Research Article

Optimization of Blending Parameters and Fiber Size of Kenaf-Bast-Fiber-Reinforced the Thermoplastic Polyurethane Composites by Taguchi Method

Y. A. El-Shekeil,¹ S. M. Sapuan,^{1,2} M. D. Azaman,^{1,3} and M. Jawaid²

¹ Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia (UPM), 43400 Serdang, Selangor, Malaysia

² Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia (UPM), 43400 Serdang, Selangor, Malaysia

³ School of Manufacturing Engineering, Universiti Malaysia Perlis, 02600 Arau, Perlis, Malaysia

Correspondence should be addressed to S. M. Sapuan; drsapuan@yahoo.com

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“Kenaf-fibers- (KF-)” reinforced “thermoplastic polyurethane (TPU)” composites were prepared by the melt-blending method followed by compression molding. Composite specimens were cut from the sheets that were prepared by compression molding. The criteria of optimization were testing the specimens by tensile test and comparing the ultimate tensile strength. The aim of this study is to optimize processing parameters (e.g., processing temperature, time, and speed) and fiber size using the Taguchi approach. These four parameters were investigated in three levels each. The L9 orthogonal array was used based on the number of parameters and levels that has been selected. Furthermore, analysis of variance (ANOVA) was used to determine the significance of different parameters. The results showed that the optimum values were 180°C, 50 rpm, 13 min, and 125–300 micron for processing temperature, processing speed, processing time, and fiber size, respectively. Using ANOVA, processing temperature showed the highest significance value followed by fiber size. Processing time and speed did not show any significance on the optimization of TPU/KF.

1. Introduction

Natural-fiber-reinforced polymer composites are gaining great interest by researchers and industry due to advantages such as renewability, reduction in weight and cost, and less abrasiveness to equipment [1]. Compatibility between natural fibers and matrices always comes in the interface when talking about natural fiber composites. The hydrophobic nature of most polymers used in this sector against hydrophilicity of natural fibers causes fiber-matrix incompatibility (i.e., lack of adhesion and wettability between fiber and matrix). Kenaf plant is an annual plant that can be harvested 2-3 times a year. It can grow to reach 3-4 meters within 4-5 months. Kenaf plant has three layers: bast, core, and pith. Kenaf bast represents one-third of the plant. Core and pith represent the rest. Kenaf bast fiber has been reported to have superior mechanical properties than those the other

parts of the plant [2]. Polyurethane is hydrophilic, and thus the issue that always arises (incompatibility) will not be a problem when compounding it with natural fibers [3]. Previously several researchers reported about natural-fibers-reinforced polyurethane (PU) thermosets [3–9]. TPU has been compounded with synthetic fibers such as glass, aramid, and carbon fibers [10–12]. Natural-fibers-reinforced thermoplastic polyurethane (TPU) composites were studied by the authors [13–19]. It was found that kenaf fibers were compatible with TPU.

Development of new composites using an internal mixer requires proper settings for parameters such as temperature, time, and speed in order to get the best results. Temperature is critical in processing; if it is low, it will lead to nonhomogeneous distribution of fibers. In contrast, higher temperature might lead to thermal degradation of the fibers as well as the matrix. Optimizing mixing time is also essential,

TABLE 1: Properties of thermoplastic polyurethane (TPU).

Hardness	Tensile strength	Specific gravity	Melting temperature
55D	48 MPa	1.21	210°C

TABLE 2: The parameters for three levels of selected factors.

Factors	Level 1	Level 2	Level 3
Melting temperature, A (°C)	180	190	200
Speed, B (rpm)	30	40	50
Time, C (min)	11	13	15
Size, D (micron)	<125	125–300	300–425

TABLE 3: L9 orthogonal array.

Trail no.	Column no.			
	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

since in short mixing time homogeneous distribution might not take place. On the other hand, longer processing time causes thermal degradation of the matrix and breakage of polymer chains, due to shear stress and temperature. Moreover, processing speed might lead to breakage of the fibers if high speed is applied. Low speed is inadequate to mix the compounds well. Fiber size (i.e., aspect ratio) used in composite materials significantly affects the mechanical properties of the composite [20].

In the previous studies by the authors choosing the best parameters and fiber size was optimized in sequence, each one at a time (i.e., optimizing temperature, speed then time and finally fiber size), but there was no method that can give a combination of optimized parameters [13]. The authors found that kenaf-fibers-reinforced TPU is promising and decided to use a proper method to optimize processing parameters and fiber size. The aim of this study is to optimize processing parameters and fiber size of TPU/KF composites by using the Taguchi method to have a combination of optimized parameters. Furthermore the significance of parameters will be determined using ANOVA.

2. Materials

Polyester based thermoplastic polyurethane (TPU) was supplied by Bayer Co. (Malaysia) Sdn Bhd, Petaling Jaya, Selangor, Malaysia. The properties of TPU are summarized in Table 1. Kenaf bast fiber was obtained from KEFI (M) Sdn Bhd, Setiu, Terengganu, Malaysia.

TABLE 4: The combination parameters for the effective factors.

Trail no.	Temperature A (°C)	Speed B (rpm)	Time C (min)	Size D (micron)
1	180	30	11	<125
2	180	40	13	125–300
3	180	50	15	300–425
4	190	30	13	300–425
5	190	40	15	<125
6	190	50	11	125–300
7	200	30	15	125–300
8	200	40	11	300–425
9	200	50	13	<125

3. Methods

3.1. Preparation of Fiber. Bast fiber was extracted from core by a mechanical decortication method. Fibers were pulverized and then segregated into three different sizes (300–425, 125–300, and <125 μm) using an automatic shaker sieve; using mesh 40–50, 50–120, and 120.

3.2. Preparation of Composite. TPU/KF composite was mixed using a Haake Polydrive R600 internal mixer. The matrix was mixed in the mixer until stabilization of torque, and then fiber was added into the mixer. The fiber loading was fixed at 30% wt. After mixing the materials using the internal mixer, the compression molding process was used to form the sample sheets. The material was hot-pressed at 190°C for 10 min after preheating for 7 min at the same temperature. After that the sample was cool-pressed at 25°C for 5 min.

3.3. Tensile Testing. Tensile properties were measured using an Instron 3365 machine, according to ASTM D 638. The specimens were prepared by cutting them into dumbbell shapes using a hydraulic cutter machine. Five specimens were tested with a crosshead speed of 5 mm/min.

3.4. The Taguchi Approach. The Taguchi method is well known by simplification of experimental plan and feasibility of study of interaction between various parameters. In this method a less number of experiments are carried out; hence, time and cost are reduced considerably. Main effect analysis is performed based on the average output of the quality characteristic at each parameter level. Analysis of variance (ANOVA) is used after that to appoint the significance and contribution of each of the processing parameters towards the output characteristic. Using the main effect and ANOVA a prediction of the best combination of optimum parameters can be calculated.

3.5. Selecting of Processing Parameters and Fiber Size. Three different temperatures (180, 190, and 200°C) were examined.

TABLE 5: Summary of the experimental results.

Trail no.	Temperature A (°C)	Speed B (rpm)	Time C (min)	Size D (micron)	Tensile strength (MPa)	S/N
1	180	30	11	<125	18.185	25.152
2	180	40	13	125–300	23.720	27.481
3	180	50	15	300–425	24.058	27.580
4	190	30	13	300–425	17.982	25.074
5	190	40	15	<125	12.265	21.751
6	190	50	11	125–300	20.153	25.985
7	200	30	15	125–300	12.036	21.403
8	200	40	11	300–425	11.972	21.439
9	200	50	13	<125	12.888	21.896

There are some reasons behind choosing these temperatures. Temperatures less than 180°C are much less than the melting temperature of the matrix, which will result in nonhomogeneous mixing. Moreover, temperatures more than 200°C will be critical for natural fibers; thermal degradation might start affecting mechanical properties of the natural fibers [21]. Three different times (11, 13, and 15 min) were examined. Choosing these processing times was based on observation of the torque in the mixer. The torque gives a precise image of the condition of compounds inside the mixer. If the torque is not stabilized, this indicates that ingredients have not been sufficiently mixed, which will lead to poor dispersion. In contrast if the compounds are kept mixing for long time after stabilization of the torque, this may lead to thermal degradation and breakage of matrix chains. Fibers also break due to shear stress and temperature. Thus, the overall performance of the composite will be affected [20]. Finally, three speeds of mixing (30, 40, and 50 rpm) were chosen. It is thought that low speeds will not produce a homogenous mixture while high speeds may cause breakage of fibers. Finally, fiber size was also one of the parameters chosen due to its influence on the strength of the composite. Three fiber sizes (300–425, 125–300, and <125 μm) were chosen. Effect of blending parameters and fiber size was studied based on tensile strength as an essential test that indicates fiber-matrix interfacial bonding. Three levels are selected for each parameter as shown in Table 2. The L9 orthogonal array, based on the Taguchi method (Table 3) will be used based on the number of factors and levels that has been selected previously. Nine experiments have been done with combination of different parameters as shown in Table 4.

4. Results and Discussion

After mixing kenaf with TPU in the internal mixer, hot press machine was used to produce sheets of one millimeter thickness. Dog-bone-shaped tensile specimens were cut from the sheets using pneumatic cutter. Since tensile strength is the criterion that was chosen to study the optimum parameters, then in determination of S/N ratio, the larger the better quality characteristic has been selected.

TABLE 6: Average of S/N ratio.

Factor	Level 1	Level 2	Level 3
Temperature A (°C)	26.738	24.270	21.579
Speed B (rpm)	23.877	23.557	25.153
Time C (min)	24.192	24.817	23.578
Size D (micron)	22.933	24.956	24.698

For the bigger the better quality characteristic,

$$S/N = -10 \log (\text{MSD}),$$

$$\text{where } \text{MSD} (\text{QC} = B) = \frac{\sum_{i=1}^n (1/y_i)^2}{n}, \quad (1)$$

where “MSD” is the mean square deviation, “y” the observation or data, and “n” is the number of tests in a trail.

The results that were calculated for tensile strength and S/N are summarized in Table 5. From the data in Table 5 the average S/N ratio can be determined. The average effect factors are shown in Table 6. An example of the average factors calculations is shown as follows.

For temperature we have

$$\text{level 1} = ((25.15 + 27.48 + 27.58)/3) = 26.738,$$

$$\text{level 2} = ((25.07 + 21.75 + 25.98)/3) = 24.270,$$

$$\text{level 3} = ((21.4 + 21.43 + 21.98)/3) = 21.579.$$

Based on the data in Table 6, the S/N response diagram can be plotted as shown in Figure 1. The best combination of parameters can be observed in Figure 1. The highest value from each figure represents the best level. Thus, level 1 from processing temperature (180°C), level 3 from processing speed (50 rpm), level 2 from processing time (13 min), and level 2 from fiber size 125–300 micron are the best.

The data in Table 5 are analyzed using ANOVA. In order to determine the relative contribution of each parameter relative variances are compared. ANOVA will compute the following quantities which are summarized in Table 7:

- (i) degree of freedom (DOF),
- (ii) dums of square,

TABLE 7: ANOVA table.

Factor	DOF (f)	Sum of square	Variance	F-ratio	% contribution
Temperature A (°C)	2	39.9374	19.9687	—	74.24093
Speed B (rpm)	2	4.280777	2.140388	—	7.957674
Time C (min)	2	2.302038	1.151019	—	4.279333
Size D (micron)	2	7.274102	3.637051	—	13.52206
f error	0	—	—	—	100
Serror	—	$-1.8E - 12$	—	—	—

FIGURE 1: S/N response for processing parameters temperature (A), processing speed (B), processing time (C), and fiber size (D).

- (iii) variance,
- (iv) F-ratio,
- (v) percentage contribution.

From Table 7, it can be seen that the highest contribution from all the factors is the one from processing temperature which is 74.24%; the contribution of fiber size comes next which is 13.52%. Lastly the processing speed and time got low percentage, and thus these two factors can be considered insignificant.

By looking at the most significant factors affecting the production of TPU/KF it can be noted that temperature took the first place. This indicates the fact that the best interfacial bonding takes place when a proper temperature is selected, whereas high temperatures will negatively affect the matrix as well as the fibers. Kenaf fibers are better processed under 200°C to prevent thermal degradation. The matrix also when mixed under high temperatures will thermally degrade, as TPU used in this study is mainly produced for the extruding process which will take shorter time under the processing temperature. Thus, if the temperature is high, the matrix will be affected. After temperature, fiber size takes place in the significance of parameters affecting the process of producing TPU/KF. This is attributed to the importance of fiber size and aspect ratio (length/diameter) of short natural fibers in the field of natural fiber composites. Aspect ratio of the fibers used in this study is presented in a previous research by El-Shekeil et al. [14]. A small fiber size with low aspect ratio possessed larger surface area and left more surfaces nonreactive to the matrix; therefore, more stress points are created, resulting in reduced tensile strength [7]. Long fibers with high aspect ratio will cause poorer dispersion and agglomeration.

5. Conclusions

By using the Taguchi method nine trails were run. The optimum parameters that can result in the highest tensile strength are processing temperature (180°C), processing speed (50 rpm), processing time (13 min), and fiber size 125–300 micron. Among these factors ANOVA analysis calculations showed that processing temperature was the most significant parameter affecting the production of TPU/KF composites. The fiber size was the second parameter. Processing speed and time were not significant in producing the composite.

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