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Physical Properties of Novel Kenaf Short Fiber Reinforced Bulk Molding Compounds (BMC) For Compression Moulding ☆

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Abstract

The recent trends have seen natural fiber reinforced composites (NFRC) garnering a large following due to their low density, commercially viability, low health risk, high tensile strength and modulus and renewability. Many have attempted to applythe NFRC in automotive and other practical applications. This paper discusses the physical properties such as the Gel time, specific gravity, and also the volumetric shrinkage of a recently developed kenaf reinforced bulk molding compound with unsaturated polyester matrix. It has been found that the specific gravity declines as the fiber loading increases all fiber length. The highest was the BMC reinforced with 9 mm kenaf short fiber with 1.81. It has also been found that the Gel time increases proportionally to the loading of the fiber due to the fibers absorbing the heat released during bond formation. And a compression molding technique was used to study the shrinkage of the respective materials. It can be concluded that both fiber loading and fiber length plays a significant part in the physical properties of the composites

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Keywords: BMC; Composites; Kenaf; Physical Properties, Shrinkage, Gel time:

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1. Introduction

Natural Fibers (NF) have been materials that have been used since the beginning of civilization. Historical data depict how early humans, who were hunter gatherers, have made daily usage items such as rope, baskets etc. from NF. Later these crops were cultivated. Engineering interest has been shifting from monolithic materials to composites especially fiber reinforced polymers. Synthetic fibers especially glass fibers have been used as reinforcement materials initially, however glass fibers have some shortcomings. Table 1 [1], shows the disadvantages of the glass fibers when compared to NF. To overcome these drawbacks there has been many studies done on the usage of NF as reinforcement for polymeric materials. Table 1 shows some areas where the NF has a good advantage over glass fibers such health risks and CO_2 neutrality. Kenaf (Hibiscus cannabinus, L.) fibers that are derived from the bast are amongst the most widely used NF. Although there are many different types of thermosetting resin used for natural fiber reinforced composites, the majority are made with three main types, namely polyester (UP), vinyl-ester (VE), and epoxy. Such low-viscosity resins provide excellent fiber wetting and adhesion, and the composites can be compression molded into a multitude of complex shapes [2].Bulk Molding Compound (BMC) is polyester based, thermosetting composite. BMC has traditionally been molded into components requiring significant electrical, structural, corrosion resistant and/or heat resistant properties. Successful BMC applications have generally been restricted to the non-visual or "working" areas of appliances. Brush holders, armature sleeves, and A-coil drip pans name a few. BMC materials, although functional, have been somewhat rudimentary in their approach to ingredient content, mold design and molding processes. BMC is popular as a low cost alternative for non-aesthetic, high heat applications. However in order to promote better wetting, the surface of the fibers need to be modified and treated.

Table 1. Comparison Of Natural Fibers And Glass Fibers

Properties	Natural Fibers	Glass Fibers
Density	Low	Twice that of NF
Cost	Low	Low, but higher than NF
Renewability	Yes	No
Recyclability	Yes	No
Energy consumption	Low	High
Distribution	Wide	Wide
CO2 neutral	Yes	No
Abrasion to machines	No	Yes
Inhalation Health risk	No	Yes
Disposal	Biodegradable	Not Biodegradable

Nomenclature

BMC	Bulk Moulding Compound
UP	Unsaturated Polyester
NF	Natural Fibers

2. Materials And Methodology

2.1. Bulk Moulding Compound Preparation

The bulk molding compound was prepared by using a twin Z-blade mixer at Wah Ma Chemical Sdn. Bhd., Penang Malaysia. The kenaf fibers were prepared at University Putra Malaysia using the custom built fiber cutting machine. The unsaturated polyester resin, inhibitors, hardeners and the fillers were both obtained from Wah Ma Chemical Sdn. Bhd., Penang, Malaysia. Figure 3 shows the mixing methodology for the bulk molding compound.

According to research done by Sreenivasan et al. [3] the fibers that were pretreated with glycidoxypropyltrimethoxy-silane showed the best surface adhesion. Hence all the fibers used in this research was pretreated with glycidoxypropyltrimethoxy-silane for 24 hours before being dried and vacuum packed for mixing with the unsaturated polyester resin. The premixed resin was mixed with the inhibitors and hardeners using a propeller mixer-agitator machine for 600 seconds at a constant high rpm. The fillers and the resin were initially mixed in the Z-Blade mixer at medium rpm for 300 seconds and then the fiber was added and the BMC was mixed at low rpm for 1200 seconds.

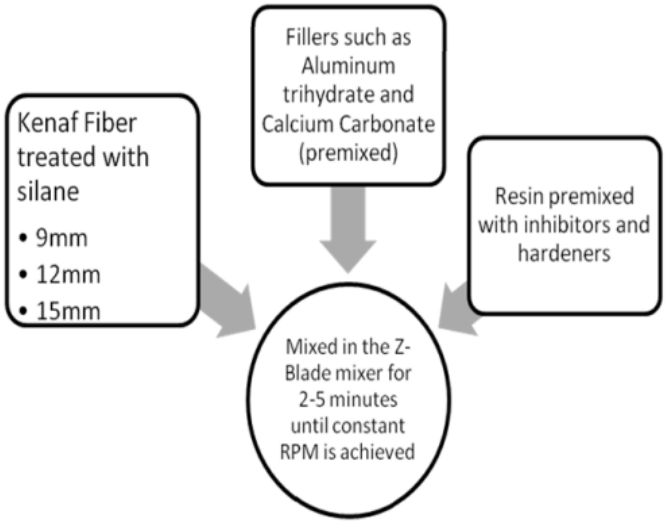

Fig. 1. Mixing Methodology for the Bulk Molding Compound.

2.2. Tests

Chemical Sdn. Bhd. using a hot plate measurement technique according to a slightly modified ASTM D3532 Standard Test Method for Gel Time of Carbon Fiber-Epoxy Prepreg. The modification was the temperature used; the temperature used was 150°C±1°C instead of 120°C±1°C as the material was expected to cure at that temperature range. The specific gravity (SG) was measured at Wah Ma Chemical Sdn. Bhd. according to the ASTM D792 - 13 Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.

The molded shrinkage was tested using samples molded according to ASTM D6289 - 13 Standard Test Method for Measuring Shrinkage from Mold Dimensions of Molded Thermosetting Plastics. According to the standard the materials were molded in two unidirectional fiber settings i.e. x and y direction. Each sample was molded in a multiple cavity mold to observe the flow as well as the direction of the aligned fibers. Figure 2 shows the molded samples and fiber direction. A single shot provided the test specimens for the shrinkage and also the impact test. The shot size as well as the pressure settings was also recorded for further studies.

3. Results and Discussions

3.1. Molded Shrinkage

Molding shrinkage is a normal phenomenon that occurs in plastic injection molded part that can be defined as the dimensional difference between the parts and the molds. The major cause of this has been found to be the polymer density change which occurs as the material cures and solidifies [4].Shrinkage was calculated according to the formula given in (1) below. There were two axes of fiber alignments that were considered. It could be seen that the

Y axis gives a larger shrinkage percentage compared to the x axis. Figure 2 below also shows a schematic diagram of the alignment of the fibers with the injection gates. From the table it is evident that the X axis alignment gives the lowest shrinkage due to the position of the fibers being more densely packed, the length of the fibers allow the fibers to closely pack together, thus reducing the shrinkage. The lowest shrinkage was for the 12 mm 20 percent fiber with 0.046% allowing for better dimensional accuracy. This was due to the width of the test mold being 12.7 mm which is closer to 123 mm compared to 15 and 9 mm respectively. Also in previous research done by the researchers have shown that 12 mm 20 percent gives the best mechanical properties due to optimum fiber content and length. It can also be seen that the shrinkage is increasing as the length of fiber increases. Generally neat UPE resins have shrinkage of about 7%. This molding method and the shrinkage on this material have been reduced to a maximum 0.046 percent, which translates into better dimensional stability. These results however show that both the directional results have been significantly reduced.

$$MS = ((L_0 - L_1)/L_0) \times 100\% \quad (1)$$

Where;
L_0: Mold cavity dimensions
L_1: Product dimensions after leaving the molded product at room temperature for 24 hours after molding

Table 2. Unidirectional Molded Shrinkage.

Fiber Length and Loading	X Direction		Y Direction	
	Shrinkage(%)	Error(%)	Shrinkage(%)	Error(%)
9mm 10 %	0.132%	1.31%	0.304%	1.12%
12mm 10 %	0.069%	1.51%	0.268%	0.63%
15mm 10 %	0.061%	1.31%	0.252%	1.85%
9mm 20 %	0.159%	1.21%	0.591%	0.49%
12mm 20 %	0.046%	0.82%	0.480%	1.41%
15mm 20 %	0.050%	1.04%	0.482%	2.11%
9mm 30 %	0.247%	2.89%	0.822%	1.93%
12mm 30 %	0.126%	7.13%	0.746%	4.47%
15mm 30 %	0.109%	2.52%	0.702%	4.14%

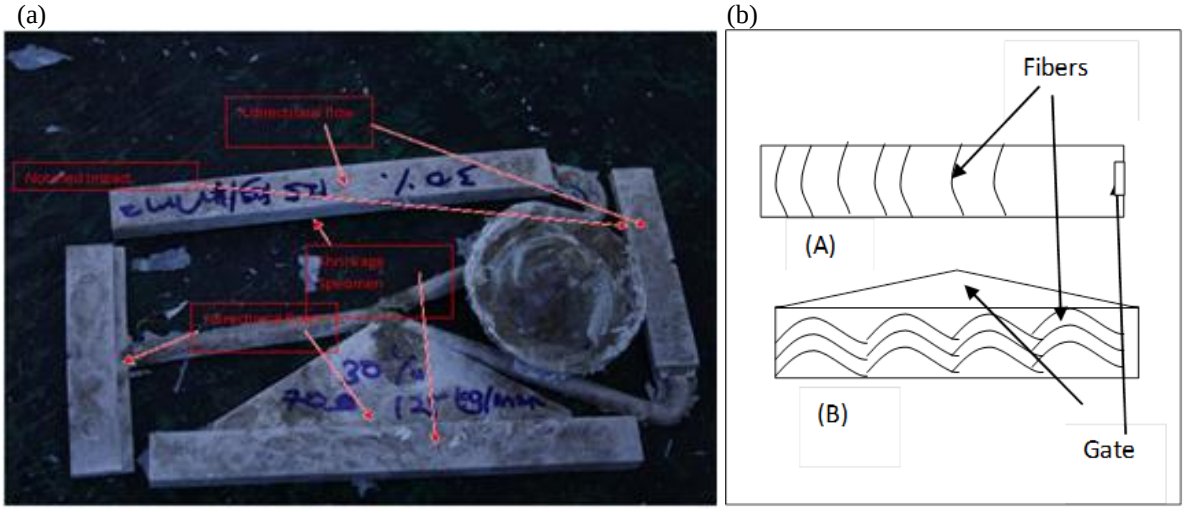

Fig. 2. (a) Molded Specimen for Shrinkage test and (b) fiber orientation (A) X-Axis and (B)Y-Axis

3.2. Gel Time

One of the most important stage in the processing of unsaturated polyester based composites is the curing or the cross linking stage. The cross linking stage begins with the gelling or the change of viscosity of the material ending with the material hardening, i.e. curing into the composite. It is an exothermic reaction whereby it can exhibit a temperature increase of up to 200 ºC. As mentioned earlier the BMC material was cured at 150ºC and the material condition was repeatedly measured until gelling occurred. Table 3 below shows the effects of fiber length and loading on the gel time of the BMC, it can be said that the gel time decreases with the increase of fiber percentage. An analysis of variance was also conducted, it showed that the fiber loading did in fact affect the gel time with a p value of 0.004 which was lower than 5%. Hence proving that percentage of fiber does impact greatly on the gel time. This was due to the fibers absorbing some of the heat released, this was in agreement with the studies conducted by Waigaonkar et al[5], who found that gel time was increased as the loading increased. The fiber length however did not affect the gel time, even if the data showed a trend of slight increase of gel time over length, the ANOVA conducted showed that the fiber length did not play a significant impact on the gel time. The lowest gel time was at the 9mm 10% with an average of 61.4 seconds and the 15 mm 30% samples having the highest gel time at an average of 72.2 seconds. All of the data showed an error percentage of below 5 percent.

Table 3. Material Gelling time and Specific Gravity.

Fiber Length and Loading	Gel Time (s)		Specific Gravity (SG)	
	Average	Error (%)	Experimental	Error (%)
9mm 10 %	61.4	4.29%	1.804	0.20%
12mm 10 %	65.2	3.02%	1.796	0.30%
15mm 10 %	66	3.26%	1.812	0.24%
9mm 20 %	65.8	2.56%	1.65	0.30%
12mm 20 %	67	4.03%	1.634	0.22%
15mm 20 %	68.2	3.94%	1.632	0.20%
9mm 30 %	70.2	1.77%	1.292	1.04%
12mm 30 %	71	2.67%	1.304	0.98%
15mm 30 %	72.2	2.30%	1.312	1.20%

3.3. Specific Gravity

The specific gravity of a substance is the measure of ratio of the substance's density to another known density. Normally the reference density used is water. As can be viewed from the table 3 above, it can be said that the specific gravity of the BMC is inversely related to the fiber loading. The highest specific gravity obtained were those with the lowest amount of fibers i.e. at 10 percent and 15mm with 1.812. And the lowest was at 9mm, 30 percent with 1.292. This is in agreement with the fact that the resin and filters such as $CaCO_3$ and AlO_3 have a higher specific gravity compared to the kenaf fibers. Reddy and Yang [7] found that all natural cellulose fibers including kenaf fibers are multi cellular. Natural polymers such as lignin and pectin bound these bundles of individual fibers. They also agreed that all these fibers have a hollow cavity called lumen. The density of the fiber is thus greatly reduced by the hollow lumen present within them. Shinichi et al [8] have found that bulk density of kenaf is only 0.9 g/cm^3, compared to the density of the resin at 1.9 g/cm^3 that was provided by the manufacturer. By mixing both the components by weight fraction it can be deduced that increasing the weight fraction of the fiber would reduce the overall density of the composite. The density was then calculated using equation (2) and then both these densities were compared. This comparison provides as estimate of the accuracy of the density to the ideal calculation. It can also show if there are voids and or trapped air bubbles in the composite. As the trapped air would result in reduced density, it would mean that the interface between the fiber and the matrix was weak, thus making the composite structurally weaker. As evident in figure 3 below, the experimental specific gravity is greatly reduced for the higher fiber loading and greater fiber length. This may be due to the difficulty in the fiber filling up cavities at a higher loading as the thickness of the mold cavity used was only 2.7 mm which was less than 20 percent of the

fiber length for the 15 mm long fibers. This caused an increase of voids thus reducing the specific gravity greatly. The shortest and the lowest fiber loading had the most similar specific gravity compared to the experimental results

$$\frac{1}{\rho_c} = \frac{m_f}{\rho_f} \times \frac{m_m}{\rho_m} \tag{2}$$

Where: ρ_c: density of composite
m_f: mass of fiber used
ρ_f: density of fiber used
m_m : mass of matrix used
ρ_m: density of matrix used

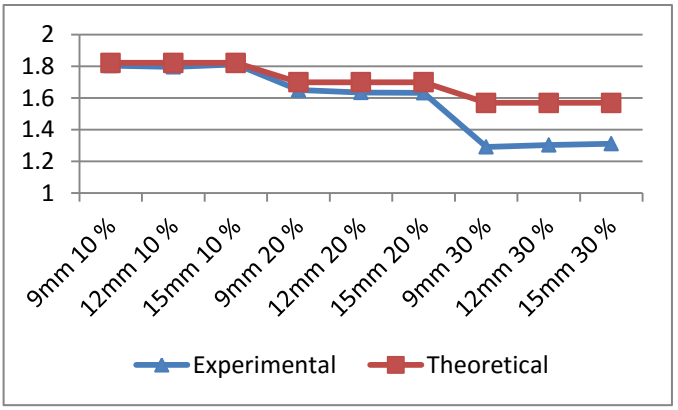

Fig. 3 Comparison between Experimental and Theoretical Specific gravity.

4. Conclusions

Through the above experimentation work, it is obvious that shrinkage is very much influenced by both the fiber loading and also the axis of flow. As mentioned above, the molding is done with high pressure, causing those with low fibers and very high fiber content to show high shrinkage. The optimum fiber loading here was 20 percent. The highest gel time was for the composites with the highest fiber by weight percentage, i.e. 30%, this is due to the increased fiber loading, increases the ability for the composite to absorb the exothermic heat released during curing, thus providing a higher gel time. The specific gravity which was compared to theoretical calculations showed better results for lower fiber loading and lower length compared to higher fiber loading and length. By comparing all three results, the optimized fiber length is 12 mm as in all the conducted tests, as it has the lowest shrinkage, and acceptable gel time of about 1 minute which translates to an optimum mold cavity filling time, even for larger products. The specific gravity also produced the most consistent result with an error of 0.22 percent. The specific gravity of the 12mm 20% loading also did not deviate much from the calculations. It can safely be said that the objective to study and characterize the physical behavior, mainly gel time, shrinkage and specific gravity behavior of kenaf reinforced BMC has been achieved.

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