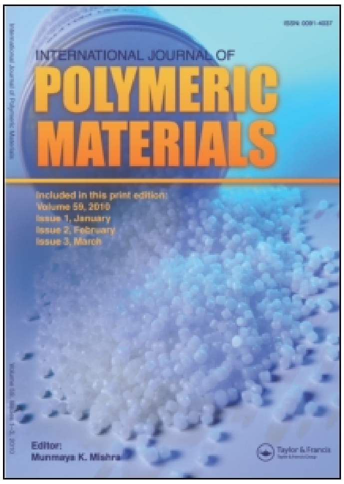

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Effect of Samples Cutting Position and Gage Length or Specimen Geometry on the Mechanical Properties of Woven Thermoplastic Prepreg

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Woven composites are getting acceptance in many engineering applications such as tranportation, construction and automotive, albeit in most instances are rather confined to those of thermoset matrices. In view of many favourable circumstances, thermoplastic based systems are slowly gaining recognition which can be easily attributed to their unique properties. For example, these include better damage tolerence, ease of handling, recyclability, *etc.* However, they are always referred to those derived from fabrics, either impregnated or otherwise. Here, an alternative system was realized by utilizing the impregnated towpreg or simply continuous fiber impregnated thermoplastic (COFIT). Results on composite testing, using tensile measurement as an example apart from type of towpregs, weave characteristics, *etc.*, it clearly shows that the tensile properties of any woven structures are dependent on specimen cutting position coupled with gage length too. Generally, the woven system's properties are manifested by the presence of what is called weave characteristics such as interlaces, floats length, crimps, *etc.*

Keywords: Thermoplastics; Composites; Prepregs; Specimen geometry; Properties

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1. INTRODUCTION

In view of many differences in characteristics for different composite systems, numerous testing methods, standards or otherwise which have been developed for a particular system might not be suitable for others. For example the testing methods, which were developed for unidirectional tape composites are known to be fully inapplicable for woven composite system [1] and the standard testing methods which were established by NASA under its Advanced Composite Technology (ACT) Program on 2-D and 3-D braided and 3-D woven fabric system might not be fully adequate for a 2-D woven system based on COFIT prepregs, which is the current system presented here. Instead of using dry fabric preform, the plain weave was prepared from COFIT prepeg using a solution based prepreging system.

Unlike the more common unidirectional (UD) composites, woven composites are known to be a complex system. Due to its complexity, the testing and characterization can therefore be influenced by many factors such as interlace point, unit cell, length of the float, interlace spacing or gap, fiber crimp and fiber count [1].

Hence, under such circumstances, it is therefore felt appropriate to carry out a series of experiments in which further understanding on the roles of samples' cutting positions, coupled with effect of varying the gage lengths on the mechanical properties are examined. Attempts will also be made to correlate them with the woven or weave characteristics such number of interlaces, unit cell and so forth. Moreover, since they are preliminary in nature testing was solely based on tensile properties and the weave pattern used was the plain weave. In our earlier study [2], we have reported the effect of samples' cutting directions on mechanical properties of the similar woven prepreg based thermoplastic composite.

2. EXPERIMENTAL

2.1. Materials

General purpose grade Acrylonitrile Butadiene Styrene (ABS) resin, Polylac PA 757 from Chi-Mei (M) Ltd., was made into 30% w/w solution using Methyl Ethyl Ketone (MEK) as a solvent. The continuous E glass fiber which was manufactured by Central Glass Ltd., Japan and was supplied locally by EuroChemo-Pharma (M) Sdn Bhd were utilized throughout. High impact polystyrene (HIPS) of grade Poly-Star, HT-50 was bought from local supplier, PetroChemical (M) Sdn Bhd.

2.2. Preparation of COFIT Prepreg

Both ABS and HIPS COFIT prepregs or towpregs were prepared under similar molding conditions using the SIRNA prepregger system, *viz*. Dryer temperature, 80°C; die temperature, 220°C and pulling rate, 0.35 m/min. Here, ABS towpregs of 4, 7 and 12 tows and also that of 12 tow with HIPS as a matrix were prepared. Their properties such as dimensions, specific gravity (S.G) and also tensile properties were then determined.

2.3. Preparation of Woven System

To ensure quality of the woven composite, only prepregs having acceptable properties such as dimensions, density and fiber fraction (W_f) were chosen. Then they were woven manually into a single ply laminate plain weave. This was molded by compression molding under a similar condition of 220°C for 15 minutes preheating and subsequently pressure of 12 MPa for 5 minutes. To prevent sticking and assist demolding, they were placed between TEFLON sheets. Also here no spacer or mold was used. In short, an open mold was used throughout. Finally, they were removed from the press and allowed to cool to room temperature under pressure so as to prevent warping and warpage. Here, the 0° tensile specimen coupons were cut-out from the laminated woven composites. For the cutting positions, two different cutting positions such as type I and II were prepared. Type I refers to specimen having 50% less interlaced points than those of type II. The test coupons of 100-mm gage length were arbitrarily chosen. To investigated effect of varying sample's geometry, represented only by changes in the gage lengths of 100, 120, 160 and 180-mm were prepared. All specimens were tested according to tensile test method (ASTM D638).

3. RESULTS AND DISCUSSION

3.1. Effect of Samples' Cutting Positions

The present study on sample's cutting position will determine the influence of weaving parameters especially the interlace points on woven composites' properties. Although, the earlier study [2] of sample cutting directions has identified the effect of interlace points on woven composite properties, here the importance of interlace points is more obvious. This is because the two positions taken, known as Types I and II contain large amount of interlaces. Type II has 50% more interlace content than Type I. It must be noted that the differences between COFIT based woven system with the common one are obvious for example the weave characteristics of the COFIT woven system is different such as the number of interlaces/area, unit cell, *etc.*, Figure 1 shows a schematic view of the two positions. The figure clearly demonstrates how Type II gives rise to specimen with 50% more interlace points than that of Type I. Perhaps, the cutting positions might be important in the case of other directions, however it will not be covered here since the 0° cutting direction was chosen from earlier study [2] as it imparts minimum presence of weave characteristics, the highest average tensile strength and stiffness. This study was carried out using 0° tensile strength properties with the same sample gage length of 100-mm.

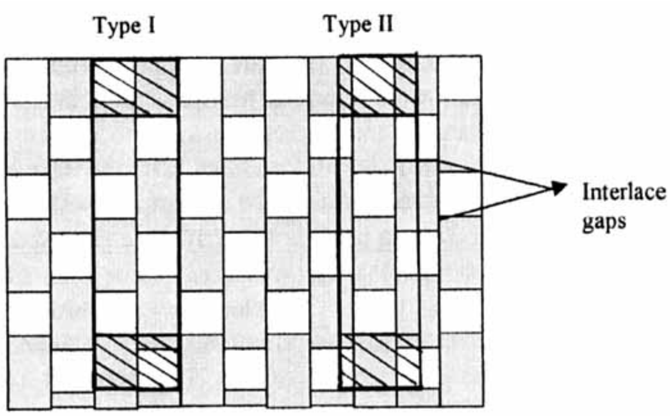

FIGURE 1 A schematic illustration showing the differences between Types I and II specimens.

Table I summarizes the differences in the nature of weave characteristics between Types I and II positions, while maintaining the sample size. It is obvious, apart from number of interlaces, Types I and II cutting positions result in specimens having dissimilarities in unit cell, coupled with varying distances of the interlaces from the respective edges, respectively. A unit cell is defined as the smallest section of architecture required to repeat a textile pattern. Obviously these differences would play an important role in influencing the composite properties.

The overall 0° stress–strain deformation behaviors for both types II and I are shown in Figure 2. By referring to the previous discussion and the characteristic of the sample cutting position, it is well expected that Type II will exhibit low tensile properties which might be attributed from the nature of weave characteristics such as unit cell, interlace points and distance of interlaces from the edge.

Theoretically, the lower tensile properties of Type II might be due to the stress concentrations which are known to occur at the interlace points. As mentioned by Poe [3], the fiber crimp which was introduced by frequent exchanges of position from top to bottom at interlace points reduce the tensile strength and stiffness of the woven structures by increasing the stress concentration at the interlace point [4].

In short, from the above the position of cutting as defined as Types I and II here, clearly identified the role of weave characteristics such as number of interlaces, the unit cell and the distance of interlace from the edge which if unaccounted for might lead to unreliable result. For example, in our previous study [2], the differences in reliability of 0°, 90° and 45° cutting directions which were shown in Figure 3 might

TABLE I Influence of cutting position on the nature weave characteristics based on same sample size

Type of samples	*Characteristics*
Type I	
	◆ contains 3 interlace points ◆ covers 2 unit cells ◆ distance of interlace point from edge about the size of towpreg
Type II	
	◆ contains 6 interlace points ◆ no unit cell; incomplete unit cell ◆ distance of interlace point from edge is half size of towpreg from both sides

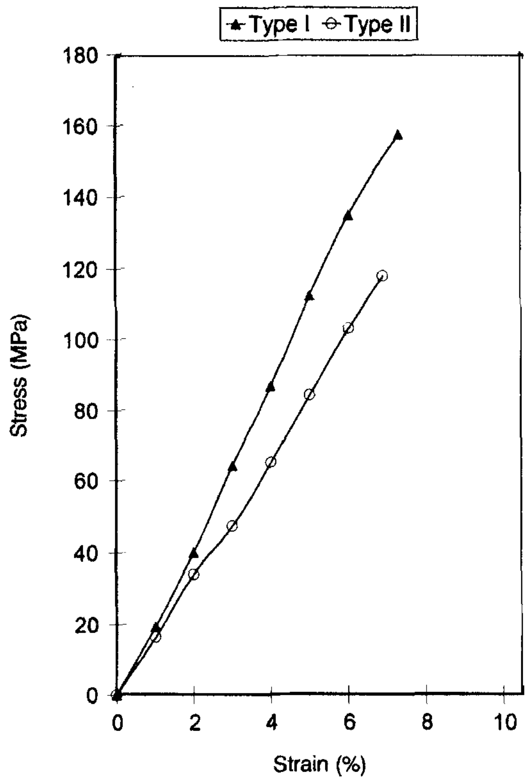

FIGURE 2 The stress–strain deformation behaviors of different cutting position of a single ply plain weave.

have been further attributed to these factors, apart from the influence of weaving parameters alone.

In other words, samples' cutting position is important when dealing with a woven composite system, failure to do so might result in undesirable effects. The next section, a look at role of specimen's gage length on 0° tensile property measurement.

3.2. Effect of Gage Length or Specimen Geometry

The gage length selection was reported as one of the factors which influences the composite testing and it is important in characterizing the materials properties [3]. For example in UD composite, the longer

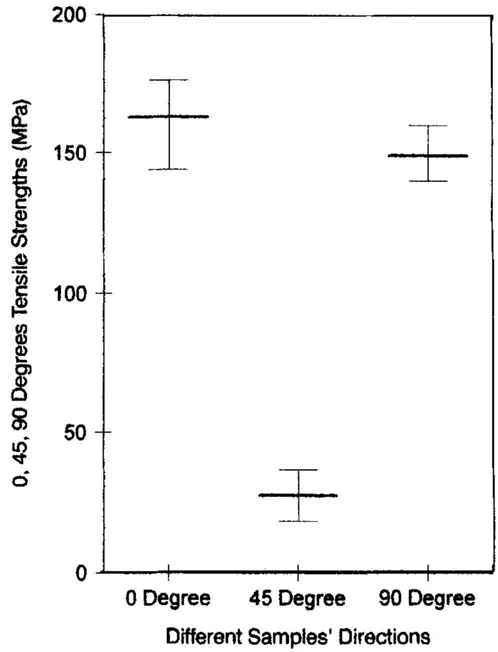

FIGURE 3 Variation of tensile strength with different samples' directions of single ply plain weave.

gage length will result in lower strength of the composite due to the presence of increasing imperfections or inherent flaws in the material. Some of the imperfections are misorientation of fibers, interfacial condition, residual stresses and discontinuous of fibers [5]. The same phenomenon is also known for woven composite system. As woven composite is a complex system, apart from imperfections similar to those of UD towpregs (precursor to woven system), the corresponding properties are also governed by additional weaving influences such as interlace point, unit cell, *etc.*, NASA in their standard testing methods of textile composite testing has recommended that the gage length should be at minimum equal to the length of a unit cell of a textile pattern [3]. However, the study did not mention why the gage length should be longer than the size of unit cell. However it was stated that more reliable data was obtained as the gage lengths is increased from a size of a unit cell. From our previous study [2], we observed that the complete unit cell which are present at 0° cutting direction is one of the factor which imparts to a more reliable data and higher tensile properties.

Based on this information, an attempt to investigate further the gage length of single ply plain weave has been carried out. The gage lengths of 100, 120, 160 and 180-mm were examined while the width was fixed. Here, sample cutting was confined to 0° direction and Type I position was selected. These selections were made because as shown earlier [2], they generally impart better tensile properties. This present study is aimed to reconfirm the role of weave characteristics *viz.* interlace, unit cell, *etc.*, on tensile properties. Figure 4 shows a simple pictorial illustration on how varying the gage lengths from 100 to 180-mm for Type I and 0° position affect the weave characteristics.

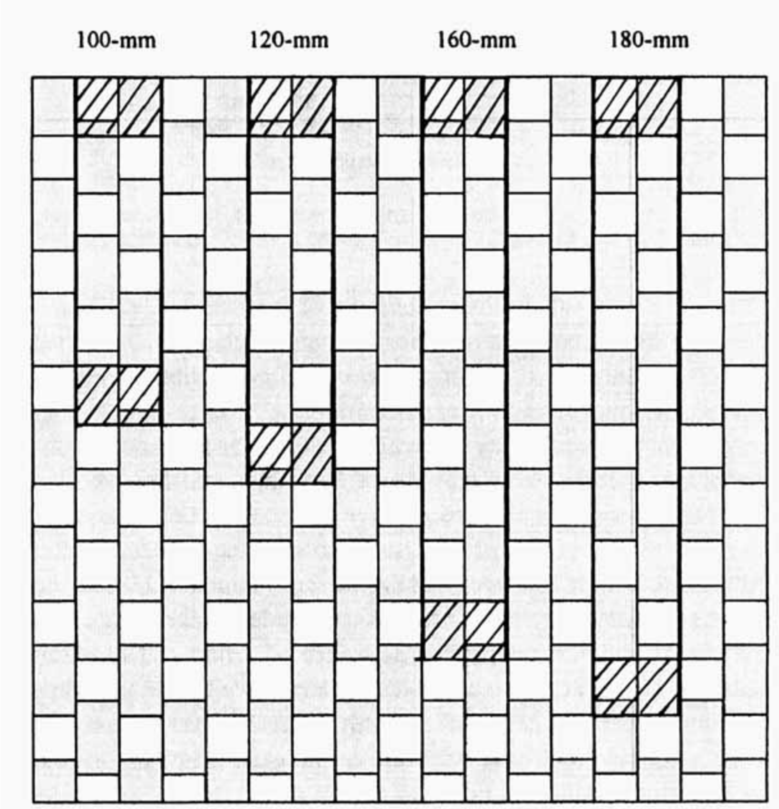

FIGURE 4 A schematic diagram highlighting the effect of gage length on weave characteristics present in any specimen geometry.

Table II highlights the relationship between weave characteristics and the 0° tensile properties, obtained from specimens having the varying gage lengths. From the schematic illustration in Figure 4 and the data presented in Table II, it is apparent that the differences between the gage lengths are in the number of interlace points, unit cell, fiber length and the quantity of fibers at the transverse directions. All these differences would then attribute to the different tensile properties.

Figure 5, shows the overall stress–strain deformation behavior of different gage length of a single ply plain weave. In overall, it is apparent that with increase gage length, the stiffness increases, however the elongation to failure decreases. This means that those of longer gage length failed at a lower deformation than the shorter ones.

Figure 6 shows the average tensile strength of these different gage lengths. Theoretically, a unit cell of woven patterns is composed of more than one interlace points, which means that there is a positive correlation between number of interlace points and unit cell. Thus as expected, with increase of a gage length, result to increase in quantity of unit cells and interlace points, this might increase the role of interlaces and thus reducing the average tensile strength.

Another factors that might contribute to this observation are the dissimilarities of different gage lengths in fiber lengths and the quantity of fibers at the transverse direction. These two factors basically were not observed earlier [2] since in both cases the same gage length was applied. It is well known that the composite strength depends on fiber length [6] and different gage lengths were found to exhibit different fiber lengths. Theoretically, long fiber length has a higher probability of having weak points such as cracks along the fiber length, matrix-fiber interface problem, *etc.* As a result these imperfections leading to lower tensile strength of long gage lengths. Another dissimilarities among these gage lengths is the quantity

TABLE II Effect of gage length on the weave characteristics and the subsequent 0° tensile properties

Properties	100-*mm*	120-*mm*	160-*mm*	180-*mm*
No. of Interlaces	4	5	8	9
Unit cell	2	2.5	4	4.5
Tensile Strength (MPa)	183.8	229.2	212.9	209.6
Tensile Modulus (GPa)	4.4	4.9	5.4	7.4

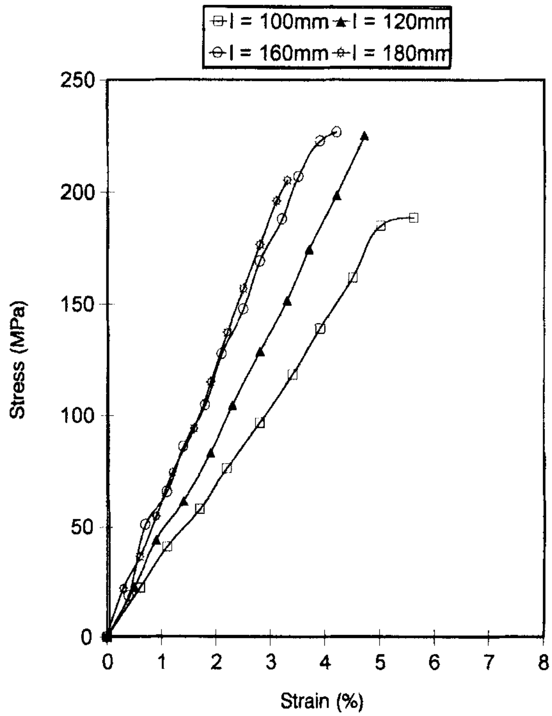

FIGURE 5 The stress–strain deformation behaviors of different gage lengths of single ply plain weave.

of fibers at the transverse direction. As the composite properties depends on the number of fibers which are not parallel to the loading direction [5], thus as the quantity of fiber at transverse directions of long gage length increases. This subsequently resulted to a lower tensile strength of the long gage length.

However, an anomaly result is observed to occur in the case of 100-mm gage length where the tensile strength was found to be lower but it is more reliable, as shown from less variation or scatter in the data. The differences in reliability of these different gage lengths might be attributed from weaving parameters presented in the sample, for example as the gage length increases, the number of interlace points and unit cell increases. Thus apart from weaving characteristics, possibility of imperfection such as % of voids, fiber distortion at interlace points, matrix-fiber interface problem and

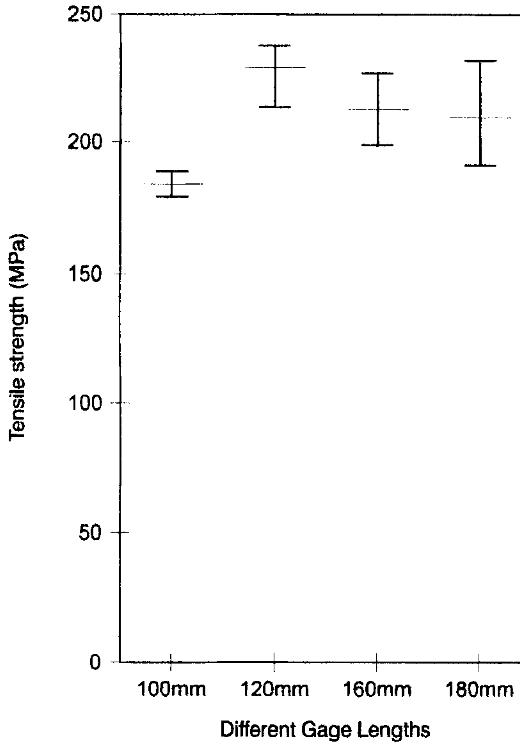

FIGURE 6 Tensile strength response on different gage lengths of single ply plain weave.

intraply bonding presented in the long gage lengths are higher than those of the shorter ones. This in return results to lesser reliability and lower average tensile strength of the long gage lengths.

In short, from the experiment carried out on different gage lengths, it is apparent that the number of interlace points, unit cell, fiber length and quantity of fibers at transverse direction influenced the woven composite tensile properties. For example, long gage length increases the possibility of imperfections in the system. Because instead of flaws existed in the UD towpreg which is the precursor to woven prepreg system, the imperfection might be presented from the nature of weave characteristics such as interlace points and gap, unit cell, *etc*. These additional imperfections will reduce the tensile strength, reliability and elongation at break in a long gage length.

Thus by selecting a short gage length, more reliable results can be obtained.

4. CONCLUSION

Judging from the result obtained, one can conclude that the woven tensile properties are also governed by cutting position and the specimen's gage length, which in return depend on the nature of weave characteristics such as number of interlaces, nature of unit cell, *etc.*, apart from weave geometry, molding condition, ply thickness and so forth.

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