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Communication

Optimum Drilling Parameters of Coir Fiber-Reinforced Polyester Composites

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Abstract: This paper presents optimum drilling parameters of coir fiber reinforced polyester composites following the Taguchi design of experiment. A simple multi-objective optimization approach is suggested and presented an efficient prediction methodology to estimate thrust force, torque and tool wear for the identified optimum process parameters.

Keywords: Coir Fiber-Reinforced Polyester Composites, Drilling Parameters, Taguchi Method, Thrust Force, Tool Wear, Torque

1. Introduction

Natural fiber composites are emerging as realistic alternatives to glass reinforced composites and metals in various engineering applications. Coir, an important lingo-cellulosic fiber from coconut trees has been tested as filler or reinforcement in different composite materials. Satyanarayana et al. [1] have examined structure properties (such as size, density, electrical resistivity, ultimate tensile strength, initial modulus, and percent elongation) of fibers from various parts of the coconut tree. Balan [2] has examined the behavior of geo-textiles with natural fibers. Khedari et al. [3] have examined the possibility of utilization of coconut and durian fibers to reduce the thermal conductivity of mortor to construct wall and other building components. Geethamma et al. [4] have studied dynamic mechanical behavior of short coir fiber reinforced with natural rubber composites. It is noted that composites with poor interfacial bonding tend to dissipate more energy than that with good interfacial bonding. Chaudhury et al. [5] have made investigations on the viability of the thermo-mechanical recycling of post-consumer milk pouches and their use as polymeric matrices for coir fiber reinforced composites. Extensive studies have been made to examine the mechanical and machinability behaviors of coir-fibre reinforced polymeric composite materials [6-14].

Jayabal and Natarajan [6] have considered rectangular composite sheet of 360 x 360 x 3 mm made up of randomly oriented coir fiber composite by the hand layup process. They have fabricated the composite using green husk coir fibre (19%wt) of length 50 mm (mixing of 1.5g cobalt octoate and 1.5g methyl ethyl ketone peroxide per 100g polyester resin). Following ASTM-D 638, ASTM-D 790 and ASTM-D 256 standards, specimens are tested and obtained tensile strength of 16.2 MPa, flexural strength of 29.3 MPa and impact strength of 46.2 J/m. They have performed drilling analysis of coir fiber-reinforced polyester composites adopting Taguchi's approach to arrive optimum parameters namely drill bit diameter, spindle speed and feed rate for obtaining minimum thrust force, torque and tool wear. Careful examination of their analysis indicates that the assignment levels of process parameters and the values specified in L_9 orthogonal array are found to be different. The optimum cutting parameters proposed by them are as per the assignment levels of process parameters. The process variables specified in the test runs are not as per the Taguchi's L_9 orthogonal array. The mathematical models for the responses (viz., thrust force, torque and tool wear) in terms of the process variables (viz., drill bit diameter, spindle speed and feed rate) are found to be erroneous. Hence, there is a need to reinvestigate this interesting problem and demonstrate the potentiality of the

Taguchi's design of experiments to trace the optimum process parameters for achieving the desired output response.

In this paper the experimental data of Jayabal and Natarajan [6] are re-arranged as per the orthogonal array of Taguchi approach. A simple and efficient prediction methodology is presented to estimate thrust force, torque and tool wear for the optimum process parameters. The optimum drilling parameters are traced for a randomly oriented coir fiber composite to achieve minimum thrust force, torque and tool wear, which are confirmed through comparison of test results [6].

2. Taguchi's Design of Experiments and Analysis of Variance

Most processes have many process parameters influencing the output response. Taguchi has devised a method for analyzing the results from less number of experiments by defining a set of orthogonal arrays [15-18]. Jayabal and Natarajan [6] have conducted a series of experiments using CNC milling machine to drill the coir–polyester composites. They have used a Kistler-make drill tool dynamometer and recorded the thrust force and torque, whereas a Rapid I machine vision system from Customized Technologies (P) Ltd. has been used to measure the tool wear. They have considered the chip type as another parameter which was produced according to the operating conditions and material properties. It is noted that continuous (C) and discontinuous (D) chip formation was produced for minimum cutting forces and tool wear in HSS tool due to low cutting speed and high feed rate. The chip formation during drilling for the specified conditions is shown in Figure 2 of Ref. [6]. In fact the data in Table 2 of Ref. [6] are not in-line with the assignment levels of process parameters in Table 1 of Ref. [6].

In the present study the assignment levels of process parameters (drill bit diameter, chip- formation, spindle speed and feed rate) are arranged in such a way that the data generated in Ref. [6] will fit the L_9 orthogonal array of Taguchi's approach. Table 1 gives the assignment levels of process parameters and the performance/output responses (viz., Thrust force, Torque and Tool wear) for the assigned process parameters and the chip type as per L_9 orthogonal array.

Table 1. *Performance output responses (viz., thrust force, torque and tool wear) for the assigned process parameters (viz., drill bit diameter, chip formation, spindle speed and feed rate) as per L_9 orthogonal array.*

Level	Drill bit diameter, d (mm)	Chip formation	Spindle speed, s (rpm)	Feed rate, f (mm/rev)
1	6	C	600	0.05
2	8	D	1200	0.35
3	10	CD	1800	0.2

Assignment of levels of process parameters

Test runs	Drill bit diameter (d)	Chip formation	Spindle speed (s)	Feed rate (f)	Thrust force (N)	Torque (N-m)	Tool wear (mm)
1	1	1	1	1	50	2.02	0.07
2	1	2	2	2	88	1.56	0.15
3	1	3	3	3	58	2.94	0.2
4	2	1	2	3	52	2.30	0.16
5	2	2	3	1	55	3.45	0.2
6	2	3	1	2	32	1.02	0.03
7	3	1	3	2	49	3.92	0.25
8	3	2	1	3	69	1.56	0.12
9	3	3	2	1	39	2.25	0.21

Performance output responses

Prior to selection of an orthogonal array, it is customary to estimate the minimum number of experiments from [15-18]:

$$\text{Ntaguchi} = 1 + \text{Number of factors} * (\text{Number of levels} - 1) = 1 + 4(3-1) = 9 \tag{1}$$

Experiments will be conducted as per the level combinations in the selected orthogonal array to record the output response. Mean values of the output response will be evaluated for the level settings. In order to study the sensitiveness of the change in the level of setting, the sum of the squares of deviation of each of the mean value from the grand mean will be evaluated. Percentage contribution is obtained by dividing the sum of the squares of the each process parameter with the total sum of squares. Let ψ_i $(i = 1 \; to \; N)$ be the output responses of N number of experiments. The total sum of squares (*TSOS*) or total variation is calculated from [15-18]

$$TSOS = \sum_{i=1}^{N} (\psi_i - \bar{\Psi})^2 \tag{2}$$

Here $\bar{\Psi} = (\sum_{i=1}^{N} \psi_i) / N$, is the average of the total data.

The sum of squares due to factor A (*SOSFA*) is

$$SOSFA = \sum_{i=1}^{k_A} N_{Ai} (\bar{\Psi}_{Ai} - \bar{\Psi})^2 \tag{3}$$

Here k_A is the number of levels of factor A; $\bar{\Psi}_{Ai}$ is the average of observations under A_i level; and N_{Ai} is the number of observations under A_i level. Percentage contribution of factor A to the total variation (*PCFA*) which may affect the average response is

$$PCFA = \frac{SOSFA}{TSOS} \times 100 \quad (4)$$

The percentage contribution of each factor to the total variation can be calculated in a similar manner from the sum of squares due to each factor.

The orthogonal array chosen was the L_9 (3^4). The plan of experiments in Table 1 is made of 9 tests (array rows) where the second column was assigned to drill bit diameter, the third to the chip formation, the fourth to the spindle speed and the fifth to feed rate. Following Ref.17 the analysis of variance (ANOVA) is performed and the results are presented in Table-2. The optimum cutting parameters in Table 3 are found for the minimum output responses (viz., thrust force, torque and tool wear).

3. Prediction Methodology

The process parameters for the optimum thrust force are found to be the drill bit diameter: 8mm, spindle speed: 600rpm, and feed rate of 0.05mm/rev with CD type of chip formation. For these process parameters, the thrust force value is not available in Table 1. A confirmation experiment has to be performed to verify the output response (i.e., thrust force). By means of additive law [16] the optimal output response for the desired process parameters can be estimated from

$$\eta_{opt} = \eta_m + \sum_{j=1}^{n} \{\eta_m(i,j) - \eta_m\} \quad (5)$$

Here η is the output response (i.e., thrust force, torque and tool wear) for the process parameters. η_{opt} = Optimum value for output response; η_m is the overall mean of η with 9 test runs; $\eta_m(i,j)$ is the mean of η at the optimal level (i) and the process parameter (j); and n is number of process parameters.

Table 2. *Analysis of variance (ANOVA) for thrust force, torque and tool wear.*

Factors	1-Mean	2-Mean	3-Mean	Sum of Squares	% contribution
Thrust force (N)					
Drill bit diameter	65.33	46.33	52.33	566.0	26.3
Chip formation	50.33	70.67	43	1233.1	57.4
Spindle speed	50.33	59.67	54	132.9	6.2
Feed rate	48	56.33	59.67	216.7	10.1
Torque (N-m)					
Drill bit diameter	2.17	2.26	2.58	0.2787	3.9
Chip formation	2.75	2.19	2.07	0.7905	11.0
Spindle speed	1.53	2.04	3.44	5.8683	81.5
Feed rate	2.57	2.17	2.27	0.2601	3.6
Tool wear (mm)					
Drill bit diameter	0.14	0.13	0.2	0.9-02	19.8
Chip formation	0.16	0.157	0.147	0.474-03	1.0
Spindle speed	0.07	0.17	0.22	0.351-01	77.2
Feed rate	0.16	0.14	0.16	0.9-03	2.0

Table 3. *Optimum cutting parameters for thrust force, torque and tool wear.*

	Drill bit Diameter (mm)	Chip formation	Spindle speed (rpm)	Feed rate (mm/rev)	Optimum values
Thrust force (N)	8	CD	600	0.05	23.65
Torque (Nm)	6	CD	600	0.35	0.92
Tool wear (mm)	8	CD	600	0.35	0.037

In order to examine the validity of the prediction methodology, levels of the process parameters corresponding to the lowest value of the thrust force in Table 1 is considered. For these values one can find from the ANOVA Table-2 that $\eta_m(2,1) = 46.33$ $\eta_m(3,2) = 43$, $\eta_m(1,3) = 50.33$, $\eta_m(2,4) = 56.33$ and $\eta_m = 54.67$. Equation (5) gives 31.98 which is found to be in good agreement with the test result of 32 in Table 1. Regarding the lowest value of torque in Table 1 one can find from the ANOVA Table 2 that $\eta_m(2,1) = 2.26$ $\eta_m(3,2) = 2.07$, $\eta_m(1,3) = 1.53$, $\eta_m(2,4) = 2.17$ and $\eta_m = 2.34$. Equation (5) gives 1.01 which is found to be in good agreement with the test result of 1.02 in Table 1. Regarding the lowest value of tool wear in Table-1 one can find from the ANOVA Table 2 that $\eta_m(2,1) = 0.13$ $\eta_m(3,2) = 0.147$, $\eta_m(1,3) = 0.07$, $\eta_m(2,4) = 0.14$ and $\eta_m = 0.15$. Equation (5) gives 0.037 which is found to be in good agreement with the test result of 0.03 in Table-1. In this way the test data of Table 1 is verified. Comparison of test results with the empirical relation of Jayabal and Natarajan [6] in Figures 1 to 3 indicates the erroneous representation of empirical relations.

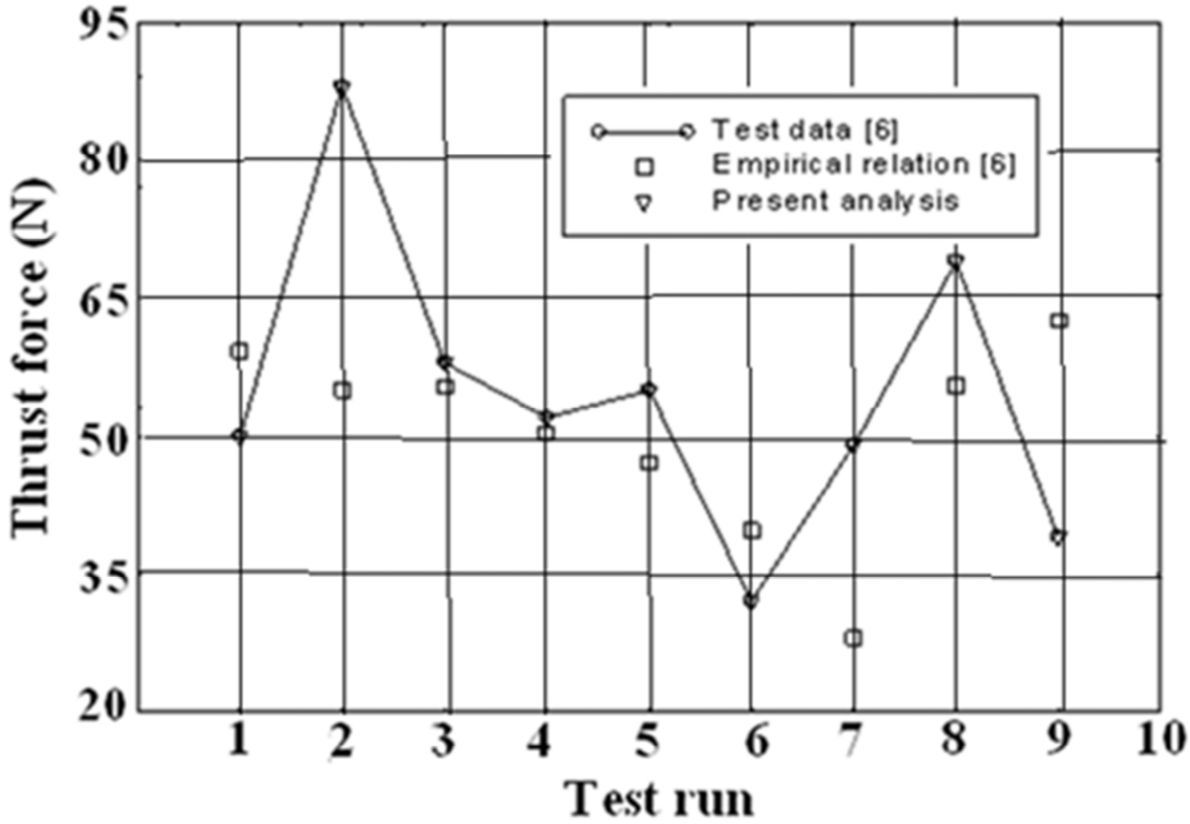

Figure 1. *Comparison of predictions with test data of thrust.*

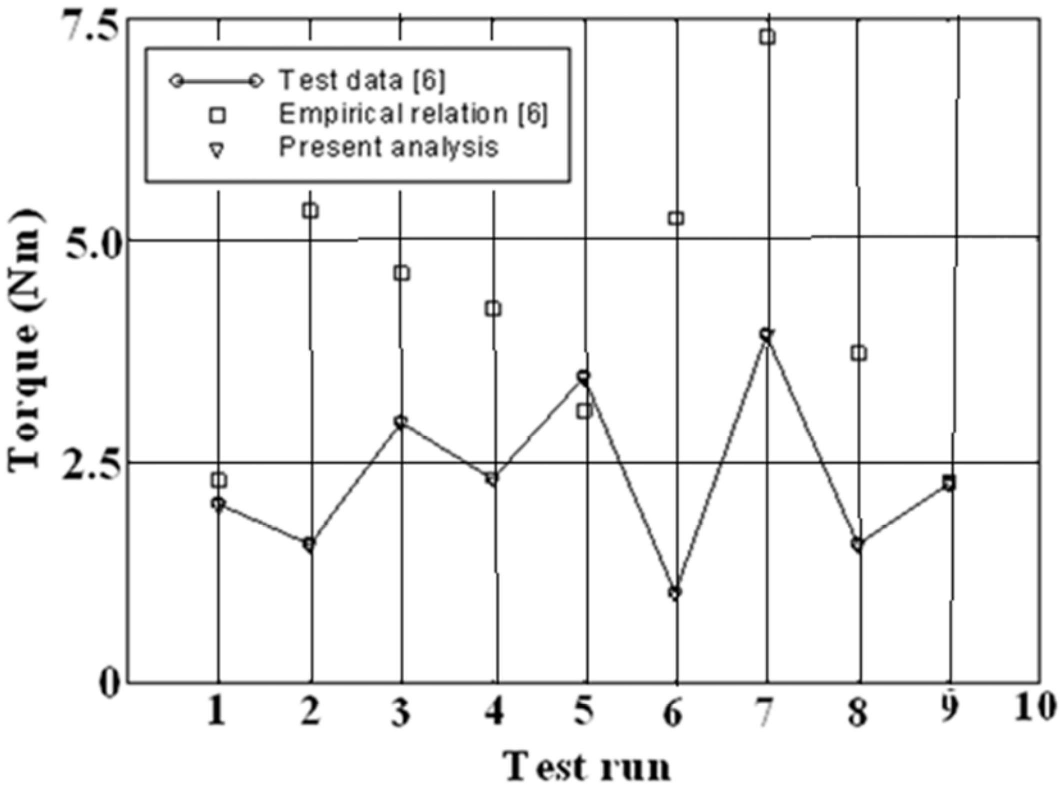

Figure 2. *Comparison of predictions with test data of torque.*

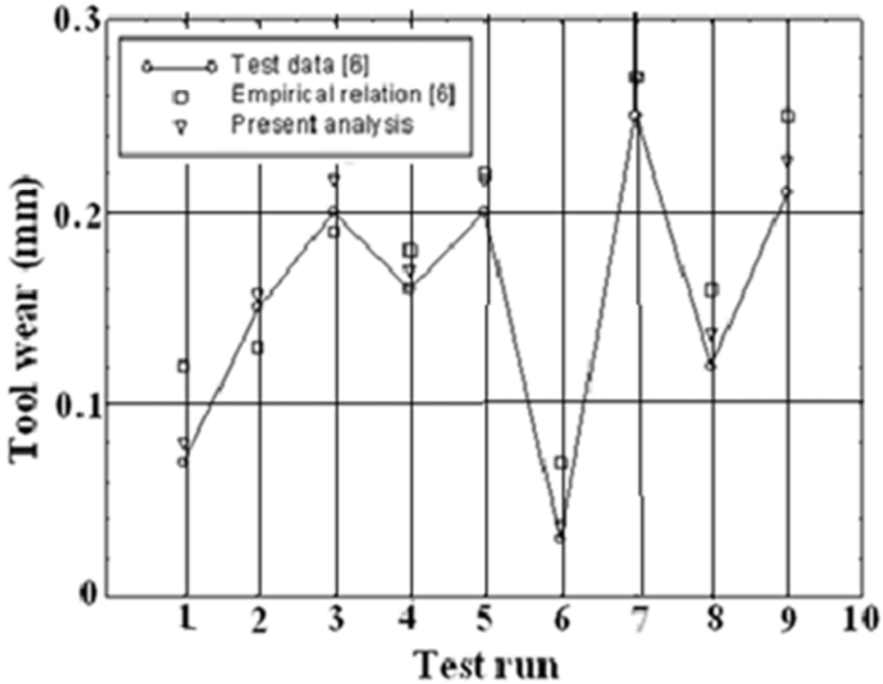

Figure 3. *Comparison of predictions with test data of tool- wear.*

From equation (4) the optimum values of thrust force, torque and tool wear for the process parameters in Table 3 obtained are 23.65N, 0.92Nm and 0.037mm respectively. The optimal process parameters to achieve minimum output responses are found to be different. To obtain the optimal process parameters to achieve the objective of minimum thrust force, torque and tool wear, a non-dimensional parameter ζ is introduced as

$$\varsigma = w_1 \frac{Th}{(Th)_{\max}} + w_2 \frac{Tq}{(Tq)_{\max}} + w_3 \frac{Tw}{(Tw)_{\max}} \quad (6)$$

Here w_1, w_2 and w_3 are weighing factors, whose sum is unity (i.e., $w_1 + w_2 + w_3 = 1$). $w_2 = 0$ and $w_3 = 0$ in equation (6) provides the optimum cutting conditions for the thrust force. To have common optimum cutting conditions, equal weights are given (i.e., $w_1 = w_2 = w_3 = 1/3$). The maximum values of Thrust $(Th)_{\max}$, torque $(Tq)_{\max}$ and tool wear $(Tw)_{\max}$ are estimated by means of the additive law (5) are: 91.33N, 4.32Nm and 0.29mm respectively. The ζ values for all the 9 test runs of Table 1 are generated and ANOVA is performed on ζ and obtained the optimum process parameters to achieve minimum ζ as 8mm drill bit diameter, 600rpm spindle speed and 0.35mm/rev feed rate and CD type of chip formation. The thrust force, torque and tool wear corresponding to the optimum process parameters estimated are 32N, 1.02 Nm and 0.03mm respectively, which are found to be in good agreement with test results [6].

4. Concluding Remarks

Following the concepts of Taguchi design of experiments, the optimum drilling parameters are arrived for a randomly oriented coir fiber composite to achieve minimum thrust force, torque and tool wear. Specimens are tested as per the ASTM-D 638, ASTM-D 790 and ASTM-D 256 standards and obtained tensile strength of 16.2 MPa, flexural strength of 29.3 MPa and impact strength of 46.2 J/m. A drill bit of diameter 8mm, spindle speed: 600rpm and feed rate of 0.35mm/rev with CD type of chip formation can be preferred for optimizing the thrust force, torque and tool wear while drilling of coir fiber reinforced polyester composites. Optimum values of the thrust force, torque and tool wear are 32N, 1.02 Nm and 0.03mm respectively, which are found to be in good agreement with test results [6]. The methodology adopted in the present study is quite simple and the Taguchi's approach works well by generating the data of the test runs as per the orthogonal array.

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