thermal strength responses of coir-plantain fiber hybrid reinforced polyester matrix composites materials. Hence, an attempt was made in this paper to evaluate and optimize the thermal properties of coir-plantain fibers hybrid reinforced polyester matrix (CPFRP) using Taguchi technique. The optimal level of each parameter was identified by employing analysis of means (ANOM), and the relative importance among the parameters was found by using the analysis of variance (ANOVA).

## 2.0 Materials and methods

In this study, coir/plantain hybrid fibers of different ratios were the reinforcement; aqueous sodium hydroxide (NaOH) and Maleic Anhydride (MAH) were for fiber chemical treatment; and polyester resin served as the matrix. Experimental design of Taguchi methods were used for evaluation and optimization of the thermal properties of coir/plantain hybrid fiber reinforced polyester matrix composite (CPFRP).

### 2.1 Fiber extraction and Chemical treatment

Retting was a process employed to extract fiber. Cellular tissues, gummy substances, cellular tissues and pectin surrounding the fiber bundles in the plant will always give way due to the action of bacteria and moisture on the plants. Consequently, the fiber can then be easily separated. For coir fiber, this action partially decomposes the husk's pulp allowing it to be separated into coir fibers and a residue called coir pith. The plantain fibers were removed from the pseudo stem (PS) and empty fruit bunch (EFB) by hand; the stems and fruit bunch were then stripped one by one. The loosed fibers were then separated and washed. The clean fibers were spread loosely on the ground to naturally dry at room temperature.

**Figure 1: Coir Fiber**

**Figure 2: EFB Plantain Fibers**

**Figure 3: PS Plantain Fibers**

Alkaline treatment was conducted on coir and plantain fibers by immersing them in 5% aqueous NaOH solution for 72 hours at room temperature for proper depolymerisation of cellulose, removal of lignin and better strength of coir and plantain fibers. Thereafter, the treated fibers were carefully spread on mat and then finally air dried. Afterwards, the alkaline treated coir and plantain fibers were esterified with maleic anhydride (MAH) solution of different percentages (conc. 0.1%, 0.25% and 0.5%) and left for 45 minutes under agitation for condensation and chemical bonding of maleic anhydride and cellulose fibers. Treated fibers were then washed to remove excess coupling agents.

**Figure 4: Treated Coir Fiber**

**Figure 5: Treated EFB fibers**

**Figure 6: Treated PS fibers**

**2.2 Taguchi Technique**

The Taguchi method involves stepping down the variation in a process through robust design of experiments. The main objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method checks how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning (Design of Experiments, 2005).The experimental design proposed by Taguchi involves using orthogonal arrays to arrange the parameters affecting the process and the levels at which they should be varied. It is done for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources (JMP, 2005). The most important stage in the design of experiment is in the selection of the control factors.

**Table 1: Process parameters and levels for the preparation of specimens**

| Code | Parameters | Levels | | | Units |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | |
| A | **Volume Fraction** | 10 | 30 | 50 | % |
| B | **Coupling Agent** | 0.1 | 0.25 | 0.5 | $\%w/v$ |
| C | **Fiber Ratio (coir/plantain)** | 30/70 | 50/50 | 70/30 | |

Fiber volume fractions are the fiber concentrations in different specimens. It helps in determining the properties of short-fiber composites. At low fiber volume fraction, a drastic decrease in strength is usually observed. As the volume fraction of fibers is increased to a higher level, the properties gradually improve to give strength higher than that of the matrix.

Coupling agents are usually employed in order to increase compatibility between fiber and matrix and to decrease hydrophilic nature of fibers (Li, 2007). Coupling agent will act as an interface between organic substrate (hybrid of coir and plantain fibers) and inorganic material (polyester resin) to couple the two dissimilar materials. Li (2007) reported that this is an esterification method which should stabilize the cell walls, especially in terms of humidity absorption and consequent dimensional variation.

Fiber ratio of coir and plantain fibers in the volume fraction of hybrid fiber reinforced polyester composites helps to differentiate the level of contribution of each fiber to each specimen. Different properties associated with coir fiber and the two classes of plantain fibers (Okonkwo et al., 2015; Ihueze et la., 2012) necessitated the three categories of coir/plantain fiber ratio in this work.

The results, from the experiments as per orthogonal array (OA), are converted into signal to noise (S/N) ratio data. In Taguchi technique, the term “signal’’ represents desirable value (mean) and “noise’’ represents undesirable value (standard deviation) for the response. Therefore, S/N ratio is the mean to standard deviation, which specifies the degree of predictable performance of a product or process in the existence of noise factors (Phadke, 1989; Ross, 1996). The S/N ratio measures the performance characteristics and identifies the important parameters through analysis of variance (ANOVA). Taguchi classifies objective functions into three categories: smaller the better type, larger the better type and nominal the best type (Phadke, 1989; Ross, 1996). The optimum level for a factor results in highest S/N ratio value in the experimental space.

**Table 2: Taguchi Standard Orthogonal array L9 ($3^3$)**

| Experiment Number | Parameter A | Parameter B | Parameter C |
|---|---|---|---|
| **1** | 1 | 1 | 1 |
| **2** | 1 | 2 | 2 |
| **3** | 1 | 3 | 3 |
| **4** | 2 | 1 | 2 |
| **5** | 2 | 2 | 3 |
| **6** | 2 | 3 | 1 |
| **7** | 3 | 1 | 3 |
| **8** | 3 | 2 | 1 |
| **9** | 3 | 3 | 2 |

**3.0 Preparation of Composites and Tests**

The method adopted for composite production in this study, based on open molding, is the Hand Lay-up process. The reinforcement is placed manually in this process. This process is labor intensive and less expensive. The mold is first polished; then followed by applying a mold-releasing agent (Polyvinyl alcohol) on the surface to facilitate easy removal of the composite from the mold after curing. The mixture of resin and hardener was applied on the already arranged chopped fiber reinforcement, as recommended by Ashby et al. (2007). The hybrid fiber is placed in discontinuous and randomly oriented manner on the top of the mold. A roller is used to impregnate the fiber with the resin. More resin may be applied until a suitable thickness builds up.

**3.1 Thermal Conductivity Test**

The test samples were prepared in accordance with ASTME1530 (ASTM, 1999).

**Figure 7: Thermal Conductivity Test specimen**

Thermal conductivity of a composite depends upon the thermal conductive nature of the fiber and matrix. As the thermal conductivity of a polymer composite is based upon the conductivity of fiber and resin, resins are usually insulating and the conductivity is dominated by fiber material (Grady, 2011). The compactness of fibers per unit area influences the conductivity of the composite. The equation (1) calculates the thermal conductivity of each specimen (ANTER co; NecatiOzisik, 1985):

The Heat flux, $q$ , is given by

$$q = \frac{\lambda(T_1 - T_2)}{L} (Wm^{-2}) \tag{1}$$

The Thermal resistance of specimen, $R$, is given by

$$R = \frac{(T_1 - T_2)}{q} (m^2 KW^{-1}) \tag{2}$$

While the Thermal Conductivity of specimen, $\lambda$, is also given by

$$\lambda = \frac{L}{R} (Wm^{-1} K^{-1}) \tag{3}$$

where$T_1 - T_2$ is the difference in temperature$(K)$, and $L$ is the thickness of the specimen$(m)$.

### 3.2 Linear Thermal Expansion Test

Specimens of 25x25x7 $mm^3$ dimensions were prepared for conducting the linear thermal expansion test.

**Figure 8: Linear Thermal Expansion Test specimen**

Most solid materials expand upon heating and contract when cooled. Coefficient of linear thermal expansion (CTE or α) is a property of materials that indicates the extent to which a material expands upon heating. The change in length with temperature for a solid material can be expressed as:

$$\left(l_f - l_o\right) / l_o = \alpha\left(T_f - T_o\right) \tag{4}$$

where$l_o$ and $l_f$ represent the initial and final lengths respectively, with the temperature change from $T_o$ to $T_f$. The parameter, $\alpha$ or CTE, has units of reciprocal temperature, $(/K \ or \ /°C)$.

### 3.3 Specific Heat Test

The specimens of 30 mm diameter were prepared for specific heat test.

**Figure 9: Specific Heat Test Specimen**

Heat capacity is the ratio of the amount of energy transferred to a material and the change in temperature:

$$C = Q / \Delta T \quad (5)$$

where $C$ is heat capacity, $Q$ is energy (usually expressed in joules), and $\Delta T$ is the change in temperature (usually in degrees Celsius or in Kelvin).

Specific heat and heat capacity are related by mass:

$$c = C/m \quad (6)$$

where $C$ is the heat capacity, $m$ is the mass of a material, and $c$ is the specific heat.

## 4.0 Results and Discussions

The results of thermal conductivity test, linear thermal expansion test and specific heat test of CEFB and CPS hybrid fiber reinforced polyester composites are shown in Table 3 and 4 respectively

**Table 3: Mean Thermal property responses of CEFB hybrid fiber reinforced composites**

| **Exp. No.** | **Parameter Settings** | | | **Thermal Properties** | | |
|---|---|---|---|---|---|---|
| | Volume Fraction A | Coupling Agents B | Fiber Ratio C | Mean Thermal conductivity response (W/m-K) | Mean Linear Thermal Expansion x $10^{-5}$(/℃) | Mean Specific Heat $(J/kg-K)$ |
| **1** | 1 | 1 | 1 | 0.215 | 11.79 | 1467.00 |
| **2** | 1 | 2 | 2 | 0.229 | 6.02 | 1147.32 |
| **3** | 1 | 3 | 3 | 0.245 | 5.54 | 1913.36 |
| **4** | 2 | 1 | 2 | 0.124 | 5.82 | 1481.67 |
| **5** | 2 | 2 | 3 | 0.187 | 4.57 | 2654.01 |
| **6** | 2 | 3 | 1 | 0.201 | 4.31 | 2209.96 |
| **7** | 3 | 1 | 3 | 0.352 | 5.54 | 2106.01 |
| **8** | 3 | 2 | 1 | 0.208 | 3.56 | 2116.58 |
| **9** | 3 | 3 | 2 | 0.127 | 4.36 | 1422.98 |

**Table 4: Mean Thermal property responses of CPS hybrid fiber reinforced composite**

| Exp. No. | Parameter Settings | | | Thermal Properties | | |
|---|---|---|---|---|---|---|
| | Volume Fraction A | Coupling Agents B | Fiber Ratio C | Mean Thermal conductivity response (W/m-K) | Mean Linear Thermal Expansion x $10^{-5}(/°C)$ | Mean Specific Heat Response $(J/kg-K)$ |
| **1** | 1 | 1 | 1 | 0.203 | 11.47 | 1438.79 |
| **2** | 1 | 2 | 2 | 0.231 | 5.97 | 1126.46 |
| **3** | 1 | 3 | 3 | 0.196 | 5.31 | 1859.21 |
| **4** | 2 | 1 | 2 | 0.202 | 5.40 | 1465.74 |
| **5** | 2 | 2 | 3 | 0.191 | 4.44 | 2617.32 |
| **6** | 2 | 3 | 1 | 0.221 | 4.10 | 2201.21 |
| **7** | 3 | 1 | 3 | 0.322 | 5.88 | 2024.11 |
| **8** | 3 | 2 | 1 | 0.214 | 3.49 | 2104.61 |
| **9** | 3 | 3 | 2 | 0.156 | 4.00 | 1263.26 |

From results in Table 3 and 4, it is observed that the thermal conductivity of CEFB materials ranges from 0.124 to 0.352 W/m-K, while the thermal conductivity of CPS materials are in the range 0.156 and 0.322W/m-K. The same category (volume fraction of 50%, coupling agent 0.1% and fiber ratio of 70/30) of CEFB and CPS materials has the highest thermal conductivity.

The tables 3and 4 also reveal that the linear thermal expansion of CEFB specimens ranges from 3.56 x $10^{-5}$ to 11.79 x $10^{-5}/°C$, while that of CPS specimens range from 3.49 x $10^{-5}$ and 11.47 x $10^{-5}/°C$. The least category (50% volume fraction, 0.25% coupling agent and 30/70 fiber ratio) and highest category (volume fraction of 10%, coupling agent 0.1% and fiber ratio of 30/70) of CEFB and CPS materials are the same. The specific heat of CEFB specimens fall in the range of 1147.32 and 2654.01$J/kg-K$, but specific heat of CPS specimens are in range of 1126.46 and 2617.32$J/kg-K$. The least category (volume fraction of 10%, coupling agent 0.25% and fiber ratio of 50/50) and highest category (volume fraction of 30%, coupling agent 0.25% and fiber ratio of 70/30) are the same for both CEFB and CPS specimens.

### 4.1 Analysis of Data based on S/N Ratio

The signal-to-noise ratio, in Taguchi design, measures the sensitivity of the quality investigated to those uncontrollable factors (error) in the thermal property experiment. To determine the optimum condition for each of the thermal properties considered, smaller-the-better type was used for thermal conductivity and linear thermal expansion; and larger-the-better type was employed for specific heat.
S/N ratio for smaller-the-better type category is

$$S/N = -10Log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (7)$$

S/N ratio for larger-the-better type category is

$$S/N = -10Log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \qquad (8)$$

where, $y$ is the response and $n$ is the number of replications for each experiment $i$. The values of S/N ratio for each specimen of L9 Orthogonal Array for each of the thermal properties are demonstrated in Table 5.

### 4.1 Analysis of Means and Analysis of Variance

Analysis of means (ANOM) is the process of determining the direct effects of each variable; and the effect of a parameter level is the deviation it causes from the overall mean response (Phadke, 1989; Raju et al., 2012).The S/N ratio for each process parameter level is determined by averaging the S/N ratios when the parameter is kept at that level. The ANOM helps in identifying the optimum factor combinations. Analysis of variance (ANOVA) assists in ascertaining the comparative importance of the parameters in terms of percentage (%) contribution to the response (Phadke, 1989; Ross, 1996; Raju et al., 2012). Percentage (%) contribution defines the relative power of a parameter to diminish variation. For a parameter with a high percentage (%) contribution with a small variation has a huge control on the response.

**Table 5: S/N ratios for thermal properties**

| Exp. No. | S/N ratio for thermal properties for CEFB | | | S/N ratio for thermal properties for CPS | | |
|---|---|---|---|---|---|---|
| | Thermal conductivity | Linear thermal expansion | Specific heat | Thermal conductivity | Linear thermal expansion | Specific heat |
| **1** | 13.3512 | -21.4303 | 63.3286 | 13.8501 | -21.1913 | 63.1599 |
| **2** | 12.8033 | -15.5919 | 61.1937 | 12.7278 | -15.5195 | 61.0343 |
| **3** | 12.2167 | -14.8702 | 65.6359 | 14.1549 | -14.5019 | 65.3866 |
| **4** | 18.1316 | -15.2985 | 63.4150 | 13.8930 | -14.6479 | 63.3211 |
| **5** | 14.5632 | -13.1983 | 68.4781 | 14.3793 | -12.9477 | 68.3571 |
| **6** | 13.9361 | -12.6895 | 66.8877 | 13.1122 | -12.2557 | 66.8532 |
| **7** | 9.0691 | -14.8702 | 66.4692 | 9.8429 | -15.3875 | 66.1247 |
| **8** | 13.6387 | -11.0290 | 66.5127 | 13.3917 | -10.8565 | 66.4634 |
| **9** | 17.9239 | -12.7897 | 63.0640 | 16.1375 | -12.0412 | 62.0299 |

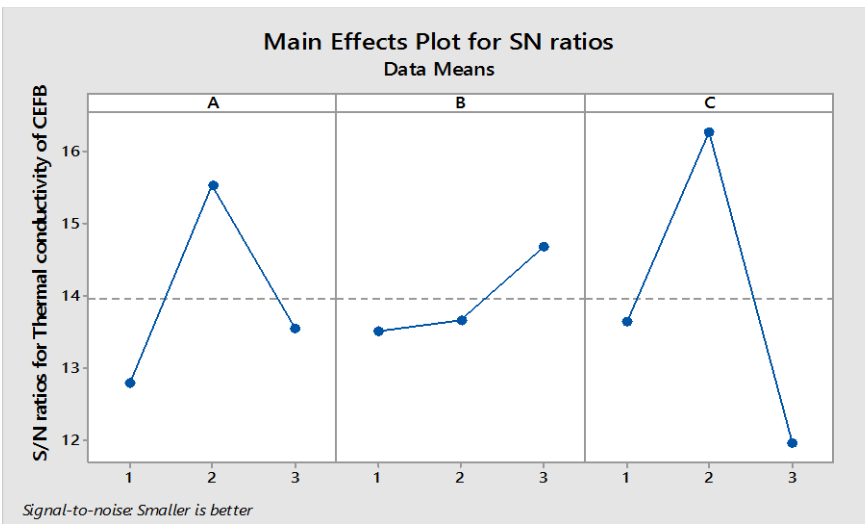


**Figure 10: S/N ratio response graph for Thermal Conductivity of CEFB hybrid fiber reinforced composite**

For thermal conductivity, the result of ANOM for CEFB composites is represented in response graph shown in Figures 10. The optimum combination of process parameter settings for minimizing the thermal conductivity of CEFB hybrid fiber reinforced polyester composite is A1,B1 and C3 i.e. the specimen having volume fraction of 10% with 0.1%$w/v$ of coupling agent using coir/plantain fiber ratio of 70/30. The ANOM result for CPS composite is also represented in response graph of Figure 11. It demonstrates the optimum combination of process parameter settings for minimizing the thermal conductivity of CPS hybrid fiber reinforced polyester composite is A3, B1 and C3 i.e. the specimen having volume fraction of 50% with 0.1%$w/v$ of coupling agent using coir/plantain fiber ratio of 70/30.

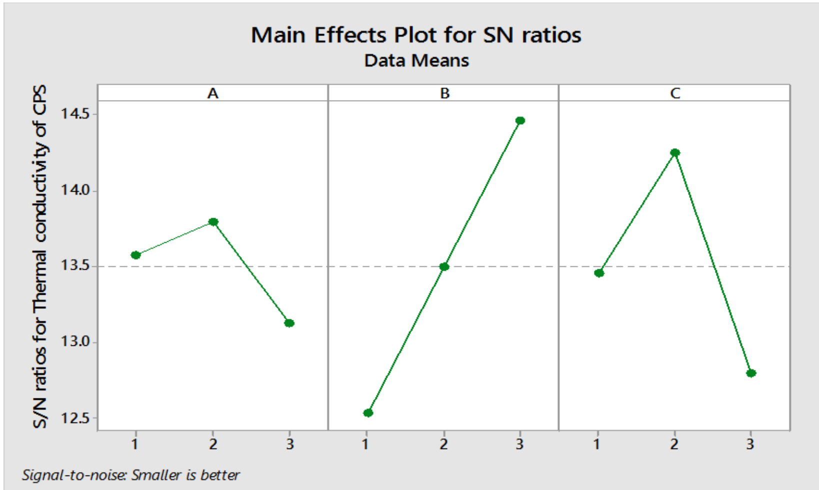


**Figure 11: S/N ratio response graph for Thermal Conductivity of CPS hybrid fiber reinforced composite**

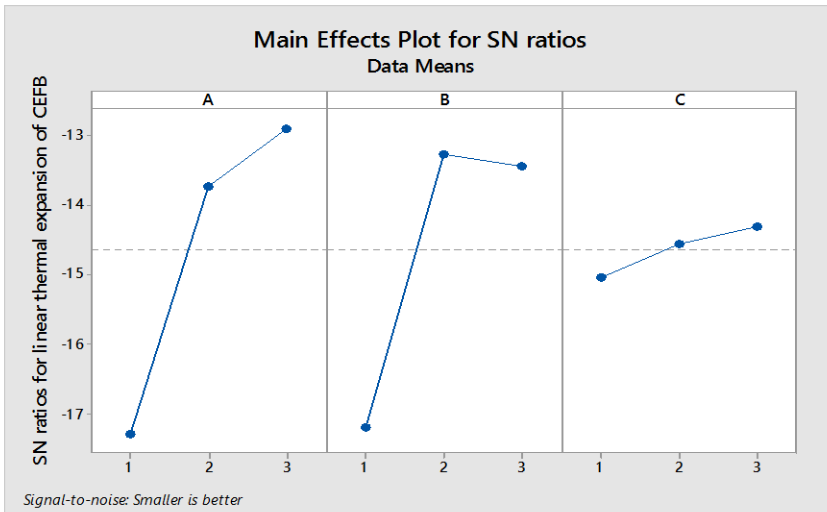


**Figure 12: S/N ratio response graph for Linear Thermal Expansion of CEFB hybrid fiber reinforced composite**

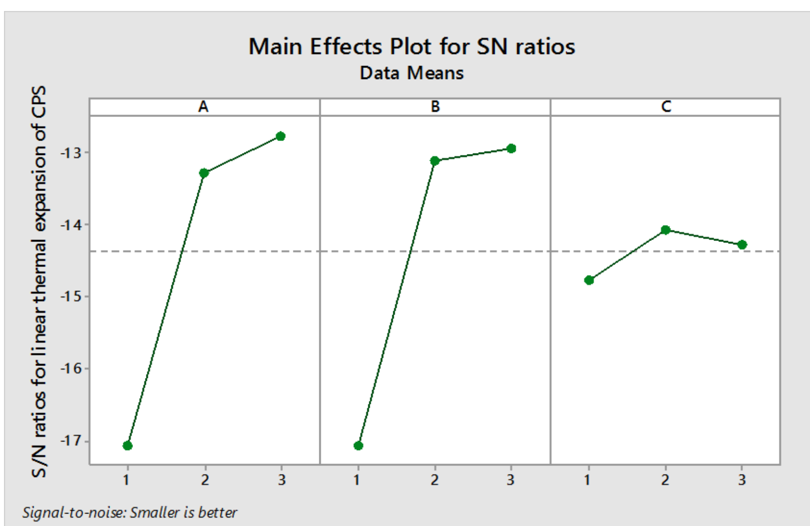


**Figure 13: S/N ratio response graph for Linear Thermal Expansion of CPS hybrid fiber reinforced composite**

Figure 12 shows that the optimal combination of parameter settings for minimizing the thermal expansion of CEFB hybrid fiber reinforced polyester composite is A1, B1 and C1 i.e. the specimen having volume fraction of 10% with 0.1%$w/v$ of coupling agent using coir/plantain fiber ratio of 30/70. It is also found that the optimum combination of process parameter settings in Figure 13 for minimizing the thermal expansion of CPS hybrid fiber reinforced polyester composite is A1, B1 and C1 i.e. the specimen having volume fraction of 10% with 0.1%$w/v$ of coupling agent using coir/plantain fiber ratio of 30/70.

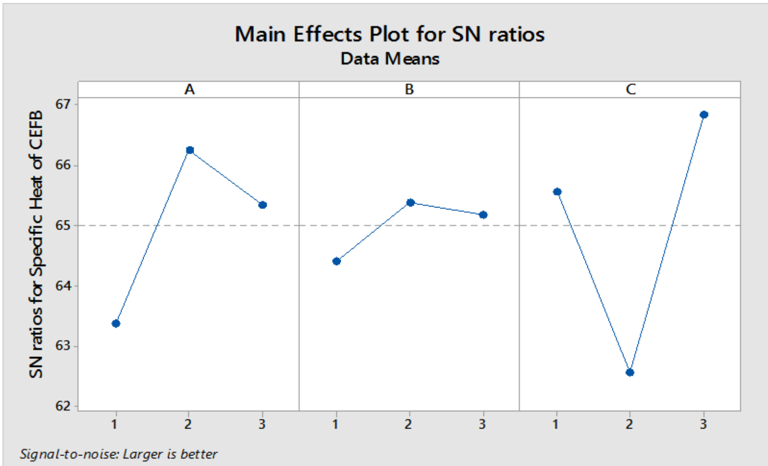


**Figure 14: S/N ratio response graph for Specific Heat of CEFB hybrid fiber reinforced composite**

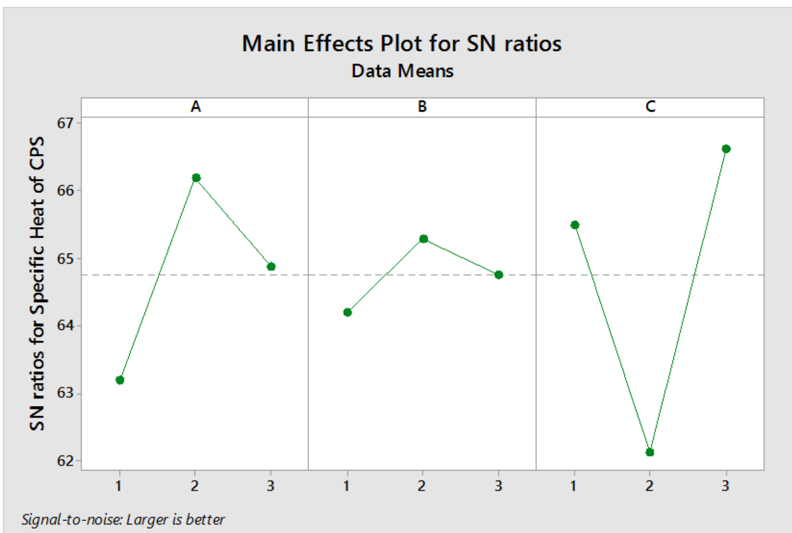


**Figure 15: S/N ratio response graph for Specific Heat of CPS hybrid fiber reinforced composite**

The results of ANOM for CEFB and CPS composites in response graphs (Figures 14 and 15) present the optimal combination of process parameter settings for maximizing the specific heat of CEFB hybrid fiber reinforced polyester composite is A2, B2 and C3 i.e. the specimen having volume fraction of 30% with 0.25%$w/v$ of coupling agent using coir/plantain fiber ratio of 70/30; and the optimum combination of parameter settings for maximizing the specific heat of CPS hybrid fiber reinforced polyester composite is A2, B2 and C3 i.e. the sample having volume fraction of 30% with 0.25%$w/v$ of coupling agent using coir/plantain fiber ratio of 70/30.

**Table 6: ANOVA on S/N ratio for Thermal Conductivity of CEFB hybrid fiber reinforced composite**

| Source | Degree of freedom | Sum of squares | Mean square | F-Ratio | % contribution |
|---|---|---|---|---|---|
| **Volume Fraction (A)** | 2 | 12.147 | 6.073 | 0.64 | 19.51 |
| **Coupling Agent (B)** | 2 | 2.451 | 1.226 | 0.13 | 3.94 |
| **Fiber Ratio (C)** | 2 | 28.662 | 14.331 | 1.51 | 46.04 |
| **Residual Error** | 2 | 18.990 | 9.495 | | 30.51 |
| **Total** | 8 | 62.250 | | | 100 |

**Table 7: ANOVA on S/N for Thermal Conductivity of CPS hybrid fiber reinforced composite**

| Source | Degree of freedom | Sum of squares | Mean square | F-Ratio | % contribution |
|---|---|---|---|---|---|
| **Volume Fraction (A)** | 2 | 0.7028 | 0.3514 | 0.05 | 3.11 |
| **Coupling Agent (B)** | 2 | 5.6427 | 2.8214 | 0.43 | 25.00 |
| **Fiber Ratio (C)** | 2 | 3.2092 | 1.6046 | 0.25 | 14.22 |
| **Residual Error** | 2 | 13.0138 | 6.5069 | | 57.69 |
| **Total** | 8 | 22.5685 | | | 100 |

Tables 6 and 7 present summary of ANOVA results for thermal conductivities of CEFB and CPS hybrid fiber reinforced polyester composite materials. For CEFB, the coir/plantain fiber ratio is the most dominant significant parameter (46.04%) and the volume fraction of the fiber (19.51%) has the moderate effect to minimize its thermal conductivity; while the coupling agent has major influence (25.00%) on minimizing thermal conductivity of CPS hybrid fiber reinforced polyester composite material and the coir/plantain fiber ratio has less effect (14.22%), whereas the volume fraction of the fiber does not have significant effect.

**Table 8: ANOVA on S/N for Linear Thermal Expansion of CEFB hybrid fiber reinforced composite**

| Source | Degree of freedom | Sum of squares | Mean square | F-Ratio | % contribution |
|---|---|---|---|---|---|
| **Volume Fraction (A)** | 2 | 32.7988 | 16.3994 | 4.86 | 46.92 |
| **Coupling Agent (B)** | 2 | 29.5103 | 14.7551 | 4.37 | 42.22 |
| **Fiber Ratio (C)** | 2 | 0.8435 | 0.4217 | 0.13 | 1.21 |
| **Residual Error** | 2 | 6.7466 | 3.3733 | | 9.65 |
| **Total** | 8 | 69.8991 | | | 100 |

**Table 9: ANOVA on S/N for Linear Thermal Expansion of CPS hybrid fiber reinforced composite**

| Source | Degree of freedom | Sum of squares | Mean square | F-Ratio | % contribution |
|---|---|---|---|---|---|
| **Volume Fraction (A)** | 2 | 33.1835 | 16.5918 | 5.22 | 45.31 |
| **Coupling Agent (B)** | 2 | 32.9346 | 16.4673 | 5.18 | 44.97 |
| **Fiber Ratio (C)** | 2 | 0.7704 | 0.3852 | 0.12 | 1.052 |
| **Residual Error** | 2 | 6.3533 | 6.3538 | | 8.67 |
| **Total** | 8 | 73.2423 | | | 100 |

The summary of ANOVA result for linear thermal expansion of CEFB hybrid fiber reinforced polyester composite material in Table 8 shows that the volume fraction of the fiber has more contribution (46.92%) for minimizing thermal expansion followed by the coupling agent (42.22%). However, the volume fraction has the least effect for minimizing thermal expansion of CEFB hybrid fiber reinforced polyester composite material. In Table 9, ANOVA result for linear thermal expansion of CPS hybrid fiber reinforced polyester composite material indicates that the volume fraction of the fiber has more influence (45.31%) for minimizing thermal expansion of CPS hybrid fiber reinforced polyester composite material followed by the coupling agent (44.97%).

**Table 10: ANOVA on S/N for Specific Heat of CEFB hybrid fiber reinforced composite**

| Source | Degree of freedom | Sum of squares | Mean square | F-Ratio | % contribution |
|---|---|---|---|---|---|
| **Volume Fraction (A)** | 2 | 12.9436 | 6.4718 | 72.40 | 29.38 |
| **Coupling Agent (B)** | 2 | 1.6473 | 0.8237 | 9.21 | 3.74 |
| **Fiber Ratio (C)** | 2 | 29.2836 | 14.6418 | 163.80 | 66.47 |
| **Residual Error** | 2 | 0.1788 | 0.0894 | | 0.41 |
| **Total** | 8 | 44.0533 | | | 100 |

**Table 11: ANOVA on S/N for Specific Heat of CPS hybrid fiber reinforced composite**

| Source | Degree of freedom | Sum of squares | Mean square | F-Ratio | % contribution |
|---|---|---|---|---|---|
| **Volume Fraction (A)** | 2 | 13.4226 | 6.7113 | 28.78 | 27.71 |
| **Coupling Agent (B)** | 2 | 1.7598 | 0.8799 | 3.77 | 3.63 |
| **Fiber Ratio (C)** | 2 | 32.7924 | 16.3962 | 70.31 | 67.70 |
| **Residual Error** | 2 | 0.4664 | 0.2332 | | 0.96 |
| **Total** | 8 | 48.4412 | | | 100 |

From Table 10 and 11, it is clear that coir/plantain fiber ratio has major influence (66.47% for CEFB and 67.70% for CPS) on maximizing specific heat and the volume fraction of the fiber has less effect (29.38% for CEFB and 27.71% for CPS), whereas coupling agent does not have significant effect in maximizing specific heat of both CEFB and CPS hybrid fiber reinforced composites.

### 4.3 Estimation of expected responses based on optimum settings

The best combinations of parameters for achieving minimum thermal conductivity and thermal expansion, and for maximum specific heat capacity along with the corresponding optimum values of thermal properties are exhibited in Table 12.

**Table 12: Optimum setting of control factors and expected optimum values of Thermal properties**

| Thermal Properties | Materials | Optimum control factors settings | | | Optimum values |
|---|---|---|---|---|---|
| | | Volume fraction (%) | Coupling agent (%$wt$) | Fiber ratio (-) | |
| **Thermal conductivity** | CEFB | 10 | 0.1 | 70/30 | $0.3016 W/m-K$ |
| | CPS | 50 | 0.1 | 70/30 | $0.2791 W/m-K$ |
| **Linear thermal expansion** | CEFB | 10 | 0.1 | 30/70 | $10.6070 \times 10^{-5}/°C$ |
| | CPS | 10 | 0.1 | 30/70 | $10.395 \times 10^{-5}/°C$ |
| **Specific heat** | CEFB | 30 | 0.25 | 70/30 | 2641.51 J/kg-K |
| | CPS | 30 | 0.25 | 70/30 | 2633.10/kg-K |

### 5.0 Conclusions

In this study, the characterization and optimization of the thermal conductivity, linear thermal expansion and specific heat of both CEFB and CPS hybrid fiber reinforced polyester composite materials using the application of Taguchi techniques was done. Hybrid fibers of different volume fraction percentages were esterified with different percentages of maleic anhydride coupling agent. Then, the treated hybrid fibers were manually arranged in discontinuous and randomly oriented manner to prepare CEFB and CPS hybrid fiber reinforced polyester composite specimens. The optimum settings were identified and the contribution of each control factors in controlling the different thermal properties was determined. From the analysis of results using S/N ratio and ANOVA, the following conclusions are drawn from this study:

1. The lowest volume fraction of CEFB hybrid fiber (10%) and highest volume fraction of CPS hybrid fiber (50%), both esterified with lowest $\%wt$ of coupling agent ($0.1\%wt$) at the coir-plantain fiber ratio of 70/30 is expected for minimizing the thermal conductivity of CEFB hybrid fiber reinforced polyester composite materials and CPS hybrid fiber reinforced polyester composite materials respectively.
2. For both CEFB and CPS hybrid fibers, the same lowest volume fraction of CEFB hybrid fiber and CPS hybrid fiber (10%), both esterified with lowest $\%wt$ of coupling agent ($0.1\%wt$) at the coir-plantain fiber ratio of 30/70 is expected for minimizing the thermal expansion of CEFB hybrid fiber reinforced polyester composite materials and CPS hybrid fiber reinforced polyester composite materials.
3. The same higher volume fraction of CEFB hybrid fiber and CPS hybrid fiber (30%), both esterified with higher $\%wt$ of coupling agent ($0.25\%wt$) at the coir-plantain fiber ratio of 70/30 is expected for maximizing the specific heat of CEFB hybrid fiber reinforced polyester composite materials and CPS hybrid fiber reinforced polyester composite materials.
4. The coir/plantain fiber ratio is the most dominant significant effect, followed by the volume fraction of the fiber in minimizing its thermal conductivity of CEFB hybrid fiber reinforced polyester composite materials; while the coupling agent has major influence on minimizing thermal conductivity of CPS hybrid fiber reinforced polyester composite material and the coir/plantain fiber ratio has less effect.
5. The volume fraction of the both CEFB and CPS hybrid fibers has more contribution followed by the coupling agent in minimizing thermal expansion of both CEFB hybrid fiber reinforced polyester composite materials and CPS hybrid fiber reinforced polyester composite material.
6. Coir/plantain fiber ratio has major influence for both CEFB and CPS hybrid fibers in maximizing specific heat and the volume fraction of the fiber has less effect for both CEFB and CPS, whereas coupling agent does not have significant effect in maximizing specific heat of both CEFB and CPS hybrid fiber reinforced composite materials.

The control factors setting of CEFB hybrid fiber reinforced composite materials and CPS hybrid fiber reinforced composite materials are the same except in thermal conductivity where only the volume fractions differ (10% for CEFB and 50% for CPS). However, CEFB hybrid fiber reinforced composite materials have maintained higher optimum value; in other words, CEFB hybrid fiber reinforced composite materials are more useful than CPS hybrid fiber reinforced composite materials

**6.0 Recommendation**

The moisture and heat retention capacities of the coir-plantain hybrid fiber reinforced composites in long time use should be studied. Adequate attention to this retention capacity will assist in avoiding any potential and critical mistake in the composite materials. It will also help in determining life-time of CEFB and CPS composite material. Other factors that may influence the thermal strengths of CEFB and CPS composites as car bumpers and for any other use can also be of future research interest.

**Acknowledgements**

I wish to acknowledge Mr. Okechukwu Nwoye, Technologist Daniel Ezenduka, Engr. Dr. Arinze Nwosu and Engr. Kingsley Ewuzie all from National Engineering Design and Development Institute, Nnewi; for providing their technical guidance and valuable contributions throughout the research period.

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