The effect of twin screw compounding parameters on the tensile properties of pineapple leaf/sea shell hybrid polymer composite using DOE approach

Ng Tian Ching¹, Khairul Anwar Abdul Halim¹,*, Mohd Firdaus Omar¹,², Azlin Fazlina Osman¹,² and Muhammad Salihin Zakaria¹,²

¹ School of Materials Engineering, Universiti Malaysia Perlis (UniMAP), Kompleks Taman Muhibbah, Jejawi 2, Perlis, Malaysia
² Centre of Excellence Geopolymer and Green Technology (CEGeoGTech), Universiti Malaysia Perlis (UniMAP), Kompleks Taman Muhibbah, Jejawi 2, Perlis, Malaysia

Abstract. Pineapple leaf and sea shell were used as natural fillers in this research due to its biodegradable nature, wide availability, continuous resources and low cost. This research work was carried out to investigate the effect of compounding process using twin screw extruder on the tensile performance of pineapple leaf/sea shell polymer composite using Design of Experiment (DOE) approach. A total of nine runs of were formulated and the resulting hybrid composites were compounded using twin screw extruder. The short term tensile test was carried out to determine the tensile properties and the data were subsequently analyse using DOE software. Pareto chart of the standardized effect and the main effect plot were employed to investigate the relationship between processing parameters and the tensile performance of the hybrid composite systems. Based on the initial DOE analysis, it is shown that compounding parameters had influenced the final mechanical behavior of the hybrid composites.

1 Introduction

Composite material comprises of two or more different materials that combined or mixed to form new material that is superior compare to its constituents. For instance, the addition of filler into polymer matrix is to improve the mechanical properties and increase the strength of the resulting composite materials [1]. In recent years, the use of natural fillers as reinforcement have gain attention due to low cost, lightweight, wide availability and biodegradable [2]. Natural fillers are referred to the filler which obtained from natural resources such as plant and animals. In this study, pineapple leaf and sea shell are used as the natural fillers to form polymer composite materials. Natural fibers such as pineapple leaf are

* Corresponding author: kanwar@email.unimap.edu.my
mainly constituted of lignin, cellulose and hemicelluloses whereas sea shell is contains of calcium carbonate, CaCO3 or chitin.

Natural fibers are having lower hydrophilic natural fiber which gives the fibers high durability and resistance to water. The utilisation of natural fiber based composite, it is able to provide significance functional and economic growth and benefits due to its properties of high strength, durability features [3]. Natural fiber based composites are be chosen due to its properties of environmentally-friendly and abundant of supply, it is easy to process and cheap, and its biodegradable nature [1]. In this research, polypropylene, PP is used and it acts as matrix in the experiment whereas pineapple leaf fiber and sea shell are acts as the natural fillers to hybrid polymer composite materials.

Design of experiment (DOE) is a statistical method that uses optimization techniques to produce processing parameters. DOE is a statistical method that use as a control and also to optimize the parameter processing [4-5]. The main purpose of DOE in this research is to investigate the effect of twin screw compounding parameters on the tensile properties of pineapple leaf/seashell hybrid composites. The main parameters involve were such as filler loadings, barrel temperature and screw speed.

2 Materials and Method

Pineapple leaf and sea shell were utilised as natural fillers in this study. Pineapple leaf was collected from Bukit Tambun, Simpang Ampat, Pulau Pinang, Malaysia while sea shell was collected from the seaside of Persiaran Gurney, Pulau Pinang, Malaysia. Natural fillers was then compounded with polypropylene (PP) PROPELINAS G452 which was produced by Polypropylene Malaysia Sdn. Bhd.

2.1 Sample Preparation

The pineapple leaf and sea shell was washed and cleaned by tap water to remove the dirt particles that found on the surface. The pineapple leaf and sea shell was dried under sunlight for about 3 days. After the pineapple leaf and sea shell was fully dried, it was then undergone alkaline treatment process by immersed pineapple leaf and sea shell into sodium hydroxide, NaOH solution for 24 hours for the purpose of softening and cleaning to remove the impurities that found on the raw materials. After immersion, pineapple leaf and sea shell were removed from sodium hydroxide, NaOH solution and put inside oven at 75 °C to remove moisture and water content of the pineapple leaf and sea shell. Pineapple leaf and sea shell were put inside oven for few days until it was completely dried and pineapple leaf become dry leaf and crispy. Next, when the pineapple leaf and sea shell were completely dried, pineapple leaf was blend by using blender whereas sea shell was grind by using grinding machine. After obtaining powder of two natural fillers, the powders were sieved by using 63 μm siever. After the two natural fillers powders were completely sieved by 63 μm siever, hybrid natural fillers were proceed to the next step which is compounding process. The compounding process was conducted by using twin screw extruder machine. Twin screw extruder was operated by according to the processing parameter based on DOE. After obtaining hybrid filler polymer composites pellets through compounding process, the next step was hot press. The hot press machine was set according to the desired temperature, pressure, time required and other related parameters.
2.2 Design of Experiment (DOE)

DOE was conducted for the compounding process using twin screw extruder where the factors of interest namely screw speed, barrel temperature and filler loading were selected and set out using the Minitab software as listed in Table 2.1.

Table 2.1: The DOE compounding parameters.

| PARAMETER                              | LOW | MIDDLE | HIGH |
|----------------------------------------|-----|--------|------|
| Sea shell and pineapple leaf fiber loading (wt%) | 5   | 15     | 25   |
| Speed (rpm)                            | 50  | 80     | 120  |
| Max barrel temperature (°C)            | 180 | 185    | 190  |

A total of nine runs (including a middle run) with different hybrid filler loadings, speed of screw and maximum barrel temperature were formulated as listed in Table 2.2.

Table 2.2 Parameters and formulations of DOE (full fraction factorial design).

| Run | Sea Shell and Pineapple Leaf Fiber loading (wt%) | Screw Speed (rpm) | Max Temperature (°C) | Code            |
|-----|--------------------------------------------------|-------------------|-----------------------|-----------------|
| 1.  | 5                                                | 50                | 180                   | 5% 50S 180T     |
| 2.  | 5                                                | 50                | 190                   | 5% 50S 190T     |
| 3.  | 5                                                | 120               | 180                   | 5% 120S 180T    |
| 4.  | 5                                                | 120               | 190                   | 5% 120S 190T    |
| 5.  | 25                                               | 50                | 180                   | 25% 50S 180T    |
| 6.  | 25                                               | 50                | 190                   | 25% 50S 190T    |
| 7.  | 25                                               | 120               | 180                   | 25% 120S 180T   |
| 8.  | 25                                               | 120               | 190                   | 25% 120S 190T   |
| 9.  | 15                                               | 85                | 185                   | 15% 85S 185T    |

2.3 Tensile Test

The tensile test was carried out to analyze the tensile strength, break elongation and young modulus of the polymer composite samples. Tensile test was conducted by using Universal Tensile Machine (UTM), Instron Model 5569, with 50 kN load cell, with a loading speed of 10 mm/min, the average ambient temperature during the test is 25 ± 2 °C and referring to ASTM 638.

3 Results and Discussion

Based on the tensile data tabulated in Table 3.1, it can be clearly seen that for sample 15% 85S 185T has the highest tensile strength compared to the other runs which was
39.37 MPa. This also indicates that the optimum screw speed was 85 rpm where at this speed, it is believed that the hybrid fillers are well dispersed in the matrix phase. Further, it can be seen that at higher screw speed i.e 120 rpm, the tensile strength were slightly decrease compared to lower screw speed of 85 rpm. This due to the hybrid fillers could not dispersed homogenously where agglomeration of fillers can be present.

Table 3.1: Tensile strength versus filler loading of PP/pineapple leaf and sea shell hybrid composites under various processing parameters.

| No of Runs. | Samples       | Tensile Strength (MPa) | Break Elongation (%) | Modulus of Elasticity (MPa) |
|-------------|---------------|------------------------|----------------------|-----------------------------|
| 1.          | 5% 50S 180 T  | 25.201                 | 5.3                  | 847.2                       |
| 2.          | 5% 50S 190 T  | 34.202                 | 9.7                  | 860.2                       |
| 3.          | 5% 120S 180 T | 32.805                 | 7.7                  | 968.6                       |
| 4.          | 5% 120S 190 T | 31.463                 | 7.4                  | 1075.3                      |
| 5.          | 15% 85S 185 T | 39.365                 | 8.7                  | 1128.7                      |
| 6.          | 25% 50S 180 T | 28.383                 | 5.5                  | 835.7                       |
| 7.          | 25% 50S 190 T | 21.364                 | 7.5                  | 710.7                       |
| 8.          | 25% 120S 180 T| 30.758                 | 7.9                  | 930.6                       |
| 9.          | 25% 120S 190 T| 28.555                 | 8.2                  | 1050.2                      |
| *           | Virgin PP     | 30.982                 | 18.2                 | 731.5                       |

Nevertheless, the lowest tensile strength recorded was for run 25% 50S 190T. The tensile strength obtained was 21.36 MPa which is 7.9% lower than other runs. It can be observed that the tensile strength for samples with lower screw are decreased compared to virgin PP except for run 5% 50S 190T. The lower tensile strength observed is primarily due to the hybrid fillers could not effectively dispersed within the polymer matrix. The lower shear force at lower screw speed could not disperse the hybrid fillers effectively. Moreover, it is believe that this could lead to poor interfacial bonding between hybrid fillers and matrix. It can also be stipulaed that the fibres pullout from the surface and a gap existed between fibres and matrix as a result of poor wetting of fibre which can lead to decrease in tensile strength of the composite [6,7]. Furthermore, the presence of moisture due to poor drying of fillers and voids presence with the composite matrix can also lead to poor composite performance [8, 9]. Other researcher also reported that the polymer composites failed at the interface was due to weak interfacial bonding [10].

The tensile data was then analysed using statistical software for further analysis. The response recorded were tensile modulus, tensile strength and elongation of break where the factors investigated were filler loadings, screw speed and maximum barrel temperature. With the aid of DOE software tools, Pareto charts of effects and main effect plot were constructed. Pareto chart of effects plotted was to determine the magnitude and the importance of the effects. On the Pareto chart, bars that cross the reference line are statistically significant. Main effect plot was used to examine the differences between level means for one or more factors.
Figure 3.1: Pareto chart of effects for (a) tensile modulus (b) tensile strength (c) elongation at break of the hybrid polymer composites.
Figure 3.1 illustrates the samples from Pareto chart of the standardized effects for tensile modulus, tensile strength and elongation at break. On the Pareto chart, the reference line is drawn on the chart and the effects that passed over the reference line is considered as significant. Pareto chart is to analysed the result based on the factors (A, B, C). Based on the Pareto chart, it can be seen the significant of factors that includes two-way interaction and three-way interaction are located over the red line which means the factors or combination of factors are significant. For instance, as illustrated in Figure 3.1 (b), tensile strength is less affected by the barrel temperature if compared to filler loadings and screw speed. Nevertheless, combination of factors (ABC) exhibited as the highest and had significant effect on the tensile strength of polypropylene reinforced with pineapple leaf/seashell hybrid polymer composite materials. Then, followed by the two-way interaction of factors AC, AB and BC and also single factor of A and B. This indicates that the significance of factor A and B had on effect of tensile strength.

Figure 3.2 shows the main effect plot for tensile strength of hybrid polymer composites materials. Main effect plot was can effectively measure what a given variable, independent of the other process variables, has on the overall response being measured. In the main effect plot, the response mean for each of the factors level are connected by a line. The line used is for easier to study the plot diagram, make it to be more obvious and to show the comparison of the tensile strength based on each of the factors. For instance, as illustrated in Figure 3.2, it can be seen that screw speed has the larger main effect than filler loading and barrel temperature for all responses measured. The higher the screw speed, the higher the mean effect for tensile modulus, tensile strength and elongation at break:

The following are the example interpretation of main effect plot for tensile strength as illustrated in Figure 3.2 (b):

(a) Filler loading Increasing the hybrid filler loading resulted in decrease in tensile strength.

(b) Screw Speed Increasing the screw speed resulted in an increase in tensile strength.

(c) Barrel temperature Runs at higher barrel temperature had slight decrease in tensile strength.
Figure 3.2: Main effect plot for (a) tensile modulus (b) tensile strength (c) elongation at break of the hybrid polymer composites.
4 Conclusion

In this study, the effect of twin screw compounding parameters on the tensile properties of hybrid pineapple leaf/sea shell composites was investigated using DOE approach. It can be observed the optimum formulation achieved was for sample from run 15% 85S 185T where the highest tensile strength was recorded. Further, the pareto chart of effect showed the significance of factors where it was found that there were two-way and three-way interactions may exist. The main effect plots shows that by changing or increasing the screw speed and maximum barrel temperature had resulted in an increase in the responses recorded. It can observed that all factors have had influence on the tensile properties of the hybrid composites.

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