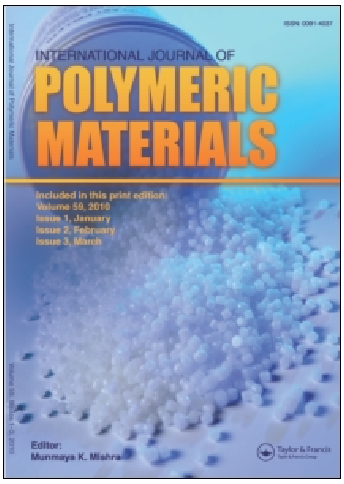

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Influence of Types of Towpreg (Number of Tows and Matrices) in Woven Thermoplastic Composite Behavior-Part 1

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Textile or woven composite structures are an important material in many engineering applications. However, in many instances these structures are confined to those of thermoset matrices. The last decades or so saw the emergence of thermoplastic composites which exhibit several obvious advantages compared to those of thermoset. These include amongst others, easy processing, versatile end properties, especially damage tolerance, better working environment, *etc.* Morever, woven composites are always referred to those derived from fabrics, either preimpregnated or otherwise. However in the present study, a different approach in producing woven thermoplastic composite has been made. Namely, these woven thermoplastic composites were made by using the preimpregnated towpregs or prepregs, prepared usually in unidirectional tape form, instead of those derived from fabrics. The effect of different types of towpregs such as number of tows and matrices on the composite properties was examined. In short, the woven composite properties are clearly dependent on the towpregs properties. In addition, the advantages in handling, control and designing in attaining the desired composites properties were noted.

Keywords: Towpreg; woven thermoplastic composite; mechanical properties; weave characteristics; prepreg

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1. INTRODUCTION

Woven or textile composites which is in the form of fabric (cloth) or yarns, consists of sets of interlacing threads are well known [1–3]. It was reported that woven objects were made during the Stone Age. However it was not composed of threads, but of reeds, grasses and saplings [2]. The first glass threads was woven by Owens Corning Company in the mid-1930s [4]. The development soon resulted in fiberglass fabric being commercially available on a mass production scale. Later the woven graphite, aramid and space age ceramics were commercially introduced and now these woven materials are available in a wide range of products [4, 5].

The woven composite can offer versatile properties such as high-impact resistance, better toughness, shapeability, dimensional stability and low cost of fabrication. These properties have made woven composites attractive in technical practice, especially in the field of aerospace, marine and sports technology [1–4, 6].

In our previous report [7], a combination of weaving and thermoplastic elements in composite was studied through the utilization of Continuous Fiber Impregnated Thermoplastic Prepreg (COFIT) to produce woven system. The effect of sample cutting directions on the prepreg plain weave's property was examined. Correlations between different specimen geometries and weave characteristics were also noted. In general, the specimen cutting directions give rise to various differences in wea-ving characteristics, which in return influence the properties obtained.

In this work attempts will be made to examine other important aspects of this composite systems and approaches to achieve these objectives will be described. Our objectives were; (i) to identify and correlate the composite properties with the towpreg properties and process variables; (ii) to evaluate the role of weave characteristics in the ultimate composite performance, and (iii) to determine the controlling factors in realizing such a complex system. It should be noted that in many cases, several assumptions were made due to the preliminary nature of the work, particularly with respect to testing and characterization. For example, mechanical testing was confined to the tensile mode and the weave geometry was limited to the plain weave.

2. EXPERIMENTAL

2.1. Materials

Acrylonitrile Butadiene Styrene (ABS) resin of general-purpose grades 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. 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 cut to determine their properties such as dimensions, specific gravity (S.G) and also tensile properties.

2.3. Preparation of Woven System

To ensure the quality of the woven composite, only prepregs having acceptable properties such as dimensions, density and fiber fraction (W_f) were chosen. For the study of the effect of number of towpreg, the towpregs of 4, 7 and 12 tows as well as 12 tows with HIPS as a matrix were used to prepare single ply plain weave laminated system. Then a single laminated woven composite was molded by the following compression molding. Conditions, preheating at 220°C for 15 minutes and subsequently exposed to pressure of 12 MPa for 5 minutes. To prevent sticking and to facilitate demolding, they were placed between TEFLON sheets. No spacer nor mold was used, and an open mold was used throughout. Finally, they were removed from the press and allowed to cool to room temperature under pressure to prevent warping. Then, the plain weave laminated systems were cut into testing specimen sizes in order to characterize the physical properties such as W_f, specific gravity (SG) and void content of the woven system. For the tensile test, the coupons were cut-out based on Type 1, 0° with 120 mm gage length as previously reported [7]. The specimens were then tested according to tensile test method (ASTM D638).

3. RESULTS AND DISCUSSION

Towpreg or prepreg can be defined as fiber impregnated with plastics, in this case, thermoplastic. Studies by earlier workers [8 – 10] in the development of solution based prepregging process have noted that towpreg properties, both physical and mechanical are somewhat controlled by the prepregging variables such as the matrix type and concentration, the pulling rate, the die temperature and so on. Thus, different types of towpregs of desirable properties are derived by using appropriate mentioned variables. In view of the towpregs being precursor to woven composites system which is examined here, it is therefore imperative to describe some relevant aspects of towpreg construction.

The Table I presents some of the typical characteristics of ABS towpregs with 4, 7 and 12 tows and also that of 12 tows but with HIPS as the matrix. All were produced under similar prepregging conditions such as concentration, die temperature, pulling rate, *etc.* Also similar die geometry was used throughout.

As seen, different tows and matrix give rise to basically different type of towpregs with respect to width, void and tensile strength but with more or less similar W_f. This has been attributed to the constant prepregging or impregnation process. Here, it must be noted that for achieving optimal result, each towpreg would require different molding conditions or in the case woven system even different weaving condition. For example, a 4-tow towpreg will have to be molded at

TABLE I Properties of different types of thermoplastic towpregs

Matrices		*ABS*		*HIPS*
tow	4	7	12	12
Width (cm)	1.03	1.52	2.5	2.52
W_f	0.83	0.84	0.86	0.85
Voids (%)	20.5	15.6	12.6	15
0°TS (MPa)	329.9	438.6	580.6	560

Viscosity of HIPS and ABS 30% solutions are 1040 and 1305 cP, respectively measured by Brookfield viscometer, spindle No. 5.

higher pressure and/or temperature than a 12-tow counterpart, judging on the void content.

This is agreement with the previous study of Chong [11], where it was stated that the void contents were different because the similar die geometry was utilized in preparing samples with different number of towpregs. Basically, the die geometry of our prepregging process is adequate for the samples having 12 towpregs, which results in better impregnation and wetting and subsequently reduces the void content of 12 towpreg tapes during the prepregging process. Perhaps, the die is not fully occupied with the smaller size towpregs, and the compaction in insufficient for adequate impregnation which results in a higher void content for a small number of towpreg system.

Similarly with the different matrices of the towpreg, it is apparent that void content of HIPS is marginally higher than that of ABS but with more or less similar W_f. This resulted in slightly lower 0° tensile strength of HIPS towpregs than those of ABS. Probably the prepregging conditions which are used in preparing the HIPS towpregs are inferior to those of ABS system which results in poorer impregnation and wetting of the system. In fact composite wetting might also be affected by the different chemical nature of both resins [12, 13]. Thus in prepregging process, these different resins might differ in degree of wetting and interface properties of the composite, which in turn affects the towpreg end properties.

Generally the properties of the towpreg can be represented by the general equation.

$$P_{\mathrm{Towpreg}(W_f, V\%, TS)} = \{f(\text{Number of tows, matrices}),\ \text{prepregging conditions constant}\}$$

In making a plain weave, a 4-tow towpreg will be easier because of its flexibility. In fact, the nature of the woven ply will be different for the different towpreg. For example at a given size, the 4-tow towpreg will have more interlaces, unit cells, *etc.* Therefore, one would expect different woven composite system with diverse properties if different towpregs were used.

A schematic representation in Figure 1 shows some of the corresponding differences between woven plain weave composites, obtained by using 4, 7 and 12 tows. To quantify these further, the weave

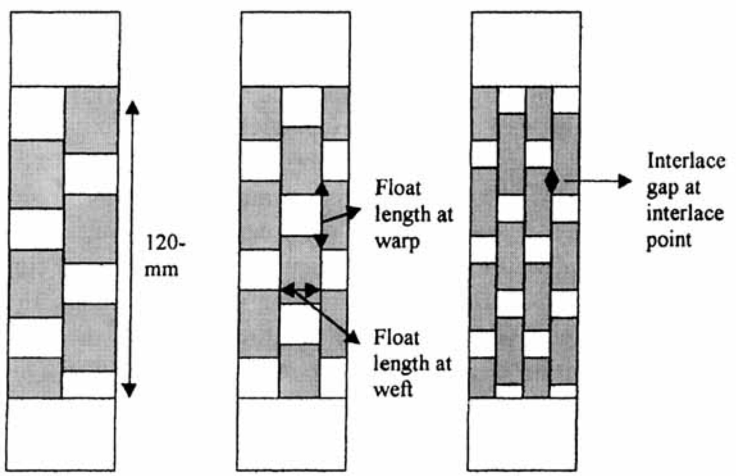

FIGURE 1 A schematic diagram highlighting the effect of number of towpreg weave characteristics present in specimen.

characteristics are reproduced for a given cross-sectional area, *e.g.*, 50 × 220-mm dimension which is equivalent to the size of tensile testing coupon. It can be seen that 4 tow system has a larger number of interlaces, unit cells and longer float length at warp direction but lesser float length at weft direction than those of 7 and 12 tows. In fact the weaveability itself are different as noted earlier by Heng [14].

The miscellaneous properties reflecting the use of different types of towpregs both in number of tows and HIPS instead of ABS in woven system are given in Table II.

It is interesting to note that in almost all cases of different number of tow in towpreg weaves, the similar trend in properties are observed with increasing number of tow in towprepreg there is a substantial reduction in voids but only a marginal change in W_f. For example, with a 4 tow towpreg and woven system, the voids drop from 20.5 to 13% while that of 12 tows from 12.6 to 5.4% while those of W_f remain around 0.84 to 0.88. Thus the reduction in void content resulted in higher tensile strength properties [11] for the higher number of towpreg in woven system.

TABLE II Properties of a single ply plain woven composites, prepared under similar conditions

Matrices		*ABS*		*HIPS*
tows	4	7	12	12
Width (cm)	1.04	1.54	2.55	2.56
W_f	0.88	0.88	0.84	0.86
Voids (%)	13	11.1	5.4	4.3
0°TS (MPa)	102	124	187	198
Number of interlace[a]	18	10	5	5
Float length 0° (weft)[b]	1.1	1.8	2.5	2.5

[a] determined in a given area, gage length of tensile test coupon.
[b] float length at weft direction.

In other words, unlike non-woven system, say UD laminates, a drop in voids while W_f remains constant would normally result in enhancement in strength and stiffness [15, 16]. It is obvious therefore that in woven system, additional effects coming from weave characteristics influence the composite properties. Here, the interply effects can be omitted since the system in discussion is a single ply.

The effects of weave characteristic such as interlace points might be significant here. Judging from the role of interlaces in woven system which has been discussed in previous work [7], perhaps there is a possibility that the void might be present at interlace region. This is due to the different number of towpreg tapes used, which results in a different number of interlace points present in the same sample gage length. For example in 4 tow plain weave, the size of the towpreg is about 1.04 cm, which means that many towpreg tapes are required to occupy the same size of gage length. This basically result to 18 interlace points and 13% of void content compared to those of 12 tows, with the towpreg width of 2.55 cm, 5 interlace points per gage length result in 5.4% of void content. The above findings are illustrated in graphic forms in Figures 2, 3, and 4. Where the correlation between the number of towpreg and woven properties in term of interlace points, void content, tensile strength are given. Apparently the decrease in interlace points relates to the reduction in void content, which results in higher tensile properties of high number of towpreg in woven system. It is well known, however that apart from void content, there are many other factors that might influence the tensile properties such as fiber orientation, weaving characteristics, *etc.*

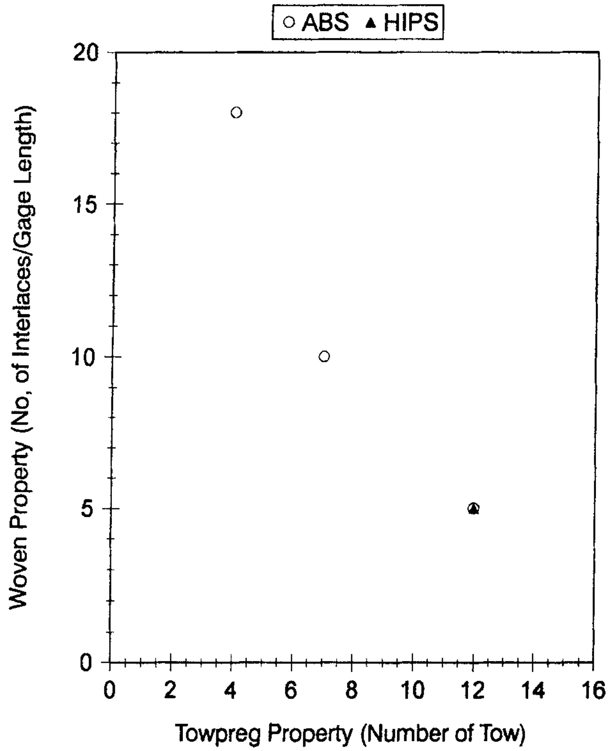

FIGURE 2 The correlation between number of interlaces/gage length and towpreg property in woven system for different number of towpreg and matrices where ply, weave, molding conditions remain constant.

In the case of different matrices in woven system, the trend is different from that of towpreg. It is apparent that with woven systems the HIPS matrix shows a slightly higher W_f but the void content is lower than that of ABS systems using the same molding conditions. This in resulted in higher 0° tensile strength. This might be due to the combination of molding and weave factors which seems to facilitate further impregnation and better wetting in the system. However, the impregnation and wetting might also be influenced by the viscosity of the resin. Since HIPS exhibits lower viscosity than those of ABS, HIPS system should have a superior ability of resin to flow and thus improve impregnation and wetting of the composite [17].

Moreover, it is interesting to note that the weaving process basically creates dimensional stability *via.* tightening effect, judging from the

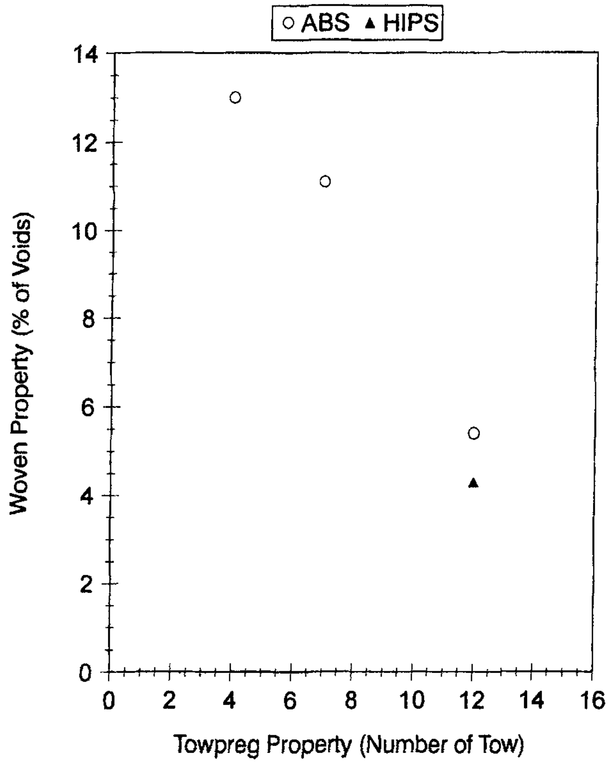

FIGURE 3 The correlation between % of voids and towpreg property in woven system for different number of towpreg and matrices where ply, weave, molding conditions remain constant.

molding itself, which was done in an open mold. These resulted in a minimal change in width of each towpreg after molding process. For example with the 4 towpreg woven system the width change only from 1.03 to 1.04 while for 12 tow from 2.5 to 2.55. This phenomenon is basically different in the case of UD towpreg behavior in an open mold system as earlier noted by Nasir *et al.* [18].

The Type I, 0° stress-strain deformation behaviors of the different number of towpreg and matrices are given in Figure 5. In all cases of different number of towpreg in woven composite system, it is apparent that with an increase of the number of towpreg, the stiffness, maximum stress and toughness of the system increases. The slight reduction of the tensile properties in smaller number of towpreg might be

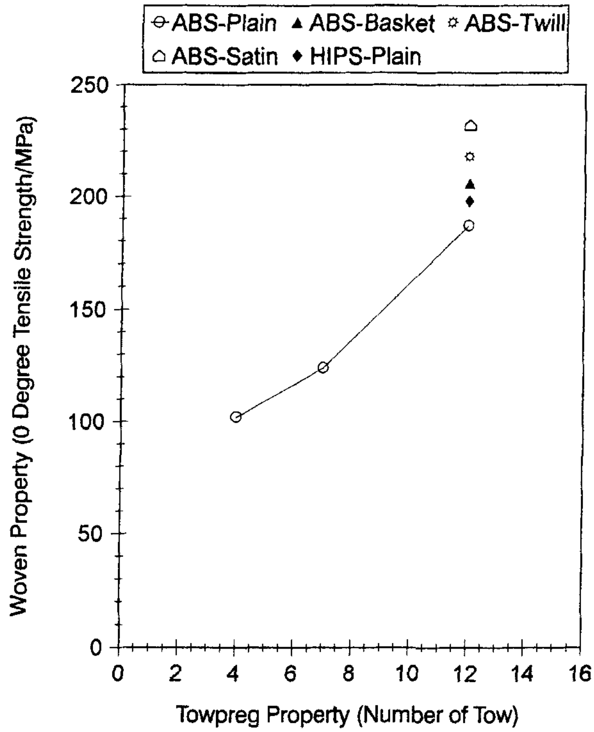

FIGURE 4 The correlation between tensile strength and towpreg property in woven system for different number of towpreg and matrices where ply, weave, molding conditions remain constant.

attributed to many weaving characteristics such as interlace points, unit cell, interlacing gaps, *etc.*, presented in the sample. And it is apparent that the 12 tow woven composite based on HIPS resin shows higher stiffness and maximum stress, with lower toughness than those of ABS resin.

It is obvious that in woven towpreg system, the mechanical properties of the system are governed by the nature of towpreg, weaving characteristics and the molding process of the system. Due to the weaving characteristics, the mechanical properties of woven composite system are lower than those of UD towpreg. The weaving characteristics, for example the interlace point reduce the strength of the plain weave system by the presence of interlacing gaps at 90° towpreg which relates to fiber distortion and void content at this region during the

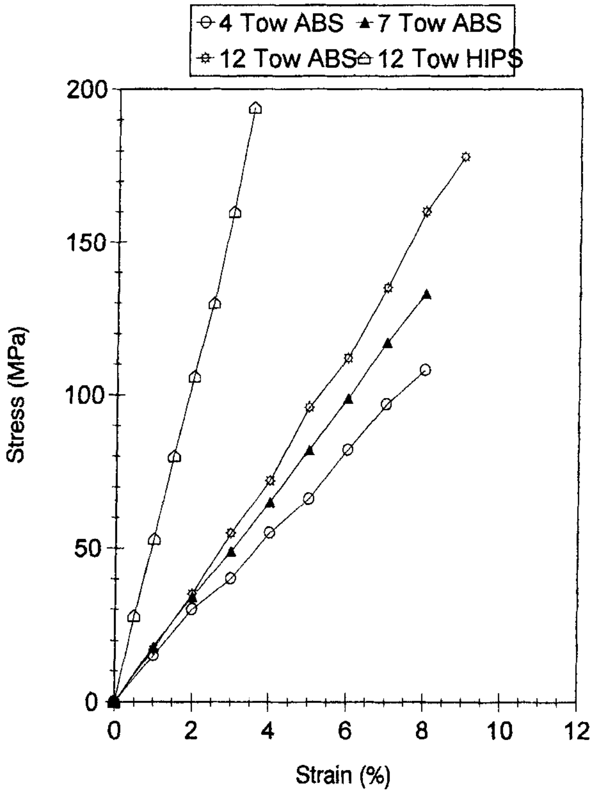

FIGURE 5 The stress-strain deformation behaviours of single plain weave with different number of tow and matrices.

molding process. The properties of woven composite, can be summarized as the following equation.

$$P_{\mathrm{woven}(W_f,V\%,TS)} = \{f_{(p\ \mathrm{towpreg}(Wf,V\%,TS))};\ \text{woven geometry, mold conditions and ply remain constant}\}$$

CONCLUSION

From the experiments carried out, it can be concluded that the woven composite's properties are dependent on the towpregs' properties either number of tows or matrices. For example, the different size of tow preg which differed in width, void content, *etc.*, results to different number of interlaces, unit cell or in general weaving characteristics of the woven system. These in return influence the physical and mechanical properties of the woven composite.

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