STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 9, Issue 3, 2021
DOI (Journal): 10.37591/JoPC

http://engineeringjournals.stmjournals.in/index.php/JoPC/index

Research JoPC

An Approach on Optimization of Thermo Physical Properties of Teak Wood Dust Filled Polymeric Composites

Ramesh Chandra Mohapatra

Abstract

The aim of the present work was to prepare the specimens with the help of hand-lay-up technique to measure the thermal properties of TWDPC. The density & voids of TWDPC were measured to determine its physical property & significantly affected some of its mechanical properties. Taguchi experimental method was applied to optimize its thermal properties. The optimal factor combinations were determined with the help of ANOM & the analysis of variance (ANOVA) identified the level of importance on the parameters on each of the thermal properties. ANOM results showed that the contribution parameters for minimum value of thermal conductivity, linear thermal expansion & maximum value of specific heat capacity were B>C >A, A>C>B & C>A>B. From ANOVA results it was found that the volume fraction & the particle size of TWD has major influence for minimizing the thermal conductivity & linear thermal expansion, whereas the polymer resin was one of the best parameters to maximize the specific heat of TWDPC. Finally, it was concluded that TWDPC was one of the eco-friendly composites which can be used for various thermal applications

Keywords: Teak wood dust, Polymer resin, Thermal properties, Taguchi technique, ANOM, ANOVA.

INTRODUCTION

The fibres that are not synthetic or manmade are known as natural fibres. The fibres can be sourced from plants or animals. Nowa days synthetic fibres are replaced by natural fibres because of its eco-friendliness, good renewable & biodegradable in nature. They are plenty available in nature. Now days, most of the industries have taken interest to produce their products considering natural fibres because of their above good properties. Researchers around the world reviewed natural fibres properties carefully & produced the eco-friendly bio-polymer composites with the help of natural fibres like Knef [1, 2], Jute [3, 4], pine apple [5] etc. Raju et al. [6] optimized the thermal properties of ground nut shell reinforced polymer composites. Mohapatra et al. [7] determined the thermal conductivity of pine wood dust filled polymeric composite at different volume fraction by using forced convection apparatus. The experiment showed that the thermal conductivity of epoxy composite decreases as the % of filler material increases. Mohapatra [8] optimized the thermal conductivity of rice husk filled polymer composite with the application of Taguchi experimental method. Jena et al. [9] determined the optimization of mechanical properties of rice husk reinforced polymer composites using Taguchi experimental method. Taguchi & Konishi [10] discussed about orthogonal array & Taguchi [11] developed an experimental method in which signal to noise ratio with orthogonal array can be applied to the design

***Author for Correspondence**
Ramesh Chandra Mohapatra

Associate Professor, Mechanical Department, Government College of Engineering, Keonjhar, Odisha, India

Received Date: May 30, 2021
Accepted Date: November 08, 2021
Published Date: December 08, 2021

Citation: Ramesh Chandra Mohapatra. An Approach on Optimization of Thermo Physical Properties of Teak Wood Dust Filled Polymeric Composites. Journal of Polymer & Composites. 2021; 9(3): 67–80p.

of products & processes. Phadke [12], Wu & Moore [13] & others [14, 15] applied the Taguchi method to design the product & process parameters. Numerous experimental & computational work have been done by the researchers to determine the optimization of the mechanical properties of natural fibre reinforced polymer composites. Very few scientists evaluated the optimization of thermo-physical properties of natural fibre reinforced polymer composites. Therefore, the focus of work is to investigate the thermo-physical properties of the composite who's natural fibres are extracted from the waste wood dust. The present work relates to investigation on the thermo-physical properties of teak wood dust reinforced polymer composites & its optimization by using Taguchi experimental method due to following reasons (i) Most of the experiments were done regarding the enhancement of thermal properties of the polymer rather than improving its insulation properties. (ii) Although a large number of natural fibres have been used as fillers in the past, there is few reports available on biobased material like any kind on wood dust being used for composite making. (iii) Investigations on thermo-physical properties of particulate filled composites are rare. (iv) the understanding of relationship between thermo-physical properties of a composite material is far from satisfactory (v) Optimization of thermo-physical properties of TWDPC can be found out considering Taguchi's experimental technique & (vi) ANOM & ANOVA were used to identify the optimal level of each parameter & find the relative importance among the parameters.

THEORETICAL INVESTIGATION

Actual (experimental) & theoretical densities of TWDPC were calculated considering Archimedes principle. Actual densities were determined considering experimental mass per unit volume of each component of TWDPC. Theoretical densities can be calculated considering weight fraction & composite's component density & using equation (1).

$$\rho_{Theoretical} = \frac{1}{\frac{w_f}{\rho_f}+\frac{w_m}{\rho_m}} \tag{1}$$

$\rho_{Theoretical}$= Theoretical density of the composite
w_f= Weight fraction of TWD
ρ_f= Density of TWD
ρ_m = Density of Polymer resin
w_m = Weight fraction of polymer resin

Simple water immersion technique was used to find out the actual density of TWDPC. Voids in the above composites were determined using equation 2.

$$V_v = \frac{\rho_{Theoretical} - \rho_{actual}}{\rho_{Theoretical}} \tag{2}$$

DETAILS OF EXPERIMENT

Polymer Resins

In this study, epoxy of grade HY554, vinyl ester of grade GR220-60 & polyester of grade P_xG_p 002 have been chosen as matrix materials. Prescribed proportion of hardeners, catalysts & accelerators to the corresponding matrix materials (i.e. epoxy with hardener HY951, vinyl ester with hardener, catalyst & accelerator, polyester with benzoyl peroxide) were added to prepare composite specimens.

Teak wood dust

TWD has been chosen as filler material for its eco-friendly, light weight, bio-degradable, waste product & low cost.

Preparation of Specimens

The TWD supplied by local vendor was dried before manufacturing in a vacuum oven for 24 hour at 80°C in order to remove moisture. The TWD particle of average size 150 µm, 200 µm & 250 µm measured through sieve shaker were filled in epoxy, vinyl ester & polyester resin & their corresponding hardeners separately with different volume fractions (11.3%, 26.8% & 35.9%) to prepare the composites with the help of a simple technique known as hand-lay-up technique for different thermal properties tests.

Thermal Conductivity Test

The specimens of circular disc shaped of size 110 mm diameter with thickness of 5 mm was prepared for thermal conductivity test with the help Lee's disc apparatus whose experimental setup was shown in Figure 1. The rate of heat conducted through the specimen

$$Q = KS\frac{T_1 - T_2}{x} \quad (3)$$

Where, Q = Heat transfer rate (J/s), K = Coefficient of thermal conductivity (W/m-K), S = Cross sectional area of specimen (m^2), T_1-T_2 = Temperature difference (K) x = Specimen thickness (m)

The rate of heat lost by the brass disc introduced in Lee's disc apparatus to the surrounding under steady state

$$Q = m_b c_p \left(\frac{\partial T}{\partial t}\right)_{T2} \quad (4)$$

Where, m_b & c_p are mass (Kg) & specific heat (J/Kg-K) of disc respectively $(\frac{\partial T}{\partial t})_{T2}$ = Cooling rate at T_2 (K/s)

Comparing equation (3) & equation (4)

$$K = \frac{m_b c\left(\frac{\partial T}{\partial t}\right)T2}{\left(A\frac{T_1 - T_2}{x}\right)} \quad (5)$$

$\left(\frac{\partial T}{\partial t}\right)_{T2}$ & (T_1–T_2) are calculated using Lee's disc apparatus. With known values of mass (m_b) & specific heat (c_p) of brass, thickness & cross sectional of the specimen, specimen thermal conductivity can be calculated.

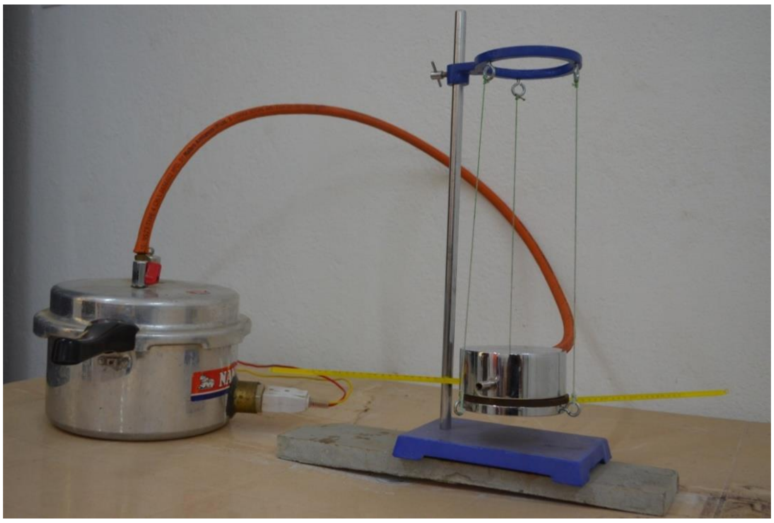

Figure 1. Experimental set up of Lee's disc Apparatus.

Linear Thermal Expansion Test

75 × 12.5 × 10 mm^3 dimension of TWDPC specimen was prepared for the test of linear thermal expansion. A heater, a conductive material made of aluminum plate, thermocouples & dial gauges were required for this experiment. Dial gauges & thermocouples were connected at the ends of the specimen to measure deflection & temperature of the specimen at different points & specimen was

placed over the aluminum plate. The environmental temperature (initial temperature) of the specimen was measured before heating the specimen. Then heat was supplied to the specimen in steady state to measure its deflection & final temperature with the help of dial gauges & thermocouples. Considering length of the specimen before & after heating & change of temperature, the linear thermal expansion can be calculated using the equation-6

$$l = l_0(1 + \alpha\Delta T) \tag{6}$$

Where, l_0 = Initial length of the specimen (m), l = Final length of the specimen (m), ΔT = Temperature difference (°C) & α = Coefficient of thermal expansion (1/°C)

Specific Heat Test

The TWDPC specimen (spherical shape) of diameter 40 mm was prepared for specific heat test. Thermocouples were placed at different points of the specimen to measure the temperature when the supply of to the specimen was at steady state. Measuring supply of heat at steady state, temperature difference & mass, the specific heat of the TWDPC specimen can be determined using the equation 7

$$C_p = \frac{Q}{m\Delta T} \tag{7}$$

Where, C_p = Specific heat of the specimen (J/Kg-K), Q = Heat supplied (J), m = Mass of the specimen (kg), ΔT = Change in temperature (K)

Design of Experiments via Taguchi Method

In this work, Taguchi technique (signal to noise ratio with orthogonal array) is applied to optimize the experiment through ANOM & ANOVA.

Orthogonal Array (OA) Selection

Taguchi's experimental method uses orthogonal arrays (OA) to reach the optimum with minimum trials at minimum.Equation 8 is used to find out minimum experiments to conduct Taguchi design of experiments.

$$N_{Taguchi} = 1 + \sum_{i=1}^{NV}(L_i - 1) \tag{8}$$

Where, $N_{Taguchi}$ = No of Taguchi experiments, NV = No. of variables, L = No of levels

Considering the equation 8, Taguchi suggests minimum 9 no. of experiments (L_9 orthogonal array) out of total 27 (3^3) to optimize the parameters. Table 1 & Table 2 show the selected process parameters, their levels & experimental layout plans for the preparation of (TWDPC) specimens.

S/N ratio

S/N ratio in Taguchi design is used to find out the optimal conditions for each thermal property of the composites. Usually, there are three categories of the performance characteristics in the analysis of the S/N ratio (the lower-the better, the higher-the better & the nominal-the better). In this work, to obtain the optical operating parameters the lower (smaller)-the better is used for thermal conductivity & linear thermal expansion & the higher (larger)-the better is used for specific heat capacity.

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

$$\eta = -10log_{1o}\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \tag{9}$$

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

$$\eta = -10log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} y_i^{-2}\right] \tag{10}$$

Where, η = Response value of S/N ratio, y is the response & n is the no. of replication for each trial i.

Table 1. Process parameters & their levels

Code	Parameters	Levels		
		1	*2*	*3*
A	Particle size (μm)	150	200	250
B	Teak wood dust (Vol. fraction %)	11.3	26.8	35.9
C	Polymers	Epoxy	Vinyl ester	Polyester

Table 2. Experimental layout plans

Trial No.	No. of parameters		
	Particle size (A)	*Teak wood dust (B)*	*Polymer resin (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

RESULTS AND DISCUSSIONS

Density & Volume Fraction of Voids

In the present work the variation in density & voids of epoxy, vinyl ester & polyester resins with TWD filler loading are shown in Figure 2 & Figure 3 respectively. Figure 2 shows that with increase in volume fraction of TWD both the theoretical & actual densities for epoxy as well as polyester matrix composites are decreasing while vinyl ester matrix composite is increasing. This is because the volume fraction of TWD influenced composite's density. On the other hand as the filler content increases the void content decreases which is directly influenced the density of the composites. Some differences are also found between actual (experimental) & theoretical densities of composites. This difference is due to presence of voids & pores in preparing the composites. The Figure 3 shows that with increase in filler (TWD) content the void fraction or porosity increases almost linearly for all three type of polymer composites. Table (3) shows the theoretical & actual (experimental) densities of TWDPC along with voids.

Table 3. Theoretical & Actual densities of composites along with voids

Composite	Theoretical Density (g/cc)	Actual density (g/cc)	Voids (%)
Neat Epoxy	1.100	1.092	0.73
Epoxy with 11.3% TWD	1.077	1.051	2.41
Epoxy with 26.8%TWD	1.042	0.994	4.60
Epoxy with 35.9% TWD	1.020	0.965	5.39
Neat Vinyl ester	0.596	0.566	5.00
Vinyl ester with 11.3% TWD	0.605	0.570	5.78
Vinyl ester with 26.8% TWD	0.619	0.580	6.30
Vinyl ester with 35.9% TWD	0.629	0.583	7.20
Neat Polyester	1.300	1.190	8.46
Polyester with11.3% TWD	1.255	1.139	9.20
Polyester with 26.8% TWD	1.190	1.073	9.80
Polyester with 35.9% TWD	1.151	1.036	10.20

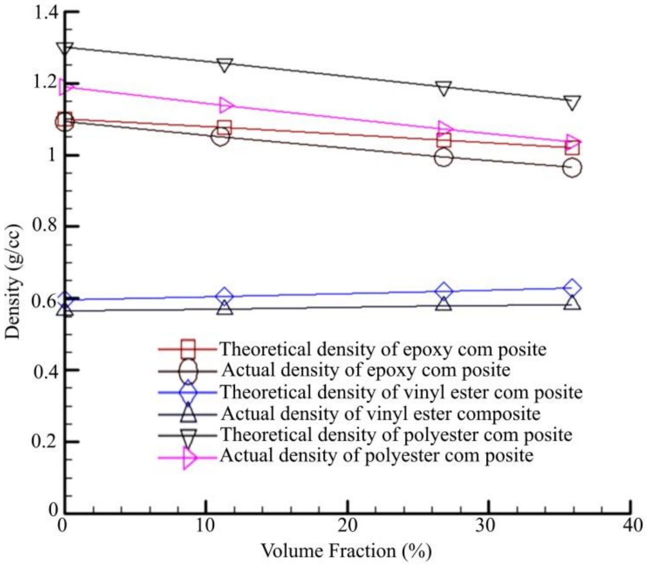

Figure 2. Comparison of density for different polymer composites.

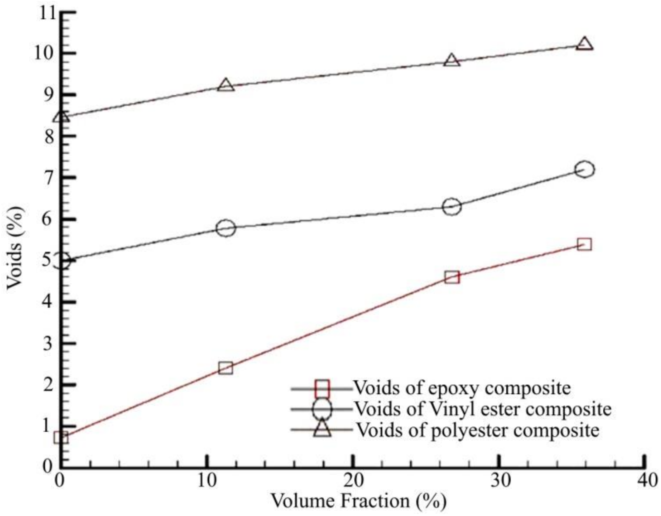

Figure 3. Voids of composites as a function of filler content.

Taguchi Experimental Results

Table 4 shows the experimental values of thermal conductivity, coefficient of thermal expansion & specific heat capacity of teak wood dust particle reinforced polymer composite (TWDPC) materials. It is seen from the Table 4 that TWDPC has thermal conductivity, coefficient of thermal expansion & specific heat capacity in the range of 0.095 to 0.240 W/m-K, 2.04 to 6.23 1/°C & 700.00 to 1750.26 J/Kg-K respectively. The specimen made from epoxy resin with particle size of 200 µm & 35.9% volume fraction of TWD shows lower thermal conductivity on comparison to epoxy resin with particle size 150 µm (11.3% volume fraction of TWD) & 250 µm (26.8% volume fraction of TWD). How-ever the specimen made from vinyl ester resin with particle size 250 µm & 35.9% volume fraction shows decreased thermal conductivity on comparison to other two particle sizes & the volume fractions. On the other hand, polyester matrix composite with particle size 200 µm & 26.8% volume fraction has the lowest thermal conductivity. For linear thermal expansion, the specimen made from epoxy matrix with particle size 200 µm & 35.9% volume fraction has the lowest coefficient of thermal expansion (∝) on comparison to the specimen made from the same matrix with different particle sizes & volume fractions. How-ever for vinyl ester & polyester matrix, as the volume fraction decreases the coefficient of thermal expansion increases. This is because of lower thermal expansion of TWD than vinyl ester & polyester matrix. The specific heat capacity of TWDPC specimen is high for 200 µm particle size in case of epoxy & polyester resins whereas the vinyl ester matrix has the higher specific heat capacity at 250 µm. On the other hand, the specific heat capacity is high for 35.9% volume fraction of TWD in case of epoxy & vinyl ester resins where as it is high at 26.8% volume fraction for polyester resin.

Table 4. Experimental values of thermal properties

Trial No.	Thermal Conductivity (W/m-K)	LinearThermal Expansion x 10^{-5} ($1/^{0}C$)	Specific heat (J/Kg-K)
1	0.191	6.23	945.36
2	0.140	3.68	700.00
3	0.152	3.14	1263.54
4	0.215	3.55	1013.60
5	0.125	3.08	1750.26
6	0.128	2.79	1531.65
7	0.240	2.04	1270.00
8	0.145	3.17	1469.84
9	0.095	2.70	1016.40

Analysis of Means (ANOM)

ANOM is a process which is used to determine the direct effects of each variable. It also helps in identifying the optimal factor combination. In the present work, the experimental S/N ratio is shown in Table 5. The mean S/N ratio value for each level & parameter can be calculated using equation

$$\eta_{A1}=\frac{1}{3}(\eta_1+\eta_2+\eta_3) \quad (11)$$

Where η_{A1} is the mean S/N ratio of level 1 of parameter A. η_1,η_2 & η_3 are S/N ratio value of the experiment No.1, 2 & 3 respectively. ANOM respond graphs are shown in Figure 4, Figure 5 & Figure 6. In the Figures the optimal level is the level of a process parameter with highest response value of S/N ratio. As shown in Figure 4 & 5 the optimal of process parameters for minimizing thermal conductivity & linear thermal expansion of TWDPC are A_3, B_3 & C_2 (i.e. the specimen made from vinyl ester matrix with particle size 250 µm & 35.9% volume fraction of TWD) & A_3, B_3 & C_3 (i.e. the specimen made from polyester matrix with particle size 250 µm & 35.9% volume fraction of TWD). As shown in Figure 6, the optimal of process parameter for maximizing the specific heat of TWDPC is A_2, B_3 & C_3 i.e. the specimen made from polyester matrix with particle size 200 µm & 35.5% volume fraction of TWD. The contribution of parameter is more for higher effect. Hence the contribution parameters for minimum value of thermal conductivity, linear thermal expansion & maximum value of specific heat capacity are B > C > A, A > C > B & C > A > B respectively. Table 6, 7 & 8 represent the mean S/N ratio for thermal conductivity, linear thermal expansion & specific heat capacity

Table 5. S/N ratio values for thermal properties

Trial No.	S/N ratio (dB) for Thermal properties		
	Thermal conductivity	***Linear thermal expansion***	***Specific heat***
1	14.379	-15.90	59.512
2	17.077	-11.32	56.902
3	16.363	-9.94	62.032
4	13.351	-11.00	60.117
5	18.061	-9.80	64.871
6	17.855	-8.91	63.703
7	12.395	-6.19	62.000
8	16.722	-10.02	63.345
9	20.445	-8.63	60.141

Table 6. Mean S/N ratio for thermal conductivity

Level	Particle size (A)	Volume fraction (B)	Polymer resin (C)
1	15.939	13.375	16.335
2	16.422	17.303	16.957
3	16.537	18.221	15.273
Effect	0.598	4.846	1.684
Rank	3	1	2

Table 7. Mean S/N ratio for linear thermal expansion

Level	Particle size (A)	Volume fraction (B)	Polymer resin (C)
1	-12.386	-11.030	-11.610
2	-9.903	-10.380	-10.316
3	-8.280	-9.160	-8.643
Effect	4.106	1.870	2.418
Rank	1	3	2

Table 8. Mean S/N ratio for specific heat

Level	Particle size (A)	Volume fraction (B)	Polymer resin (C)
1	59.482	60.777	62.186
2	62.830	61.639	59.053
3	62.062	61.958	62.700
Effect	3.348	1.181	3.647
Rank	2	3	1

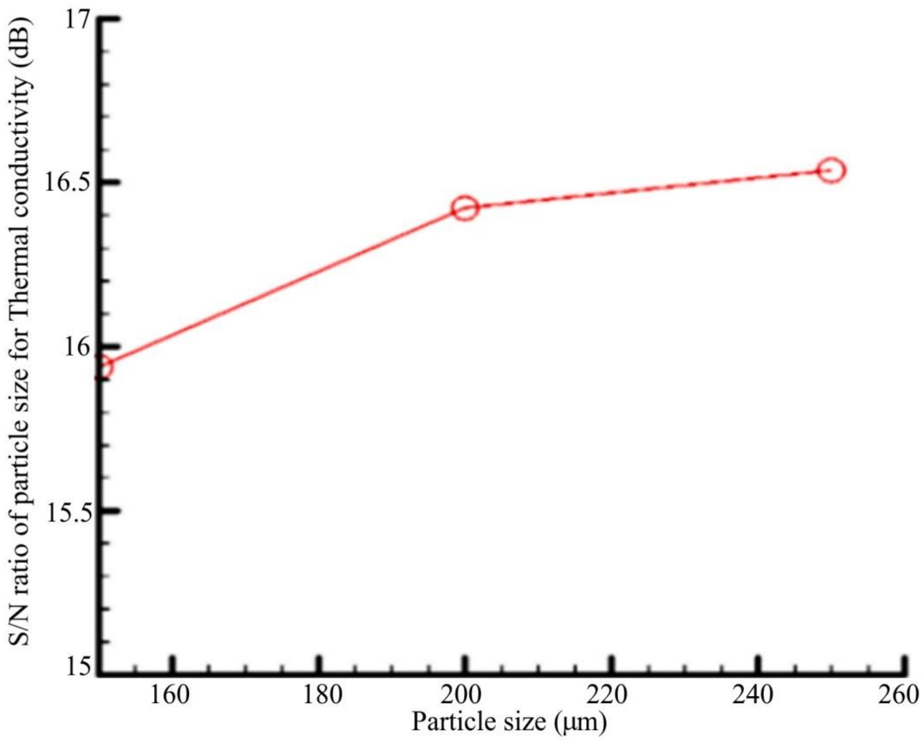

Figure 4. (a) Mean S/N ratio of particle size for Thermal conductivity.

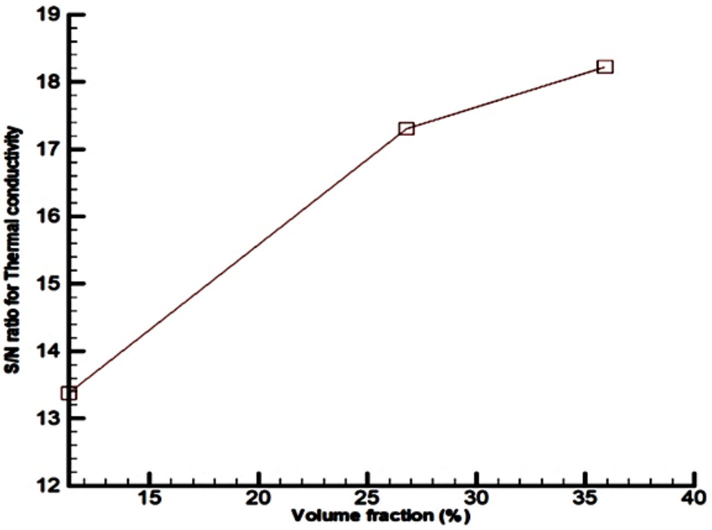

Figure 4. (b) Mean S/N ratio of volume fraction of TWD for Thermal conductivity.

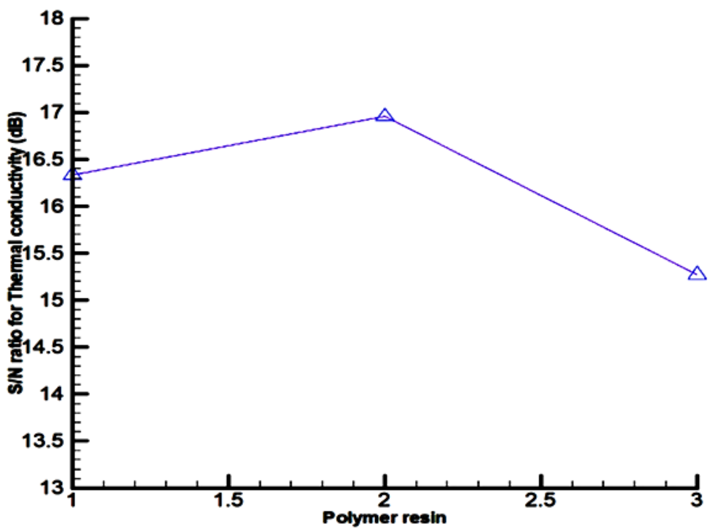

Figure 4. (c) Mean S/N ratio of Polymer resin for Thermal conductivity.

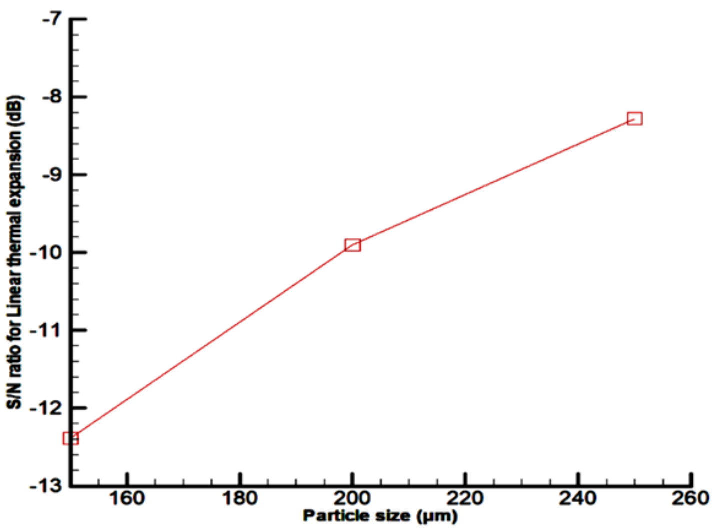

Figure 5. (a) Mean S/N ratio of Particle size for Linear thermal expansion.

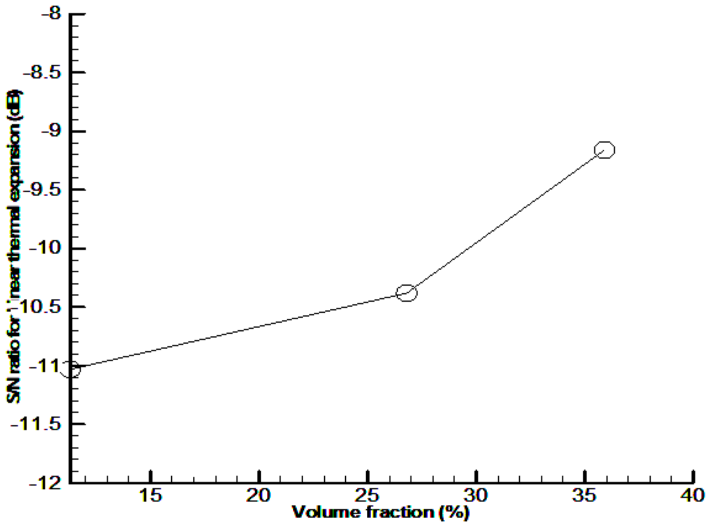

Figure 5. (b) Mean S/N ratio of volume fraction of TWD for Linear thermal expansion.

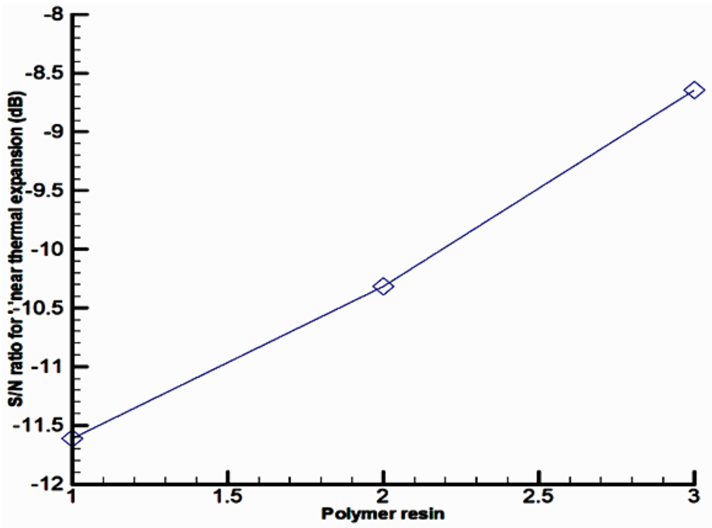

Figure 5. (c) Mean S/N ratio of Polymer resin for Linear Thermal Expansion.

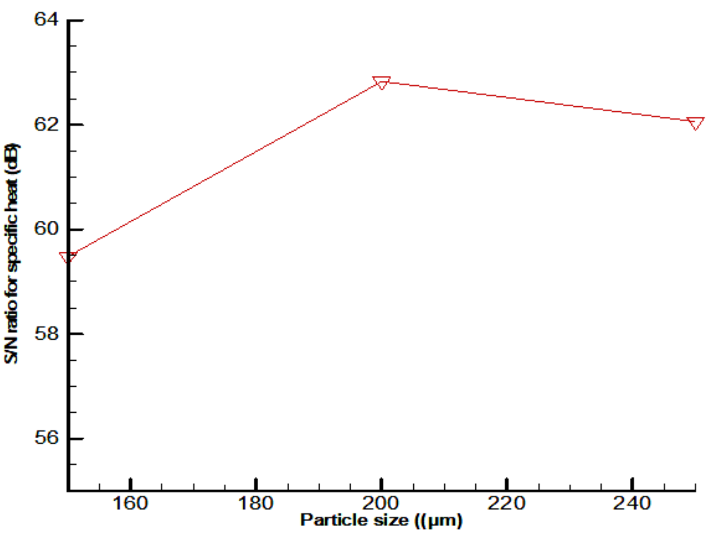

Figure 6. (a) Mean S/N ratio of Particle size for Specific Heat.

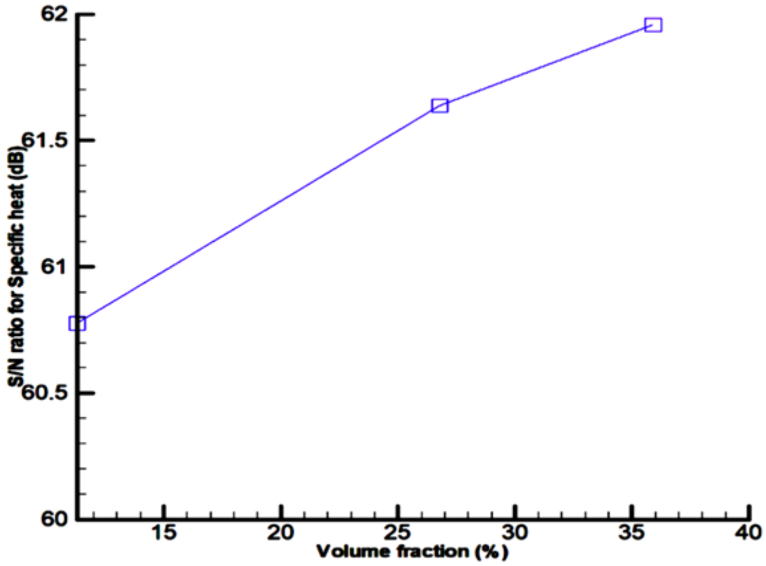

Figure 6. (b) Mean S/N ratio of volume fraction of TWD for Specific Heat.

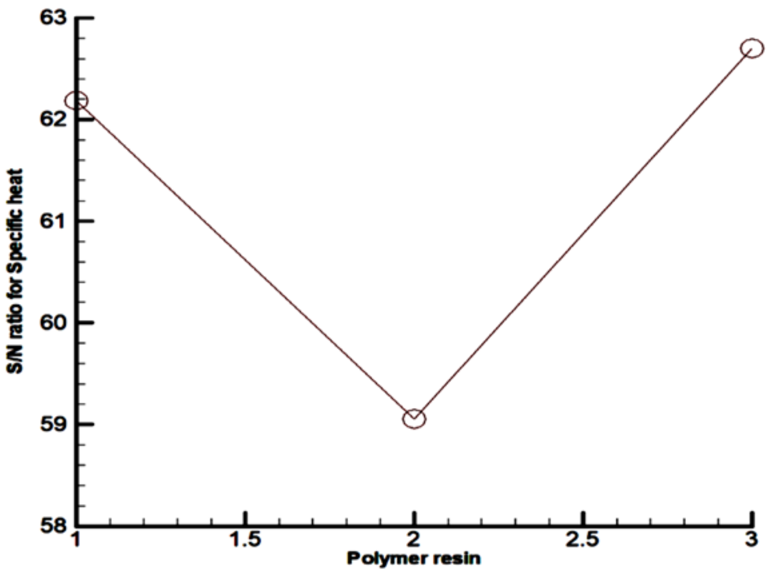

Figure 6. (c) Mean S/N ratio of Polymer resin for Specific heat.

Analysis of Variance (ANOVA)

ANOVA is employed for significance of factors & their relative contribution. It also determines the most significant factors affecting the optimum combination of process parameters on output quality & characteristics using the quantities. The equation 12 is used to calculate the total sum of squares.

$$SS_T = \sum_{i=1}^{N}[\eta_i - \eta_m]^2 \qquad (12)$$

Where, SS_T = Total sum of square, N = No. of experiments, η_i = Experimental result of i_{th} experiment, η_m = Overall mean of S/N ratio. In the present work the overall mean of S/N ratio for thermal conductivity, linear thermal expansion & specific heat capacity are 16.403, -10.19 & 61.45 respectively. Table 9, Table 10 & Table 11 present ANOVA data on thermal properties like thermal conductivity, linear thermal expansion & specific heat capacity. From Table 9, it is found that the TWD filler material has major contribution & influence (77.746%) & polymer resin has less contribution (9.295%) for minimizing the thermal conductivity of TWDPC. Whereas Particle size of TWD has almost no contribution for increasing the thermal conductivity of TWDPC. Table 10 shows that the particle size of TWD has major influence (52.732%) followed by polymer resin (25.927) for minimizing the linear thermal expansion of TWDPC. Whereas TWD filler material has the least contribution (10.232%) for minimizing the linear thermal expansion of TWDPC. It is found from the Table 11 that the polymer resin is the most dominating parameter (48.098%) & TWD particle size has the moderate effect (37.693) to maximize the specific heat capacity of TWDPC. On the other hand the volume fraction of TWD has very little contribution (4.522) to maximize the specific heat capacity of TWDPC.

Table 9. ANOVA results for Thermal conductivity

Source	Degree of freedom (DOF)	Sum of square	Variance	% contribution
Particle size (A)	2	0.701	0.3505	1.367
Volume fraction (B)	2	39.852	19.926	77.746
Polymer resin (C)	2	4.765	2.3825	9.295
Error	2	5.941	2.9705	11.592
Total	8	51.259	6.4074	100

Table 10. ANOVA results for Linear Thermal Expansion

Source	Degree of freedom (DOF)	Sum of square	Variance	% contribution
Particle size (A)	2	27.870	13.935	52.732
Volume fraction (B)	2	5.408	2.704	10.232
Polymer resin (C)	2	13.702	6.851	25.927
Error	2	5.872	2.936	11.109
Total	8	52.852	6.6065	100

Table 11. ANOVA results for Specific Heat Capacity

Source	Degree of freedom (DOF)	Sum of square	Variance	% contribution
Particle size (A)	2	18.453	9.2265	37.693
Volume fraction (B)	2	2.241	1.1205	4.522
Polymer resin (C)	2	23.547	11.7735	48.098
Error	2	4.715	2.3575	9.687
Total	8	48.956	6.1195	100

Confirmation Test

Confirmation test is generally applied to verify the estimated result with the experimental result to predict optimum performance at the selected level of significant parameters. There is no need of confirmation test if the optimal combination of the parameters & their levels coincident with one of the experiments in orthogonal array (OA). Hence this test is required when the optimum combination of the parameters & their levels does not constituent one of the rows of the orthogonal array (OA). The performance characteristics of TWDPC can be verified using optimal level of design parameters. The predicted optimum value of S/N ratio (η_{opt}) of the response is calculated using equation 13.

$$\eta_{opt} = \eta_m + \sum_{j=1}^{k_I}\left[\left(\eta_{ij}\right)\max - \eta_m\right] \tag{13}$$

Where, η_{opt} = Predicted optimum value of $\frac{S}{N}$ ratio, η_m = Overall mean of S/N ratio, $\eta_{ij\max}$ = The S/N ratio of optimum level i of factor j & k_I is the no. of main design parameter that affect the response. The closeness of observed value of S/N ratio (η_{obs}) with that of predicted optimum value (η_{opt}) can be seen by calculating the confidence interval (CI) value on η_{opt} for the optimum parameter level combination at 95% confidence level following the equation 14

$$CI = \sqrt{\frac{F_{(I,v_e)}V_e}{\eta_{eff}}} \tag{14}$$

Where CI = Confidence interval, $F_{(I,V_e)}$ is the F value for 95% confidence interval, V_e is the error of variance & $\eta_{eff} = \frac{N}{1+\nu}$. N is the total trial no. in orthogonal array (OA), ν is the degree of freedom of k_I factor. The optimum process parameter level for each thermal property is said to be valid if the prediction error is within confidence interval. In this work for each of the thermal properties, three experiments are conducted at optimal levels of process parameters & their results of conformity test are presented in Table 12.

From the table it is found that the prediction error of each of the thermal properties is within the confidence limit which indicates validation of three thermal properties. The optimal combination of process parameters for minimizing thermal conductivity & linear thermal expansion & also maximizing specific heat along with the corresponding optimal of thermal properties are shown in Table 13.

Table 12. Confirmation Test results

Performance measure	**Thermal conductivity**	**Linear thermal expansion**	**Specific heat**
Levels (A, B, C)	3,3,2	3,3,3	2,3,3
S/N predicted (η_{opt}), dB	18.909	-5.703	64.68
S/N observed (η_{obs}), dB	20.445	-6.190	64.87
Prediction error, dB	1.536	0.487	0.190
Confidence interval (CI), dB	±6.539	±6.501	±5.826

Table 13. Optimal values of thermal properties

Thermal properties	**Optimal process parameter settings**			**Optimal value**
	Particle size(μm)	***TWD particle (vf%)***	***Polymer resin***	
Thermal conductivity	250	35.9	Vinyl ester	0.095 W/m-K
Liner thermal expansion	250	35.9	Polyester	2.039×10^{-5} 1/^{0}C
Specific heat	200	35.9	Polyester	1751.862J/Kg-K

CONCLUSION

The TWD is an environmental-friendly waste product that can be utilized for preparation of composites using hand-lay-up technique. The difference between actual & theoretical density of the composites is due to the presence of voids & pores in preparing the composites. From ANOM result, it is found that the composite made from vinyl ester matrix with particle size of 250 μm &35.9% volume fraction & the specimen made from polyester matrix with particle size 250 μm & 35.9% volume fraction of TWD are beneficial for minimizing thermal conductivity & linear thermal expansion whereas the polymer resin with particle size 200 μm & 35.9% volume fraction is beneficial maximizing specific heat of TWDPC. ANOVA results pointed out that the TWD filler material has major contribution for minimizing thermal conductivity whereas particle size of TWD has major influence for minimizing linear thermal expansion. On the other hand polymer resin is the most dominating parameter to maximize the specific heat of the composite. The performance test indicates that the optimum thermal properties can be determined at 95% confidence interval. The composite specimen of particle size 250 μm, 35.9% volume fraction with vinyl ester resin has the higher thermal stability.

Abbreviations

TWDPC Teak Wood Dust Polymer Composite
TWD Teak Wood Dust
HFT Heat Flux Transducer
TMA Thermal Mechanical Analyzer
CTE Coefficient of Thermal Expansion
ANOM Analysis of Means

ANOVA Analysis of Variance
OA Orthogonal Array
DOF Degree of Freedom
CI Confidence Interval

REFERENCES

1. Nishino T.K, Hirao K., Kotera M, et al. Kenaf Reinforced Biodegradable Composite. Journal of Composites Science and Technology. 2003; 63: 1281–1286.
2. Ibrahim N.A., Hadithon K.A., Abdan K. et al. Effect of Fiber Treatment on Mechanical Properties of Kenaf Fiber Ecoflex Composites. Journal of Reinforced Plastics and Composites. 2010; 29: 2192–2198
3. Hinrichsen G., Khan M.A.,. Mohanty A.K., et al. Influence of Chemical Surface Modification onthe Properties of Biodegradable Jute Fabrics-Polyester Amide Composites. Journal of Composites: Part A. 2000; 31 (2): 143–150
4. Satapathy A., Jha A.K., Mantry S., et al. Processing and Characterization of Jute-Epoxy Composites Reinforced with SiC Derived from Rice Husk. Journal of Reinforced Plastics and Composites 2010; 29 (18): 2869–2878.
5. Mukherjee P.S., Satyanarayana K.G. Structure and Properties of Some Vegetable Fibres-Part 2 Pineapple Fibre. Journal of Materials Science 1986; 21: 51–56.
6. Raju G.U. Kumarappa S. Experimental Study on Mechanical Properties of Groundnut Shell Particle Reinforced Epoxy Composites. Journal of Reinforced Plastics and Composites. 2011; 30 (12): 1029–1037.
7. Mohapatra R.C., Mishra A., Choudhury B.B. Determination of Thermal Conductivity of Pine Wood Dust. Thermal Science. 2017 21: 199–210.
8. Mohapatra R.C. Experimental Study on Optimization of Thermal Properties of Natural Fibre Reinforcement Polymer Composites. Open Access Library Journal. 2018; 5 (4): 1–15.
9. Jena D., Mohapatra R.C., Das A.K. Optimization of Mechanical Characteristics of Rice Husk Particle Reinforced Polymer Composites Using Taguchi Experimental Technique, World Scientific News. 2019; 124 (2): 155–170.
10. Taguchi G., Konishi S. Taguchi Methods: Orthogonal Arrays and Linear Graphs; Tools for Quality Engineering. Dearborn, Michigan: American Supplier Institute Inc.; 1987.
11. Taguchi G. Introduction to Quality Engineering. Tokyo: Asian Productivity Organization; 1990.
12. Phadke M.S. Quality Engineering Using Robost Design. Upper Saddle River, NJ, United States: Prentice-Hall; 1989.
13. Y. Wu, W.H. Moore. Quality Engineering: Product & Process Design Optimization. Dearborn, Michigan: American Supplier Institute Inc.; 1986.
14. Phadke M.S., Dehnad K., Optimization of Product and Process Design for Quality and Cost. Quality and Reliability Engineering International. 1988; 4 (2): 105–112.
15. Shoemaker A.C., Kackar R.N. A Methodology for Planning Experiments in Robust Product and Process Design. Quality and Reliability Engineering International. 1988; 4: 95–103.

