The effect of fibre content, fibre size and alkali treatment to Charpy impact resistance of Oil Palm fibre reinforced composite material

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Abstract. In this research, the effect of fibre content, fibre size and alkali treatment to the impact resistance of the composite material have been investigated. The composite material employs oil palm fibre as the reinforcement material whereas the matrix used for the composite materials are polypropylene. The Oil Palm fibres are prepared for two conditions: alkali treated fibres and untreated fibres. The fibre sizes are varied in three sizes: 5mm, 7mm and 10mm. During the composite material preparation, the fibre contents also have been varied into 3 different percentages: 5%, 7% and 10%. The statistical approach is used to optimise the variation of specimen determined by using Taguchi method. The results were analyzed also by the Taguchi method and shows that the Oil Palm fibre content is significantly affect the impact resistance of the polymer matrix composite. However, the fibre size is moderately affecting the impact resistance, whereas the fibre treatment is insignificant to the impact resistance of the oil palm fibre reinforced polymer matrix composite.

1. Introduction

In recent years, the development of research related to composite material are the utilisation of natural resources waste as bio composite. Bio composite is a composite material comprising one or more phase(s) derived from a biological origin, including plant fibre such as cotton, flax, hemp, and the like, or fibres from recycle wood or waste paper i.e. natural fibres [1]. Natural fibers are exploited as replacement of conventional fiber such as glass, aramid and carbon, caused by low cost and their properties. The properties of natural fibers are: fairly good mechanical properties, high specific strength, non abrasive, eco-friendly and biodegradability characteristics [2]. Hasamudin and Soom explored Biofibre reinforcement in composite material [3]. Lopez et al. explored the effect of UV radiation to wood plastic composite. The result shows that the UV exposure provides the same effect to MOR (Modulus of Rupture) and MOE (Modulus of Elasticity) of the samples [4]. Karina et al. explored the physical and mechanical properties of natural fibres filled polypropylene composites and Its recycle [5]. Shinoj et Al. make a review about Oil Palm fiber and its composites, i.e.: oil palm fibre-natural rubber composites, oil palm fibre-polypropylene composites, and oil palm fibre-polyurethane composites. They found that oil palm fibre have been investigated by many researchers, but the information on properties of thermal, electric resistance, rheology, characteristic of high voltage breakdown, characteristic of weathering and degradation, thermal environment deflection and resistance to various chemicals are still limited [6]. Azwa et al. make a review about the degradability...
of polymeric composites based on natural fibres [7]. Zaleha et al. Make a review about mechanical and physical properties of natural fibres [8].

One of the natural resources wastes which are produced in big quantity in Indonesia and Malaysia are oil palm fibres. Malaysia and Indonesia are known as the two countries that produced edible oil from oil palm plantations in big quantity. However, the quantity of oil palm fibre waste is much larger than the oil itself. It was reported that 100 million tons of biomass were produced together with 11.9 million tons of oil from the total 6 million hectares of plantation [9]. It was also reported that for every 1 ton of oil produced, the oil palm industry also produced 1.1 tons of oil palm fibres [10]. When these fibres were not utilised for any useful things, it was disposed or burned in the incinerators [11].

The use of natural fibre, such as oil palm fibres as reinforcement in composite material has increased significantly as the increase of polymer matrix composite. Polypropylene (PP) was one of the polymers which were used as the matrix in polymer matrix composites. Polypropylene is the simplest chemical polymer which is classified as thermoplastic. Polypropylene is available as a crystalline homo-polymer with an excellent balance of chemical and heat resistance, low density and low unit cost [12]. The mechanical properties of PP are moderate. Though the polypropylenes are tough, flexible and water repellent, but it has low strength. The density of polypropylene is about 900 kg/m$^3$ [13]. The flame retardant grades are also available for PP. Therefore, it is commonly used for electrical insulation, cold water pipes, containers and packing sheets [14]. Although PP is not generally classed as an engineering plastic, reinforced PP are often successful with more expensive resin-based system with many low-stresses and ambient temperature applications [12].

There are many applications of Oil Palm Biomass (OPB) based polymeric composites in the automotive and plastic industries due to the strength of these composite compared to pure polymers. Some advantages of the polymer matrix composites are lightweight, rust resistance and generally has a high flexibility [9]. Some of goods which were made of polymer matrix composite, especially in the automotive industries also receive impact loads. That makes the importance of the impact resistance of the polymer matrix composite to be investigated.

From the previous research [15, 16], the mechanical properties of composite materials were influenced by the percentage of fibre contents. When the content of natural fibre is too low, there is less increase or insignificant increase to the mechanical properties of the composite material. However, as the fibre content is increased, the strength is also increased. For an example, the fibre content of kenaf fibre influences the mechanical properties of polyurethane composites. A 30% fibre loading is found to produce the best tensile strength as the modulus increased with the increase of fibre content [16]. The effect of lignin content obtained from Oil Palm empty fruit bunches (OPEFB) in the green epoxy composites have also been investigated. The epoxy reinforced composites cured with 25% lignin content demonstrated to produce optimum mechanical, thermal and morphological properties [17]. The effect of fibre treatment on both morphological and single fibre tensile strength of OPEFB has been evaluated [11]. The results show that alkali treatments on OPEFB fibre enhanced the tensile strength and thermal stability of the fibre samples.

The aim of this study is to investigate the impact resistance of polymer matrix composite reinforced with oil palm fibres. There are several parameters used in this work involving the significance of fibre treatment, size and contents towards the impact resistance of the composite.

2. Materials and Methods

The oil palm fibre used in this present work is obtained from Kian Hoe Plantation Berhad, Kluang, and Johor Malaysia. Whereas the matrix material used here is a commercially graded homo-polymer Polypropylene.
2.1. Fibre Preparation

![Figure 1](image1.png)

**Figure 1.** Cleaning processes of oil palm fibres: (a) the dirt oil palm fibres from Oil plant plantation, (b) the first washing, (c) the second washing and (d) the last washing.

Initially, the oil palm fibres which were obtained from the oil palm plantation are full of dirt and require cleaning processes, as demonstrated in figure 1. The cleaning process of these oil palm fibres with plain water should be done at least 3 times, depends on the condition of the fibres. Some of the oil palm fibres are too dirty which require more than three times, i.e. sometimes 4 or 5 times. After being cleaned by water, the oil palm fibres were dried for at least 2 days under enough brightness of sunlight, as shown in figure 2. This is to ensure that the fibres are dry enough to be processed for fibre preparation.

![Figure 2](image2.png)

**Figure 2.** The drying process of oil palm fibres after washed under sunlight. This drying process should be done 2 or 3 days depend on the brightness of the sunlight.

The dried oil palm fibres were then divided into 2 sections, each of them was used for preparing the untreated and the alkali treated fibres. For untreated fibres, it can be directly used for the specimen material preparation. But for the alkali treated one should be soaked in 3% NaOH and 97% water for 90 minutes. The fibres were then washed with plenty of water and dried in oven at 70°C for 15 hours.

2.2. Schematic chart of research Methods

The schematic chart of this research is highlighted in figure 3. The materials and chemicals used for this research are Oil Palm Fibres, Polypropylene (PP) and NaOH. During the fibres preparation, the fibres were prepared for two conditions, e.g. untreated and alkali treated fibres. Once the fibre treatment was done, the fibres were cut into short fibres in three different sizes, i.e. 5, 7 and 10 mm. These fibres were then mixed with polypropylene in three different fibre contents, i.e. 5%, 7% and 10% using Brabender machine.

For determining the number of sample combination that would be prepared, It should be clear first, the number of factors and levels of every factor. There are three factors are considered, e.g. fibre content, size, and treatment. The first two factors have three levels considerations which are 5%, 7%, 10% and 5mm, 7mm, 10mm, respectively. The final factor has two level considerations which are untreated and alkali treated fibres. In summary the consideration is as follows:

1. Fibre contents with 3 levels: 5%, 7% and 10%
2. Fibre size with 3 levels: 5mm, 7mm and 10mm
3. Fibre Treatment with 2 levels: Untreated and treated with 3%NaOH
In determining the number of samples for this experiment, it is important to decide what method will be used. This is to compromise between the number of experimental and number of samples. If the full factorial experimentation was used for this research [20], the total number of combination or number of test conditions was determined as follows:

$$\text{Total number of combinations} = (\text{number of levels})^{\text{number of factors}}$$

(2.1)

Number of combinations: $3^2 \times 2^1 = 18$ distinct test condition.

Every test condition consists of 5 samples. Totally there are $18 \times 5 = 90$ specimen samples should be prepared.

Another approach is Taguchi Method. This method would be used in this experimental work in order to make the most efficient approach for the experimentation in determining the nearest optimum settings for design parameters. The optimum settings here means the configuration to be studied was significantly reduced to the minimum number of combinations without reducing the validity of the experimental conclusions. This involves the layout of the experimental condition using specially constructed tables known as “Orthogonal arrays” [18]. Taguchi methods with orthogonal arrays can be applied where there are a large number of design factors in experimental work [19].
The first step in designing the experiment for this method is the selection of the orthogonal array. The array selected is the smallest one to do the job [20]. In this research, there are two three-level factors and one two levels factor. To make it more simple, in using Taguchi method, firstly can be assumed that all factors in this research have 3 levels [20]. This is only for choosing the orthogonal arrays which will be used in this research. The Arrays in which the columns predominantly contain three levels are referred to as the $3^n$ series [21] e.g. $L_9$ ($3^3$), $L_{18}$ ($3^7$), $L_{27}$ ($3^{13}$). Since there are only 3 factors in this research, $L_9$ ($3^4$) array will enough to be used, because this array can be used for research that have until 4 factors [20]. By using this array, the number of test only 9 combinations should be done, Totally there are $9 \times 5 = 45$ pcs specimen samples should be prepared. Compare to 18 test combination in full factorial experimentation with totally 90 pcs specimen should be prepared.

The orthogonal array also can be choosed by inputting factors and levels of this research in the Minitab application, the $L_9$ orthogonal arrays are obtained as shown in table 1.

| Specimen number | Fibre Contents (%) | Fibres size (mm) | Fibre Treatment |
|-----------------|-------------------|-----------------|----------------|
| 1               | 5                 | 5               | 1              |
| 2               | 5                 | 7               | 2              |
| 3               | 5                 | 10              | 3              |
| 4               | 7                 | 5               | 2              |
| 5               | 7                 | 7               | 3              |
| 6               | 7                 | 10              | 1              |
| 7               | 10                | 5               | 3              |
| 8               | 10                | 7               | 1              |
| 9               | 10                | 10              | 2              |

Since there are only two levels of fibre treatments used in this work, namely untreated fibres and Alkali treated fibres; method of downgrading column level should be done [20]. This method was done by changing number 3 of the column with number 1 or number 2 while still considering the balancing. The modified orthogonal arrays $L_9$ was constructed as shown in table 2. This newly formed $L_9$ orthogonal array were analysed with Taguchi method by using Minitab application.

| Specimen number | Fibre Contents (%) | Fibres size (mm) | Fibre Treatment |
|-----------------|-------------------|-----------------|----------------|
| 1               | 5                 | 5               | 1 (Untreated)  |
| 2               | 5                 | 7               | 2 (Treated)    |
| 3               | 5                 | 10              | 1 (Untreated)  |
| 4               | 7                 | 5               | 2 (Treated)    |
| 5               | 7                 | 7               | 1 (Untreated)  |
| 6               | 7                 | 10              | 1 (Untreated)  |
| 7               | 10                | 5               | 2 (Treated)    |
| 8               | 10                | 7               | 1 (Untreated)  |
| 9               | 10                | 10              | 2 (Treated)    |
The next step on this research are preparing the Charpy impact specimen sample base on combination showed in table 2. Every combination of specimen consist of 5 pcs. Totally 45 pcs. Samples should be prepared. The Charpy impact resistance of every specimen were calculated by using equation (2.3).

The average Charpy impact resistance of every combination then be inputted into L9 orthogonal array in the minitab application to be analysed with Taguchi method.

### 2.3. Material Preparation

The short fibres (5mm, 7mm and 10mm) were hot mixed with polypropylene by using Brabender machine at temperature 190°C. Initially the short fibres and polypropylene were prepared independently, as seen in figure 4 (a). By using equation 2.2, the appropriate weight of fibres and polypropylene were mixed together using the Brabender machine, demonstrated in figure 4 (b). The output of mixing process was demonstrated as in figure 4 (c), a non-uniform mixture.

\[
m = V \cdot \rho_c \cdot K
\]

Where:
- \(m\) = sample weight (g)
- \(V\) = mixer chamber volume = 55 cm\(^3\)
- \(\rho_c\) = density of the composite (g/cm\(^3\))
- \(K\) = constant (= 0.7 or 0.8)

**Figure 4.** a) Short fibres and polypropylene ready for mixing. b) Brabender machine for mixing the oil palm fibres with polypropylene. c) polypropylene have been mixed with oil palm fibres

**Figure 5.** a) Crushing machine, b) Injection Moulding Machine
After the mixing process, the samples were crushed with crushing machine (figure 5 (a)) to produce pellets and then ready to be processed in injection molding machine (figure 5 (b)) to make Charpy Impact specimen base on ISO 179-1:2001 as showed in figure 6. And the dimension follows the table

2.4. Charpy Impact Test

All samples (the treated and untreated fibre composites) were tested according to ISO 179-1: 2000 standard. The dimension of the specimen base on this standard is as follows:

![Figure 6. Charpy edgewise impact with single-notched specimen base on ISO 179-1:2001](image)

Table 3. Method designations, specimen types, notch dimensions - materials not exhibiting interlaminar shear fracture base on ISO 179-1: 2001

| Specimen type | Length* \( l \) | Width* \( b \) | Thickness* \( h \) | Span \( l \) |
|---------------|----------------|----------------|----------------|----------|
| 1             | 80 ± 2         | 10.0 ± 0.2     | 4.0 ± 0.2      | 02 05 03 03 03 03 03 |
| 2*            | 25s           | 10 or 15*      | 3*            | 20*      |
| 3*            | 11 or 13*     |                | 6 or 8*       |

* The specimen dimensions (thickness \( h \), width \( b \) and length \( l \)) are defined according to \( h < b < l \).

+ Specimen types 2 and 3 shall be used only for materials described in 6.3.2.

+ 10 mm for materials reinforced with a fine structure, 15 mm for those with a large stitch structure (see 6.3.2.2).

+ Preferred thickness. If the specimen is cut from a sheet or a piece, \( h \) shall be equal to the thickness of the sheet or piece, up to 10.0 mm (see 6.3.1.2).

Table 3. Method designations, specimen types, notch dimensions - materials not exhibiting interlaminar shear fracture base on ISO 179-1: 2001

| Method designation\((a)\) | Specimen type | Blow direction | Notch type | Notch base radius, \( r \) \( (\text{see Figure 5}) \) | Remaining width, \( h_{\text{notch}} \) at notch base \( (\text{see Figure 2}) \) |
|--------------------------|---------------|----------------|------------|---------------------------------|----------------------------------|
| ISO 179-1/1eP           | 1             | Edgewise       | Unnotched  |                                |                                  |
| ISO 179-1/1eA           | A             |                | Single notch | 0.25 ± 0.05 | 8.0 ± 0.2                      |
| ISO 179-1/1eB           | B             |                |            | 1.00 ± 0.05 | 8.0 ± 0.2                      |
| ISO 179-1/1eC           | C             |                |            | 0.10 ± 0.02 | 8.0 ± 0.2                      |
| ISO 179-1/1fF           | Flatwise      |                | Unnotched  |                                |                                  |

* If specimens are taken from sheet or products, the thickness of the sheet or product shall be added to the designation. Unreinforced specimens shall not be tested with their machined surface under tension.

+ Preferred method.

+ Especially for study of surface effects (see 6.3.1.1.3).
The dimensions of the specimens were made follow table 3 with B notch type. The Charpy impact test was done by using the Charpy impact equipment of the brand Wolpert with a maximum capacity of 4 Joule, located in the Polymer Laboratory, Faculty of Mechanical Engineering and Manufacturing, Universiti Tun Hussein Onn Malaysia (UTHM). The Charpy impact strength in kilojoules per square metre with notch A, B or C is calculated by using the following equation:

$$ a_{CN} = \frac{E_c}{h \cdot b_N} \times 10^3 $$  \hspace{1cm} (2.3)

Where:
- \( a_{CN} \) is the Charpy impact strength, in kilojoules per square metre
- \( E_c \) is the corrected energy, in joules, absorbed by breaking the test specimen;
- \( h \) is the thickness, in millimetres, of the test specimen
- \( b_N \) is the remaining width, in millimetres, of the test specimen

3. Result and discussion

3.1 Charpy impact test

The results of Charpy impact tests were shown in Table 4 and 5. Table 4 represented the results for untreated fibres composites, whereas Table 5 shows the results for alkali treated fibres composite.

Table 4. Charpy Impact test result of untreated fibres composite materials

| Fibre Contents (%) | 5 | 5 | 7 | 7 | 10 |
|-------------------|---|---|---|---|----|
| Fibres size (mm)  | 5 | 10| 7 | 10| 7  |
| 1                 | 0.12 | 0.12 | 0.12 | 0.15 | 0.17 |
| 2                 | 0.12 | 0.15 | 0.15 | 0.14 | 0.15 |
| 3                 | 0.14 | 0.12 | 0.12 | 0.16 | 0.16 |
| 4                 | 0.12 | 0.13 | 0.16 | 0.16 | 0.15 |
| 5                 | 0.15 | 0.15 | 0.15 | 0.15 | 0.16 |
| Average           | 0.130 | 0.134 | 0.140 | 0.152 | 0.158 |

Table 5. Charpy Impact test result of alkali treated fibres composite materials

| Fibre Contents (%) | 5 | 7 | 10 | 10 |
|--------------------|---|---|----|----|
| Fibres size (mm)  | 7 | 5 | 5  | 10 |
| 1                  | 0.14 | 0.14 | 0.12 | 0.17 |
| 2                  | 0.12 | 0.13 | 0.14 | 0.14 |
| 3                  | 0.14 | 0.13 | 0.17 | 0.17 |
| 4                  | 0.13 | 0.14 | 0.16 | 0.16 |
| 5                  | 0.15 | 0.15 | 0.15 | 0.16 |
| Average            | 0.136 | 0.138 | 0.148 | 0.16 |
3.2 Charpy Impact Strength

From the impact test result, the impact strength in kilojoules per square meter calculated by using equation 1, where \( b_N = 8 \) mm, and \( h = 4 \) mm and the results are shown in table 6 and 7. For Untreated fibre composite table 5 sample no 1 for fibre contents 5%, length 5 mm, the impact strength was calculated as follows:

\[
a_{CN} = \frac{E_c}{h \cdot b_N} \times 10^3 = \frac{0.12}{8 \cdot 4} \times 10^3 = 3.75 \text{ kJ/m}^2
\]

The impact strength of all datas from table 4 and 5 were calculated in the same way above. The result were shown in table 6 and 7.

Table 6. Charpy Impact Strength of untreated fibres composite materials in kilojoules per square metres

| Fibre Contents (%) | 5   | 5   | 7   | 7   | 10  |
|--------------------|-----|-----|-----|-----|-----|
| Fibres size (mm)   | 5   | 10  | 7   | 10  | 7   |
| 1                  | 3.75| 3.75| 3.75| 4.69| 5.31|
| 2                  | 3.75| 4.69| 4.69| 4.38| 4.69|
| 3                  | 4.38| 3.75| 3.75| 5.00| 5.00|
| 4                  | 3.75| 4.06| 5.00| 5.00| 4.69|
| 5                  | 4.69| 4.69| 4.69| 4.69| 5.00|
| Average            | 4.063| 4.188| 4.375| 4.750| 4.938|

Table 7. Charpy Impact Strength of Alkali treated fibres composite materials in kilojoules per square metres

| Fibre Contents (%) | 5   | 7   | 10  | 10  |
|--------------------|-----|-----|-----|-----|
| Fibres size (mm)   | 7   | 5   | 5   | 10  |
| 1                  | 4.38| 4.38| 3.75| 5.31|
| 2                  | 3.75| 4.06| 4.38| 4.38|
| 3                  | 4.38| 4.06| 5.31| 5.31|
| 4                  | 4.06| 4.38| 5.00| 5.00|
| 5                  | 4.69| 4.69| 4.69| 5.00|
| Average            | 4.250| 4.313| 4.625| 5.000|

The results show that as the fibre content has increased the average values of impact strength were also increased. It can be seen that different fibre contents were displayed in Table 6 and Table 7. This was due to the L9 modified orthogonal array as prescribed in table 2. Table 8 summarized the finding obtained for average values of the Charpy impact test. The Taguchi method using Minitab was implemented for the data as in table 8. The results were plotted as demonstrated in figure 7.
Table 8 Charpy impact test result (for being analyzed using Minitab application)

| Fibre content (%) | Fibre Treatment | Impact Energy (J) |
|-------------------|----------------|------------------|
|                   |                | 5 mm | 7 mm | 10 mm |
| 5                 | Untreated      | 4.063| -    | 4.188 |
|                   | Treated        | -    | 4.250| -    |
| 7                 | Untreated      | -    | 4.375| 4.750 |
|                   | Treated        | 4.313| -    | -    |
| 10                | Untreated      | 4.938| -    | -    |
|                   | Treated        | 4.225| -    | 5.000 |

Figure 7 Taguchi Method analysis graph of Charpy Impact resistance by using Minitab application.

From figure 7, the influence of fibre contents, fibre size and fibre treatment to the impact resistance were observed by the pattern of the slope or the gradient of the graph. The greater the gradient of the lines means the greater the effect. It also shows that the line of fibre contents was comparatively steeper than the other parameters, having the largest gradient compared to the gradient of fibre size and fibre treatment. It means that the fibre percentage is significantly affecting the impact resistance. The increasing in fibre percentage has increased the impact resistance to the composites.

Moreover, it was also an agreement that the fibre size is also affecting the impact resistance of the samples, even though the gradient of the line was not as large as the gradient of fibre content. However, it can be seen that the longer fibre size has increased the impact resistance of the specimen. The other parameter that was observed was the effect of fibre treatment toward the impact strength of
composite samples. However, as demonstrated in figure 7, the gradient line for this parameter was not significant. The line was almost flat and tend to negative influence were observed. Hence, the influence of fibre treatment was approaching to not influence and cannot improve the impact resistance of the composite materials. This result also have been obtained by other fibre. The influence of treatment on kenaf fibre composites has been investigated before, and the result is The impact strength of treated fibre lower than the untreated one for fibre content below 30% [22].

4. Conclusion

As a conclusion, the influences of fibre size, content and treatment to the Charpy impact resistant have been investigated. During the sample preparation, Taguchi method was demonstrated successful in selecting the optimum number of samples evaluated according to L₉ modified orthogonal array. The results show that the three parameters analyzed, namely fibre size, content and treatment, each of them demonstrated differently. The finding shows that oil palm fibre content has the greatest effect of the three parameters, which seen significant effect to the Charpy impact test, hence greatly affect the impact resistance of the oil palm fibre polymer matrix composites. The fibre size has the moderately affect of the three parameters to the Charpy impact test, hence moderately affect the impact resistance of the oil palm fibre polymer matrix composites. The fibre treatment has shown insignificant and tend to negative influence to the impact resistance of polymer matrix composites.

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