Optimization on Impact Strength of Woven Kenaf Reinforced Polyester Composites using Taguchi Method

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Abstract. This paper focuses on the effect of weaving patterns and orientations on the energy absorption of woven kenaf reinforced polyester composites. Kenaf fiber in the form of yarn is weaved to produce different weaving patterns such as plain, twill and basket. Three woven mats are stacked together and mixed with polyester resin before it is compressed to squeeze out any excessive resin. There is nine different orientations are used during stacking processes by following Taguchi orthogonal arrays method. The hardened composites are cured for 24 hours before it is shaped according to specific dimensions for impact tests. The composites are perforated with 1m/s blunted projectile. According to the experimental findings, weaving pattern and orientation have distinct potential effects on value of energy absorption. The optimization using Taguchi method reveals preferable orientation of each weaving pattern composites. Based on the fracture observation, the fragmentations after optimization indicating lower distance surface fracture perforated obtained.

1. Introduction

During the recent years, the attentions are given to crashworthiness and energy absorption management on composite structures under oblique impact loading [1,2]. Nowadays, the kenaf natural fibers have the potential to be used as a replacement for glass or other traditional reinforcement materials in composites. There have been many researchers involved in this field of kenaf reinforced plastics under perforated impact [3,4,5]. Most of these findings focus on unidirectional, short fiber and little research on woven especially in kenaf natural fiber. The ability of woven fabric is better mechanical properties compare to non-woven [3,4]. However, there are several issues such as their poor fire resistance, variable quality, depending on unpredictable influences such as weather and lower strength properties. In the light and due to the versatility and enormous potential, it is currently being explored by researchers by some aspect such as woven and orientation performance [6,7,8].

In the recent years, researchers have investigated a variety of approach in applied Taguchi orthogonal array on composite [9,10]. In this research, glass fibers and epoxy at several compositions are applied to determine which led to minimization of erosion rate of the composite. From previous research, normally Taguchi method are apply in determining parameters such as percentages material composition, temperature, pressure load and curing time. By evaluating the performance of the product in several environmental conditions, there would be a realistic data to calculate the real word variance. The classical experimental design method are too complex, time consuming and not easy to use. A large number of experiments have to be carried out when the number of process parameters are
more. To solve this problem, Taguchi method uses to study the entire parameter space with the minimum number of experiments [11].

Several of previous studies using natural fiber as the main ingredient in assessing the strength of composite, but not really focus on angle orientations. In this paper, Taguchi orthogonal array is applied to facilitate the arrangement of orientation and indirectly optimize the orientation that proposed higher energy absorption. On the other hand, optimization using Taguchi methods are more suitable tools. This systematic experiment has led to determination of significant process parameters and orientations variables that predominantly influence the energy absorption respectively.

2. Methodology

As-received kenaf yarn with a size of 1mm as shown in Figure 1(a) is used and weaved to form a woven mat as reveal in Figure 1(b). During weaving processes, three different fiber architectures are used such as plain, twill and basket. Woven mats are then stacked (four layers) together using different fiber orientations followed by Taguchi method L934 as listed in Table 1. The L934 orthogonal array was used based on the number of parameters and levels that has been selected. These parameters are four layered were investigated and three angles each composite. Taguchi method are uses a special design of orthogonal arrays to study the entire parameter space of orientation with the minimum number of experiments.

Then, the stacks are mixed with polyester resin before it is compressed to spread the resin uniformly across the fiber mats. Once the composites hardened and cured for 24 hours (Figure 1(c)), they are shaped into shape and geometry as specified in ASTM D 3763 standard of 100x100x3 mm.

Impact test is performed using Hydroshot HITS-T10 Shimadzu machine. The samples are positioned and clamped in all-degree of freedom. Before the tests, ASTM D 3763 is properly followed to ensure the results are reliable. The blunted-shaped projectile is used to perforate the samples where the speed of projectile is fixed to 1m/s and the mass of projectile is 5kg. During tests, the responses of force-displacement diagrams are recorded. The energy absorptions are determined using the area under the curves of force versus displacement.

![Figure 1: Preparation of composite (a) kenaf yarn (b) weaving process and (c) woven mats](image-url)
3. Result and Discussion

In Taguchi Method, optimizations refer to determination of the best level for control factors. In other words, the best levels of control factors are maximize the S/N (Signal to Noise) ratios value. However the experiments that conducted to determine the best levels are based on Orthogonal Array (OA) that concentrated on all factors in minimum number also minimize the cost of material besides the time in complete the experimental. In this experimental, the variables of angle were chosen as input factor. The result of response measures are converted into S/N ratio using Minitab software. The bigger value of response denoted better, such as residual energy absorption, is called ‘bigger is better’. It seems that a larger response is better and the S/N ratio will be defined as follows:

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

Where $n$ is the trial repetition and $y_i$ is the result of the $i$th experiment for each trial.

Figure 2 shows the main effects plot (data means) for S/N ratios of composites (a) Plain (b) Twill (c) Basket. Regarding to this graph pattern on Figure 2, the optimized factor of energy absorption can be express by selecting the highest level of S/N ratios value for each factor of orientation. The result for angle arrangement from Figure 2 is represented the best orientation for plain woven is $[+40/-15/+40/-15]$, twill woven is $[+40/+75/+40/+75]$ and basket woven is $[-15/+40/+75/+75]$.

Figures 3 shows value of energy absorption after optimization with different type of woven and orientation. From the result of plain woven in Figure 3(a), the value after optimization is 27.910 Joule. The percentage error compare with actual result is 9.307%. For Twill woven, value of energy absorption after optimization is 31.946 Joule and the error is 9.038%. Meanwhile for basket woven the value of energy absorption after optimization is 29.893 and the error is 8.048%. Furthermore, the value produces still under acceptable range even though it is below the value of actual result due to material yarn size under control and sensitivity to dynamic loading. Hence the result is still can be used for the research purposed although the energy absorption is lower than after optimization.

From the results that have been obtained, shows the best arrangement of angle is suggested by using Minitab software for each type of woven which is plain is $[+40/-15/+40/-15]$, twill is $[+40/+75/+40/+75]$ and basket is $[-15/+40/+75/+75]$. The analysis of data shows the influence of various process variable angles on value of energy absorption. It has been noticed that residual angles give the energy absorption enhanced. Due to the result, it demonstrated that a fiber orientation for each layers is significantly affected to value of energy absorption.

Table 1: The orientation arrangement of samples.

| Trial (Sample) | A   | B   | C   | D   |
|---------------|-----|-----|-----|-----|
| 1             | -15 | -15 | -15 | -15 |
| 2             | -15 | 40  | 40  | 40  |
| 3             | -15 | 75  | 75  | 75  |
| 4             | 40  | -15 | 40  | 75  |
| 5             | 40  | 40  | 75  | -15 |
| 6             | 40  | 75  | -15 | 40  |
| 7             | 75  | -15 | 75  | 40  |
| 8             | 75  | 40  | -15 | 75  |
| 9             | 75  | 75  | 40  | -15 |
Main Effects Plot (data means) for SN ratios

(a)

Main Effects Plot (data means) for SN ratios

(b)
Figure 2: Main effect plot (data mean) for S/N ratios (a) Plain (b) Twill (c) Basket
Figure 3: Energy absorption after optimization (a) Plain (b) Twill (c) Basket
In general, the fracture mechanisms are almost similar where the fragmentation surface after impact effect. Figure 4 shows fragmentations of three type of woven such as plain, twill and basket. Overall observation, it can see that fragmentation after optimization is smaller than before. For the plain woven it can be seen that fragmentation on the back is around distance 3.0 cm. Besides that, for twill woven the fragmentation is 2.5 cm and for basket is 6 cm. After optimization the fragmentation for plain is 2.0 cm, twill is 2.1 cm and for basket 2.0 cm. Overview from the fragmentation after optimization, it shows that, not only increase energy absorption, but also decrease the length of fragmentation. This study has found that the highest energy absorption and less perforated distance on twill woven. It can be explained that when fabric is stretched in one direction which is load direction, it amplifies in the reverse direction. Owing to the crimp, the fabric strength is less than the strength of twisted yarns, because of the twisted yarns; the yarn strength is less than the strength of fibres.

| Type woven | Before optimization | After optimization |
|------------|---------------------|--------------------|
| Plain      | ![Fragmentation Plain Before Optimization](image) | ![Fragmentation Plain After Optimization](image) |
| Twill      | ![Fragmentation Twill Before Optimization](image) | ![Fragmentation Twill After Optimization](image) |
| Basket     | ![Fragmentation Basket Before Optimization](image) | ![Fragmentation Basket After Optimization](image) |

Figure 4: Fragmentation of composite before and after optimization
4. Conclusion
Experimental study was carried out on behaviour of composite with different type of woven and orientations are investigated. This result presents the best performance on mechanical strength and energy absorption using Taguchi method. Based on the results, the following conclusions are drawn:

i. The result is represented that the best orientation for plain woven is [±40/-15/+40/-15], twill woven is [±40/+75/+40/+75] and basket woven is [-15/+40/+75/+75].

ii. The value of energy absorption after optimization still accepted and can be used because percentage of error is below than 10%, due to material yarn size under control and sensitivity to dynamic loading.

iii. The fragmentation after optimization of three type of woven plain, twill and basket shows the smaller perforated compare to before optimization.

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