THE EFFECT OF NUMBER OF PINS IN THE PULTRUSION PROCESSING OF ACRYLONITRILE BUTADIENE STYRENE (ABS) – GLASS FIBER COMPOSITE

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by

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Dedicated to

My husband for your sacrifice and encouragement
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ABSTRACT

In this project, the effect of using 6 pins and 8 pins in producing prepreg and subsequent laminated woven thermoplastic composite via weaving continuous fiber impregnated thermoplastics (COFIT) was carried out. Here Acrylonitrile Butadiene Styrene (ABS) and E glass fiber prepreg with 12 tows were produced using SIRNA prepreg where the temperature of the die was 220°C and 0.45 m/minute pulling rate was used. The other parameters such as concentration of ABS, temperature of dryer and others are similar with previous studies.

The early stage of the investigation involved studying physical and mechanical properties of the prepreg tape. Based on the investigation, the prepreg tape produced using 8 pins resulted in elimination of matrix loss, more consistency in dimension, bigger fiber weight fraction (Wf), better toughness, higher flexural strength although with slightly lower tensile properties than the prepreg tape produced using 6 pins.

Both the 6 pins and 8 pins prepregs were then woven into plain weave geometry and laminated into a single ply system by using compression molding at 220°C, and at 0 and 12 MPa molding pressure. Both laminated woven thermoplastic composites were then cut and tested via standard physical and mechanical testing in order to investigate the effect of different number of pin on the properties of woven composites. It was observed that parameters such as temperature and pressure during compression molding resulted in significant effect on the woven composite. The effect of the gap sizes of the woven composite toward the appearance, physical and mechanical properties were also observed. Different size of gap was applied to the plain weave composite such as 0 cm x 0 cm, 0.7
cm x 0.7 cm and 1.4 cm x 1.4 cm. Tensile and flexural tests were used to determine the mechanical properties. It was found that the tensile properties of all the gap size from 8-pin composite are higher than those of 6-pin composite when molding pressure was applied.
KESAN BILANGAN PIN DALAM PEMPROSESAN PULTRUSI KEATAS
KOMPOSIT AKRILONITRIL BUTADIENA STIRENE (ABS) – GENTIAN KACA

ABSTRAK

Dalam kajian ini, usaha alternatif telah diambil untuk mengkaji kesan penggunaan 8 pin dalam penghasilan prepreg dan laminasi komposit anyaman termoplastik menggunakan penganyaman gentian selanjut terisitepu termoplastik (COFIT). Disini prepreg Akrolinitrile Butadiene Stirene (ABS) dan gentian kaca jenis E (12 serat) dihasilkan dengan menggunakan sistem pempregan SIRNA dimana suhu pemampat ditetapkan pada 220°C dan kadar tarikan pada 0.45 m/min. Parameter-parameter lain yang digunakan seperti, konsentrasi ABS, suhu pengering dan sebagainya adalah ditetapkan sama seperti parameter yang diguna dalam kajian sebelumnya.

Pada peringkat awal kajian, kesan menggunakan 6 pin dan 8 pin ke atas sifat-sifat fisik dan mekanikal prepreg yang dihasilkan telah diambilkira. Berdasarkan penyelidikan ke atas prepreg yang dihasilkan oleh 8 pin, didapati penghapusan kehilangan matrik, penyeragaman dalam dimensi, Wr yang tinggi, keliatan yang baik, kekuatan pelenturan yang tinggi diperolehi walaupun sifat-sifat tensilnya lebih rendah berbanding dengan prepreg dihasilkan dengan menggunakan 6 pin.

Kedua-dua prepreg tersebut kemudiannya dianyam ke bentuk anyaman plain dan dilaminatkan menjadi lapisan tunggal dengan menggunakan pengacuanan mampatan pada suhu 220°C, dan dengan tekanan pada 0 dan 12 MPa. Kedua-dua laminat komposit anyaman termoplastik tersebut kemudiannya dipotong dan diuji menggunakan pengujian...
fizik dan mekanikal untuk mengkaji kesan bilangan pin yang berbeza-beza ke atas sifat anyaman. Didapati parameter-parametr seperti suhu dan tekanan sewaktu pengacuan mampatan menghasilkan kesan yang berkesan ke atas sifat-sifat komposit anyaman. Kesal bukaan terhadap sifat-sifat prestasi, fizikal dan mekanikal di kaji. Pelbagai saiz bukaan dikaji ke atas penampilan komposit anyaman plain sebagai contoh 0 cm x 0 cm, 0.7 cm x 0.7 cm dan 1.4 cm x 1.4 cm. Pengujian tensil dan pelenturan digunakan untuk mengegalpasti sifat-sifat mekanikal. Sifat-sifat tensil menggunakan 8 pin dengan penggunaan tekanan sewaktu pengacunan mampatan didapati tinggi berbanding dengan 6 pin, sementara itu tanpa menggunakan tekanan, keputusannya di dapati sebaliknya.
CHAPTER 1
INTRODUCTION

1.1 Composite: Overview

Composites or reinforced plastics (RPs) have been designed into many different products for more than a century, with major new composites appearing since 1940 (Rosato, 1991; Bailie, 1973; Visconti, 1992). These materials hold a special place in the design and manufacturing industries, because they are quite simply unique materials (Rosato, 1991). Composites can offer versatile ranges of properties such as high modulus, impact, fatigue, chemical, and creep resistance and so forth. Composites have led to establishment of new industries for the production of raw materials and products, ranging from aerospace vehicles to household appliance, (Partridge, 1989; Kathryn, 1993; Edwards, 1987; Naik et al., 1991).

The development and commercialization of advanced composite are continuously inventing new matrix materials and fibers. The NASA Advanced Composites Technology program was started in 1989 to develop composite primary structures for commercial transport airplanes with costs that are competitive with those of current metallic airplanes (Poe et al., 1997). The emergence of thermoplastic composites as advanced materials has occurred as a result of materials development and technological demand (Leach, 1989; Stuart, 1990). Thermoplastic composites generally offer a combination of high toughness and good environmental resistance (Leach, 1989; Nasir, 1996; Chang & Lees, 1988; Congswell, 1986). However, there is an important problem in the fabrication of thermoplastic composites as compared with thermoset composites. It is the impregnation of matrix resin into the fiber tows because thermoplastic resin has a much higher viscosity than thermoset resin (Leach, 1989; Stuart, 1990; Shanoike & Matsuo, 1996). Therefore, several impregnation techniques
and fabrication approaches have to be used. These include solvent, powder fluidizing, commingled threads, hybrid, and slurry (Leach, 1989; Nasir, 1996; Miller & Gibson, 1996). In general, it is necessary to obtain good impregnation of the matrix into the reinforcing fibers in order to achieve the full properties of the composite.

Industry-engineering development depends on innovation of new materials that has combination of properties. To obtain several combinations of properties some approach such as woven fabric composites are conducted generally.

Woven fabric composites have gained increasing technological importance and consist of two sets of interlaced threads, known as the warp and fill threads (Ishikawa & Chou, 1982; Cox & Flanagan, 1997). Weaves have been used in composites for many years (Cox & Flanagan, 1997; Ishikawa & Chou, 1982). In general, woven (2-D) fabrics have the following advantages over other forms of composite reinforcement such as chopped-strand mat and unidirectional yarns: (a) consistency; (b) uniformity of thickness and weight; (c) improved tensile strength and modulus, where more fibers can be contained within a given volume because of the precise arrangement of yarns, resulting in a high fiber volume fraction in the composite; (d) easy lay-up; and (e) improved compatibility with resin because of a wide range of fabric surface finishes (Edwards, 1987; Newton, et al., 1996).

1.2 Composite: Definition

In general, composite is a combination of two or more materials, differing in form or composition on a macro scale (Hull & Clyne, 1996). In their broadest form, composites are the result of embedding high strength, high stiffness fibers of one material in a surrounding matrix of another material (Schwartz, 1992). The basic definition then, as now, is simply that
of a plastic reinforced with either a fibrous or a non-fibrous material (Rosato & Di Mattia, 1991).

1.3 Composite: Classification

Composite materials have been classified in many ways depending on the ideas and concept that need to be identified. The major classes of structural composites that exist can be categorized as consequence of the wide choices of both matrix and reinforcement available (Schwartz, 1992; Hull & Clyne, 1996; Nasir, 1996).

One simple classification scheme is to separate them according to reinforcement forms: particulate-reinforced, fiber-reinforced and laminar reinforced composites (Schwartz, 1992; Reinhart, 1987; Richardson, 1987; Nasir, 1996). Fiber reinforced composites are composed of reinforced fibers in a matrix and it can be classified into those containing discontinuous or continuous fiber. Fiber reinforced composite materials consist of fibers of high strength and modulus embedded in or bonded to a matrix with distinct interface between them. In this form, both fibers and matrix retain their physical and chemical identities, yet they produce a combination of properties that cannot be achieved with either of the constituents acting alone (Schwartz, 1992).

According to the nature of the matrix, composites can be divided into six categories: polymer matrix composites (PMCs), metal matrix composites (MMCs), ceramic matrix composites (CMCs), carbon-carbon composites (CCCs), intermetallic composites (IMCs), and hybrid composites (Schwartz, 1992).

Polymer matrix composites (PMCs) are the most developed class of composite materials in that they have found widespread applications, can be fabricated into large, complex shape, and have been accepted in a variety of aerospace and commercial
applications. They are constructed of components such as carbon or glass fibers bound together by an organic polymer matrix. These reinforced plastics are a synergistic combination of high performance fibers and matrices.

1.4 Constituent Component of Composite

As already mentioned, PMCs are the most developed class of composite materials in that they have found widespread application. PMCs with polymer as a matrix and the fiber as reinforcement have an interface between them. In short, composite should be viewed as having three components viz.: fiber, matrix and interface. The characteristics and other properties for each component will be discussed here.

1.4.1 Matrix

The matrix is the material that gives body and grip/s or holds the reinforcements of the composites together, and is usually of lower strength than the reinforcement (Reinhart, 1987; Collyer & Clegg, 1986; Richardson, 1987) The purpose of the composite matrix is to bind the fibers together by virtue of its cohesive and adhesive characteristics, to transfer load to and between fibers and to protect them from environments and handling.

In general, plastics in neat form, homo or copolymer can be classified into two major types, thermoplastic (TP) and thermoset (TS). In PMCs, the choice of matrix is related to the required properties, the intended application of the composite and the method of manufacture (Leach, 1989; Askeland, 1994). For example, if chemical and elevated temperature resistances are needed, then obviously thermosets are preferred to thermoplastics. While if better damage tolerance or recycleability is the criterion than thermoplastic is the choice then.
Several roles of the matrix in a composite or fiber-reinforced composite are to: (Schwartz, 1996; Reinhart, 1987; Askeland, 1994) 1) transfer stresses between the fibers, 2) provide a barrier against an adverse environment, and 3) protect the surface of the fibers from mechanical abrasion.

It is apparent that the main functions of the matrix are to hold the reinforcement in place and to some extent, protects them during service. The matrix plays a minor role in the tensile load carrying capacity of a composite structure. However, selection of a matrix has a major influence on the interlaminar shear, as well as on in plane shears properties of the composite material (Schwartz, 1992). The interlaminar shear strength is an important design consideration for structures under bending loads. Here we look at some typical example of both types of matrices.

1.4.1(a) Thermosetting

Among those of current interest, most composites consist of the combination of thermosetting resins such as polyester with type E fiberglass (Visconti, 1992). In thermosetting polymers, the liquid resins are converted into hard brittle solids by chemical cross linking which leads to the formation of a tightly bound three dimensional network of polymer chains (Hull & Clyne, 1996; Nasir, 1996). The mechanical properties depend on the molecular units making up the network and on the length and density of the cross-links. The initial chemicals used and the latter determine the former by the control of the cross-linking processes, which are involved during the curing stage.

Among plastic materials, thermosetting materials generally provide one or more of the following advantages: high thermal stability, resistance to creep and deformation under load and high stability, and high rigidity and hardness (Berins, 1991).
Most applications using plastics take advantage of the inherent ease of processing and excellent balance of properties. However, it can be said that thermosetting polymer are more time consuming to process because of the chemical reaction required to cure them and are generally less impact resistance than thermoplastic (Stuart, 1990). The other problems are the preregs must be stored below room temperature and the handling time for lay-up of part is limited. Careful inventory control, scheduling and special storage conditions are therefore required; this adds to the cost (Leach, 1989; Schwartz, 1992).

1.4.1(b) Thermoplastic

High performance thermoplastic composites have been developed with glass, aramid, and carbon fiber reinforcements and with high temperature resistant engineering thermoplastic resins as matrix materials. Thermoplastic polymers have a linear macro molecular structure that will repeatedly soften when they are heated to their melt temperature and harden, or solidify, when they are cooled (Crawford, 1987; Berins, 1991; Nasir, 1996). Within each thermoplastic family, there are often scores of different varieties. The varieties can be semicrystalline or amorphous (Berins, 1991; Leach, 1989). In general, semi-crystalline polymers have high moduli and yield strengths. The amorphous polymers have lower moduli and yield strengths but higher toughness. Both amorphous and semicrystalline polymers may have anisotropy properties depending on the conditions during solidification.

Thermoplastic composites have emerged in recent years as serious candidates for use as advanced materials in applications such as aerospace and other high performance industries (Partridge, 1989; Schwartz, 1996). For example Three PAN-based carbon fibers, AU4, AS4 and AS4CGP, were obtained from Hercules, Inc. were sent to the Dupont Company for prepregging with an amorphous polyanide copolymer (Chang et al., 1994)
Some of the advantages of using thermoplastic matrix composites are: high toughness and good environmental resistance, no special storage conditions required, no chemistry during fabrication, potential for rapid or re process and easy quality control (Leach, 1989; Schwartz, 1992). Some typical properties for several unreinforced thermoplastic and fiberglass-reinforced thermoplastic are presented in Table 1.1.

Table 1.1.: Typical properties of some unreinforced thermoplastic and fiberglass-reinforced thermoplastics (Berins, 1991; ASM International Handbook, 1988)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Unreinforced TPs</th>
<th>Glass Fiber Reinforced TPs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ABS</td>
<td>ABS</td>
</tr>
<tr>
<td></td>
<td>Nylon 6/6</td>
<td>Nylon 6/6</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.03</td>
<td>1.13</td>
</tr>
<tr>
<td></td>
<td>1.22</td>
<td>1.48</td>
</tr>
<tr>
<td>Glass Fiber (% by weight)</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>41.37</td>
<td>79.29</td>
</tr>
<tr>
<td></td>
<td>75.79</td>
<td>158.47</td>
</tr>
<tr>
<td>Young’s Modulus (GPa)</td>
<td>2.07</td>
<td>6.20</td>
</tr>
<tr>
<td></td>
<td>2.76</td>
<td>8.27</td>
</tr>
<tr>
<td>Flexural Strength (MPa)</td>
<td>75.84</td>
<td>117.21</td>
</tr>
<tr>
<td></td>
<td>106.80</td>
<td>241.15</td>
</tr>
<tr>
<td>Flexural Modulus (GPa)</td>
<td>2.41</td>
<td>2.90</td>
</tr>
<tr>
<td></td>
<td>5.99</td>
<td>5.51</td>
</tr>
<tr>
<td>Tg (°C)</td>
<td>130</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>-</td>
</tr>
<tr>
<td>Tm (°C)</td>
<td>280</td>
<td>264</td>
</tr>
<tr>
<td>Morphology</td>
<td>Amorphous</td>
<td>Semi Crystalline</td>
</tr>
</tbody>
</table>

From the table, we can see the different properties between amorphous and semi crystalline matrices. The tensile strength and flexural strength for amorphous polymer is
generally lower than semi crystalline one but for modulus, the opposite seems to occur. It is shown that semi crystalline is stronger and more flexible than amorphous. Moreover, after being reinforced with fiberglass, both the tensile and flexural strength is higher than the unreinforced. It is apparent that the presence of fiberglass in composite improves the tensile and flexural strength.

In practice, a wide range of properties can be obtained and the strength and heat resistance properties are particularly sensitive to processing history, molecular weight, molecular weight distribution and molecular chemistry (Hull & Clyne, 1996). All these plastics yield and undergo large deformations before final fracture and their mechanical properties are strongly dependent on the temperature and applied strain rate. Another important feature of the properties, which is common to all thermoplastics, is that under constant load conditions, the strain increase with time, i.e. the material creeps under load. This means that in a composite system there will be a redistribution of the load between resin and fibers during deformation.

Some of the disadvantages of thermoplastic composite over thermoset composite are: high processing temperature, prepreg tapes tend to be stiff and boardy.

Fabrication temperature is generally high (more than 200°C), but the processing time is usually in minutes rather than hours. Most thermoplastics supplied in either powder or pellet forms and they are of high viscosity even at high temperature. Impregnation into fiber tows or bundles using melt method has been found to be inadequate, however several approaches have known to be possible, albeit with limitations or confined to resin suppliers. They include; solvent, powder fluidized, commingled yarn, hybrid, and slurry (Nasir, 1996; Partridge, 1989)
1.4.2 Reinforcement Fibers

Fibers are the principal constituent in a fiber-reinforced composite material. They occupy the largest volume fraction in a composite laminate and share the major portion of the load acting on a composite structure (Schwartz, 1992).

There are many forms of fiber reinforcement such as continuous, long, chopped, woven fiber and many more. A very wide range of fibers is available for reinforcing polymer, metal and ceramic matrices. The choice depends on the type of matrix, the processing route and the required properties of the composite. Not least amongst these property requirements is cost effectiveness.

In a composite matrix, a thin layer of matrix material that holds the fibers permanently in the desired orientation and distributes an applied load among all the fibers surrounds the fibers.

Glass fibers are the most important reinforcement fibers from the commercial viewpoint. They are mostly used to reinforce polymer matrices, but small amounts are used in cement, plaster and bitumen products (Bader, 1993; Schwartz, 1992). Glass fibers are usually amorphous, monolithic and although some crystallization may occur after prolonged heating at high temperature (Hull & Clyne, 1996). In the manufacture of glass-fiber-reinforced plastic laminates, bonding between glass and resin is needed. The shrinkage of the resin onto the fiber during curing provides a considerable degree of adhesion, which may be adequate in very dry conditions. Under humid conditions, owing to its affinity for glass, water penetrates at the resin-glass interface and can cause breakdown of the laminate under stress (Schwartz, 1992).

The most important factor determining the ultimate strength of glass is the damage which fibers sustain when they rub against each other during processing operations. The
application of a size coating at a very early stage in manufacture helps to minimize the damage. The size is usually applied as a very thin coating to the fibers by spraying them with water containing an emulsified polymer. The size used depend on the future application of the fibers and serves several purpose: (a) to protect the surface of the fibers from damage, (b) to bind the fibers together for easy processing, (c) to lubricate the fibers, (d) to impart anti-static properties, (e) to provide a chemical link between the glass surface and the matrixes and to increase the interface bond strength (Hull & Clyne, 1996).

Although they are many types of glass composition that are being developed, the four commons, which have been commercially made into continuous glass fiber are the A, E, C and S type. E-glass (E for electrical) originally developed for use as high-voltage electrical insulation. It is low in alkali metals and has high strength, stiffness, and good resistance to chemical attack (Hull & Clyne, 1996). Its main disadvantage is a rather low elastic modulus. However, it is manufactured in vast quantities and is therefore much cheaper than alternative glasses and most other reinforcement (Bader, 1993).

Typical chemical compositions of glasses used for reinforcing fibers, are given in Table 1.2. All predominantly are based on silica with additions of oxides of calcium, boron, sodium, iron and aluminum.
Table 1.2: Typical chemical compositions of glasses used for reinforcing fibers and inherent properties of glass fiber (Bader, 1993; Hull & Clyne, 1996; Nasir, 1996)

<table>
<thead>
<tr>
<th>Composition Of Weight</th>
<th>Type of Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A-Glass</td>
</tr>
<tr>
<td>SiO2</td>
<td>72</td>
</tr>
<tr>
<td>Na2O/K2O</td>
<td>15</td>
</tr>
<tr>
<td>B2O3</td>
<td>-</td>
</tr>
<tr>
<td>Al2O3</td>
<td>-</td>
</tr>
<tr>
<td>MgO</td>
<td>3</td>
</tr>
<tr>
<td>CaO</td>
<td>10</td>
</tr>
<tr>
<td>Properties</td>
<td></td>
</tr>
<tr>
<td>S.G.</td>
<td>2.50</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>3040</td>
</tr>
<tr>
<td>Young’s Modulus (GPa)</td>
<td>69.0</td>
</tr>
<tr>
<td>Tm (°C)</td>
<td>996</td>
</tr>
</tbody>
</table>

The properties of glass fibers depend on type of glass fiber. The types of glass have different of strength, modulus, density, melting point and the others. There are used in many applications such as windows, containers, industrial application and others depend on the properties the glass fibers.

For structural applications, most frequently used are glass fibers with high performance fibers in various forms such as pre-impregnated with a resin to such an extent. The resulting material can be cut, handled and assembled to form multi-ply laminates and to
a finished form by the application of heat and pressure. These materials are generally referred to as prepregs (Bishop, 1998). The most common pre-preg types are as follows, unidirectional tape (unitape) prepreg and woven fabric prepreg.

Table 1.2, shows the strength and modulus depend on additional of oxides, aluminum and magnesium. As already mentioned before in a composite matrix, a thin layer of matrix material that holds the fibers permanently in the desired orientation and distributes an applied load among all the fibers surrounds the fibers. The matrix also plays a strong role in determining the environmental stability of the composite article as well as mechanical factors such as toughness and shear strength. The combined fiber-matrix system in an engineering material designed to obtain the desired of mechanical properties and environment performance. Table 1.2 shows the fiberglass before impregnated by matrix, the mechanical of properties is very high. Table 1.1 while the glass fiber reinforced termoplastic the mechanical become lower but the mechanical properties from the matrix become higher than the matrix in neat form.

1.4.3 Fiber-Matrix Interface

The fiber matrix interface is an integrated part of a composite that provides a mean of stress transfer from fiber to fiber through the matrix. The reinforcement efficiency of a fiber-matrix system, and the degree, to which the material splits during failure process, depends on the adhesion at the fiber-matrix interface. The interfacial properties also influence the resistance to crack propagation in a composite and therefore affect its fracture toughness. If there is too weak a fiber-matrix bond, the material will not support loads in shear or compression. Too strong a bond and the material will be brittle. This can be affected by the
fiber structure, the fiber surface condition, the size of surface finish, and the matrix structure both at the interface and away from the interface.

It is therefore necessary to obtain a good impregnation of the matrix into the reinforcing fibers in order to achieve the full properties of the composite. Good impregnation is also a prerequisite to creating the fiber-matrix interface, which is increasingly recognized as important in determining the composite behavior. Several impregnation techniques may be used and the resulting differences in product form affect the handling, processing and properties of the composite (Leach, 1989).

The majority of effort was concentrated on increasing fiber-matrix adhesion using surface treatments and coatings. Glass fibers have a silane finish applied to protect the glass surface from degradation and to increase the adhesion to resin matrices. Other common terms used are finishing agent, coupling agent or adhesion promotion (Hull, 1981). However, the effectiveness of these agents is somewhat specific, implying its dependence on matrix and reinforcement combination.

Adhesion between fiber and matrix can be attributed to some combination, chemical bonding, mechanical adhesion, inter diffusion and so forth (Stuart, 1990; Hull, 1981; Schwartz, 1992).

1.5 Factors Controlling Fiber Reinforced Composites Properties

Many factors can influence the properties of fiber-reinforced composites. As already mentioned before, some factors that influence the properties are: the resin, the reinforcement and the interface between them. In principle, composites can be constructed of any combination of the matrix and the fiber reinforcement. These constituents of different characteristics thus will influence the composite end properties. For example, many types of
fibers are available for fiber composite materials. They could be organic or inorganic fibers, depending on the end of properties required. Composite that use as carbon fiber reinforcement will produce higher strength and modulus, while that of aramid or kevlar will obtain high impact resistance (Hull, 1981). Meanwhile, the choice of a matrix for a structural fiber composite is limited by the requirement that it has a greater elongation at break than the fibers. Many types of matrix are available for composites, which could be amorphous, semi crystalline, thermosetting, thermoplastic and others that could influence the end properties of composites. Some differences have been earlier described in Sections 1.4.1 and 1.4.2. In general, types and composition of the component available influence the properties of composite.

As been mentioned earlier the interface between matrix and fibers also influence the properties. Another important consideration in the behavior of fiber-reinforced composite is the fiber length and diameter. Fiber orientation also influences the mechanical strength of the composite and the direction in which that strength will be the greatest (Mariatti, 1998). Composite strength and stiffness will be reduced when the fibers are not parallel to the loading direction (Hull, 1981). The others factor that influence the properties is voids. Voids can be defined as air or gas that has been trapped into laminates. Voids are harmful because portion of a fiber passing through the void are not supported by surrounding resin. There are two types of voids in composite materials: a) voids along individual fiber and b) voids between laminae and resin rich pockets (Judd & Wright, 1989). The void content depends on fiber volume fraction and distribution, resin properties and processing conditions such as temperature, pressure and time (Hull, 1981; Nasir, 1996; Mariatti, 1998).
1.6 Continuous Fiber Impregnated Thermoplastic (COFIT)

The emergence of thermoplastic composites as advanced materials has occurred as a result of materials development and technological demand. However, there have been parallel developments in thermoplastic polymers and impregnation technology, which have led to the point where thermoplastic matrix composites can now fulfill the requirements of aerospace applications (Leach, 1990). Composites are available in the form of fully impregnated tapes or fabrics (prepregs) and in other forms including hybrids of polymer and reinforcing fibers, and powder impregnated forms (Leach, 1990). According to Schwartz (1992), prepregs or towpregs are thin sheets of fiber impregnated with predetermined amounts of uniformly distributed polymeric matrix. Fibers could be in the form of continuous roving, mat or woven fabric. According to Wiedemann and Rothe (1990) the term prepreg was derived from the more cumbersome expression of pre-impregnated material.

Prepregs can be divided into at least two classes: those suitable for aerospace, and those to be used in lower performance molding compounds (Mc Carvill, 1996). Aerospace applications demand high-performance, high-quality composites and molding. The lower performance applications employ sheet-molding prepregs for automotive components and appliance housing. The two general classes differ widely in composition, handling, part manufacture, and use.

When the technology was first developed in the early fifties, the term generally concerned materials based on woven fabric and epoxy resin (Wiedemann & Rothe, 1990). Nowadays, the range of available reinforced materials is much wider, and the term has been used for pre-impregnated paper, for reinforcements impregnated with thermoplastics and for sheet molding materials. Prepgreg can be in the form of continuous fiber impregnated
thermoplastic (COFIT) prepreg, continuous strand roving prepreg, woven fabric prepreg and chopped strand mat.

COFIT are slowly gaining acceptance worldwide, (Patridge, 1989; Bratukhin & Bogolyubov, 1995; Nasir, 1996) attributed by the numerous known advantageous such as storage stability, better damage tolerance, recycle-ability, rapid processing cycle which does not involve a chemical reaction. Here, another look at the various influences of process variable on the prepregs properties will be presented. Correlation between the process variable and the prepreg properties determined using the different techniques would be described.

The main problem with using thermoplastic matrices for COFIT is the difficulty impregnation of fiber reinforcement with high viscosity resins. It is necessary to obtain good impregnation of the matrix into the reinforcing fibers in order to achieve the full properties of the COFIT. Several impregnation techniques may be used and resulting in differences in product form such as affect the handling processing and properties of the COFIT. The techniques may be divided into those that give a pre-impregnated material and those that give a post-impregnated form (Leach, 1989; Miller & Gibson, 1996)

1.6.1 The Pre-impregnation Techniques

The main feature of the pre-impregnated materials is full wetting and impregnation of the reinforcing fibers, with no or minimum void. In addition, it is desirable that the matrix be uniformly distributed without resin rich areas, and that the prepreg should be of uniform thickness. This technique was aimed to reduce the viscosity of the thermoplastic matrix in order to achieve rapid impregnation. The pre-impregnation technique can be divided into
three methods: melt impregnation, solvent impregnation and impregnation using pseudo-thermoplastics.

1.6.1(a) Melt Impregnation

In principle, the simplest method of impregnation is to pull the reinforcing fibers through molten matrix. The high viscosity of thermoplastics matrix makes it extremely difficult to achieve good impregnation by this technique. The other usual problem is residence times for the fibers in the presence of the melt were not sufficient to allow complete impregnation and the pressure applied to the tows from the molten resin caused the fibers to close together, decreasing the permeability of the tow. Therefore melt impregnation has been found to operate well with low viscosity melts, such as Nylon 66, but polymers of higher viscosity require modification of molecular weight distributions (Caldwell and Cortez, 1988; Mc Carvill, 1996). The process is primarily aimed at the production of long fiber injection molded pellets but there is interest in using it to produce filament wound and pultruded product.

1.6.1(b) Solvent Impregnation

Solvent or solution impregnation has primarily been used with amorphous thermoplastic (as most crystalline thermoplastics are not readily soluble in solvent) in which the high viscosity of the melt is reduced, using solvents. The resulting thermoplastic solution enables impregnation of both unidirectional and woven reinforcement. After complete wet-out of the reinforcing fibers by the solution, the solvent must be extracted. A problem with solution impregnation is that the presence of residual solvent compromises processing and
reduces service performance. It is essential that the suitable polymers for solvent impregnation possess good solvent resistance when in service. Composite structures can often be exposed to aircraft hydraulic fluids, deicing fluids, commercial paint strippers and cleaning agents. In addition, there is the fact that materials produced by this route have a less than optimum fiber-matrix interface (Miller & Gibson, 1996).

1.6.1(c) Impregnation using pseudo-thermoplastic

Pseudo-thermoplastics may be processed in a similar manner to thermosets due to their initial low viscosity. The resultant prepreg sheets produced using the above methods are generally stacked and consolidated with the application of pressure and heat or are pultruded into sectional products. The advantage is that the fibers are fully impregnated before shaping, producing composites with a good, and reproducible fiber-matrix interface. A major disadvantage, however, is that the product forms are stiff and boardy, which reduces lay up design freedom during manufacturing (Miller & Gibson, 1996).

1.6.2 Post-impregnation Techniques

This technique brings the solid polymer and fiber reinforcement together to intimate contact. The aim of this is to reduce the distance the polymers melt must flow in order to fully impregnate the fiber. Unlike the pre-impregnation processes described, where the impregnation and consolidation steps are separated, shaping, final impregnation and consolidation can take place in a single stage. Four main techniques are employed in this area: film stacking, powder coating, co-weaving and hybridization.
1.6.2(a) Film Stacking

Film stacking was one of the first techniques to be used and may be applied to any thermoplastic that can be converted into a film. Layers of polymer film are interlayer with the reinforcing fibers and impregnation is achieved by applying heat and pressure. Film stacking may be used to make flat sheets that can then be fabricated in a subsequent stage. It is difficult to achieve good impregnation due to the viscosity of the polymer and it is usually necessary to use long times or high pressure together with high temperatures. The advantage in that it is possible to make components from combinations of fibers and polymers those are not available in commercial prepreg form.

1.6.2 (b) Powder coating

Particles of the polymer are distributed into the reinforcing fiber and impregnation is usually achieved in the processing stage. The powder technique has the same disadvantages as film stacking, in that impregnation must be completed during the processing stage. The times, temperature and pressure required will be highly dependent on the size and distribution of the particles. An advantage of the technique is that it can provide a drapeable prepreg and may have tack if a suitable agent is used.

1.6.2 (c) Co-weaving

Co-weaving consist of weaving tows of the reinforcing fiber and polymer fiber together. The technique has the simplicity of being a textile operation, and is therefore easy to
perform, and the fabric has drapability. Disadvantages are that it is necessary to obtain the polymer in a fiber form and that impregnation takes place during the processing stage. Co-woven composites are made by a number of textile suppliers, and have the advantage of providing a route to material not available in prepreg form.

1.6.2(d) Hybridization

Hybridization is also known as co-mingling and involves an intimate mixing of polymer and reinforcing fibers into a single tow. The resultant hybrid tow is normally woven into a fabric but could be used in a unidirectional form. The quality of the composite will depend upon the size and distribution of the polymer fibers. Final impregnation is achieved during the processing. In principle it should be easier to achieve full impregnation in a hybrid system than in a co-woven one as there should be a greater degree of mixing an the hybrid.

1.7 Woven composites

The science and technology of woven fabrics are not new (Ishikawa & Chou, 1982). The early systems were composed not of yarn, but of reeds, grasses, saplings, and the like. These materials were passed one across the other, over and under, to form a coherent mass.

Woven fabrics are fabrics in which two or more sets of yarn are interlaced at right angles to each other (Domínguez, 1996). All woven fabrics are formed by interlacing two sets of threads: the set of vertical threads is called the warp and the horizontal threads are known as the filling (Ishikawa and Chou, 1982). The performance of woven fabrics differs from those of other fabrics containing yarns. Usually, woven fabrics are firmer and more rigid due to the right-angle position of the interlacing yarns. Therefore, they are less drapable.
(have a higher resistance to shearing) and are not very extensible. The strength of woven fabrics cannot be directly compared to that of other fabrics containing yarns because breaking strength is the appropriate measure for woven fabrics. It can be noted, however, that breaking strength in woven fabrics is usually greater in the lengthwise than crosswise direction.

Woven fabrics have gained increasing popularity in the fabrication of structural components using fiber composites. Woven fabric prepgs are particularly suitable, as compared to unidirectional tapes (Ishikawa & Chou, 1982) and the most widely used fiber reinforced resin forms. They typically offer flexibility in fabrication technique, but at a higher cost than other prepreg form. In fact now, woven thermoplastic composites are considered as competitors in niche engineering applications such as aircraft, aerospace and construction industries (Stuart, 1990).

Until a few years ago, continuously reinforced thermoplastic composites were available only in boardy form, because of the rigidity of the resin (Bailie et al., 1973). Additionally, ensuring adequate wetting of the filament using conventional prepregging methods is at best difficult because of the high viscosity of advanced performance thermoplastics. For thermoplastic composites we can identify at least three woven product forms (Measuria & Cogswell, 1986) based on: woven impregnated single tows, directly impregnated woven fabrics, and interpenetrated fiber systems. These complement and extend the usefulness of the archetype form of preimpregnated tape based on continuous unidirectional fibers. Each of those woven product forms is itself capable of an indefinite diversity. Furthermore, here the explanation about the type of the woven composites will be described.
1.8 Types of Woven Composites

The most important categories of woven system, according to Cox & Flanagan (1997) are two-directional (2-D) and three-directional (3-D) dimensional fiber architecture. The division into 2-D and 3-D composites is determined by whether the fiber preform alone (in the absence of the matrix) can transport loads continuously in three or only two linearly independent directions.

2-D woven composites are the most commonly available, and their use is standard in circuit boards and in the marine, aerospace, and other industries. For most applications involving 2-D weaves and high performance resins, either the hot melt or the solution method to create the prepreg applies the matrix. In general woven 2-D have the following advantages over other forms of composite reinforcement such as: consistency, uniformity of thickness and weight, improved tensile strength and modulus, easy of lay-up and improve compatibility (Newton et al., 1996).

3-D woven composites are created on a multiwarp loom. The purpose of 3-D construction is to reinforce composite materials in three mutually orthogonal directions to improve their shear strength and rigidity. A number of structures for elevated temperature use, such as solid rocket nozzles, disc brakes, and space vehicle and reentry body components, may require reinforcing in 3-D.

However, these two categories of woven composite have their own advantages depending on the final properties required and the cost allocated for the project. The most basic approach to preforming is 2-D weaving. This fundamental type of weaving can be done on equipment as the late 1800’s (Edwards, 1987). These patterns are all oriented 0 and 90 degrees. The main types of 2-D weaving and their special characteristics are: plain weaves, basket weaves, twill weaves and satin weaves as described below.
Plain weave fabrics as shown in Figure 1.1 have a simple structure in which each warp and fill yarn passes over the end or pick and under the next. This construction gives a reinforcement fabric that is widely used in general applications and can be relied upon to give reproducible laminate thickness. Tightly woven plain weave fabrics are sometimes difficult to wet out quickly.

![Figure 1.1: Type of plain weave](image)

The basket weave as shown in Figure 1.2 has two or more warp yarns that interlace over and under two or more filling yarns. Although the basket weave is less stable than the plain weave, it is more pliable and will conform more readily to simple contours.

![Figure 1.2: Type of basket weave](image)
The twill weave as shown in Figure 1.3 interlaces one or more warp yarns over one and under two or more filling yarns in a regular pattern. This produces either a straight or a broken diagonal line in the fabric, which consequently has greater pliability and better drapability than either plain-woven or basket-woven fabric does.

![Twill weave diagram](image)

**Figure 1.3: Type of twill weave**

Satin weave fabrics as shown in Figure 1.4 are similar to twill but the number of ends and picks, which pass over each other before interlacing, is greater. The interlacing is always with one crossing thread so that one side of the fabric is comprised mainly of warp yarns and the other of fills yarns. Among the several characteristics that make satins eminently suitable as reinforcement fabrics are excellent drapeability, smooth surface, minimum thickness, and high tensile and flexural strength.

![Satin weave diagram](image)

**Figure 1.4: Type of satin weave**
1.9 Factors influencing the characteristics of woven composites

Many factors influence the characteristics of woven composites. Beside the woven geometry such as type or shape of woven, distance between gap or hole on the woven, and laminated between system of the woven influence characteristic of woven composites. Because woven composite consist of the warp and weft, they will result in presence of hole or cavity between them which that can reduce mechanical properties of system.

The hole or cavity formation can be as follows: 1) hole inside the prepreg that produce from the air trapped inside of the matrix, 2) hole or cavity is formed during woven process and 3) hole and gap are produced when weaving processing, but the hole or gaps are formed because of distance or gap from the prepreg between warp and weft. The influence hole in the direction of strength properties of woven fabrics has been investigated by Bailie et al, (1973) that is impression of hole influence the tensile properties of graphite and epoxy for woven fabric composites.

1.10 Pressure Molding on the Woven Composite Based on Prepreg COFIT

An obvious advantage of using woven composite based on prepreg COFIT compared to the non-woven system is that the chance of the damage to propagate are reduced with the adjacent ply and thus easily repaired. As reported by Cox and Flanagan (1997), woven or textile composite systems are favored for their superior damage tolerance. Previous study by Stuart (1990) has found that in general, laminates made by woven reinforcement have better resistance to impact damage than laminates with non woven system for example in unidirectional tape laminates.
The main purpose of using compression molding on the woven prepreg thermoplastic is to improve the penetration of the matrix resin, in order to spread all parts of woven to make an integrated structure. Other reasons are to improve wetting degree of fiber and to strengthen the laminate prepreg woven thermoplastic. In addition, the role of pressure during pressing is not only to give compaction for fiber, but also to remove any solvent, which are still traps on the hole or cavity. Therefore, void content at interplay and interlaminar can be reduced to produce laminate with better interphase condition.

On the laminating process, the mechanical properties of the materials are strongly governed by molding or processing conditions. This is because molding process, which involves changes in temperature, pressure and time, functions to soften the matrix in order to increase the fusion among plies, improve impregnation and wetting and to bond together two or more lamina into a strong laminated system. However, too high a temperature and pressure can destroy laminating quality. Therefore, to choose the suitable compression molding conditions are important, in order to optimize the laminate prepreg woven without destroying the mechanical performance.

1.11 Prepreg COFIT and woven composite based on Pultrusion Processing

The project used the COFIT prepregs in tape form, which is prepared from pultrusion technique. The SIRNA prepregging system is a prototype machine, which is based on solution impregnation approach.

Pultrusion consists of different parts (see Figure 1.5). The process begins with the delivery of fibers into a resin tank, where the fibers are impregnated with resin at room temperature. Inside the resin tank, there are few rollers, which assist the spreading of fiber and therefore increase the impregnation of the composite. Doctor Blade, which is situated at
the exit of resin tank functions to squeeze out the excess resin and increase the degree of impregnation. Next, the dryer is used to dry the prepreg and subsequently evaporate the solvent. The impregnated fibers are squeezed into a long die, which is tapered along the passage. This tapering enables consolidation of the prepreg and also to remove the excess resin. In the die, the impregnation is improved through the application of heat and shearing occurring at processing temperature. The hot prepreg coming out from the die is rapidly cooled by a cold air jet and then followed by the pulling mechanism and the cutter that enables the product to be cut to desire length.
Figure 1.5: The schematic illustration of Pultrusion type prepreging system

(1) glass fiber; (2) impregnation tank which contain resin; (3) dryer; (4) die; (5) cooler; (6) puller; (7) prepreg tape
Development of prepreg COFIT (Continuous Fiber Reinforced Thermoplastic) via Pultrusion method was investigated by Ishak (1995). It was found that Doctor Blade cannot control perfectly the matrix solution and this subsequently influences formation of the excess matrix.

According to the reports that have been published (Nasir et al., 1995, 1996) Doctor Blade opening is the most critical factor in controlling the resin uptake and the subsequent impregnation process. Moreover, prepping of ABS and HIPS Thermoplastic towpregs by solution pultrusion process also was studied. This results in an overall improvement to the towpregs combined with less excessive loss of solvent and resin at the die. Furthermore, a little solvent still retained does help the consolidation process in the die, particularly for those having large numbers of fiber tows.

Preliminary studies of woven thermoplastic composite have been studied by Mariatti (1998) and in this work, 12 tows E glass/ABS was produced using SIRNA prepregger system. The single ply laminate was prepared by weaving into different or appropriate woven patterns. A woven composite were stacked according or with varying number of woven plies followed by molding under condition of 220°C and 12 MPa for 20 minutes. It is observed that the prepreg technique shows better properties than the unimpregnated woven fabric approach. Another experiment carried out (Mariatti, 1998), the preliminary results are:

The tensile properties are governed by the weaving characteristics such as interlacing gaps, unit cell, etc. which are controlled by cutting directions, positions and specimen’s gage length.

The woven composites properties are dependent on the towpregs properties either number of tows, matrices, geometry or pattern and molding condition.

The holes sizes influence the damage behavior of the woven composite.
All the above studies and reports are using similar pultrusion equipment using 6 pins at impregnation tank, as shown in Figure 1.6.a.

![Diagram of impregnation tank with pins and doctor blade](image)

Figure 1.6: The Impregnation Tank, a: using 6 pins, b: using 8 pins

As shown in Figure 1.6.a. the impregnation tank has four pin rollers and the others are recognized as doctors Blade. The shape of doctor Blade are the same with the forth of the pin roller. Hence the doctors Blade in this research is identify with the pins, so the impregnation tank is using 6 pins.

Based on the studies before the problem using 6 pins is the function of doctor blade in controlling the resin uptake. In the present study the impregnation tank using 6 pins and 8 pins as shown in Figure 1.6 for the purpose of comparison the physical and mechanical properties. Moreover the using of additional pin is to decrease the matrix loss at the die entrance. Meanwhile, the processing was chosen and prepared under similar conditions as the study before. For example, matrix solutions, fiber, die temperature, pulling rate, number of
tow, molding condition and the others. The dimension of the prepreg reliability were analyzed and compared for both systems (using 6 pins and 8 pins).

The prepreg tape produced using 6 pins and 8 pins were used to prepare the woven composite. They were woven manually according to desirable pattern of plain weave and were molded using compression molding under a predetermined condition pressure molding of 0 MPa and 12 MPa and temperature of 220 °C. The properties for both systems were analyzed and compared. Moreover, the effect of temperature and pressure in compression molding to the gap for both systems were also studied. The prepreg tape produced using 6 pins and 8 pins were woven manually according to desirable pattern to the gap size of 0, 0.7 and 1.4 cm as shown in Figure 3.12. The appearance and the properties of the woven composite is comparing with using 6 pins and 8 pins.

1.12 Objectives of the Project

The first objectives of the project is the preparation of ABS-glass fiber composite material utilizing pultrusion technique using two different pin numbers, i.e. 6 pins and 8 pins, located at the end of the impregnation tank.

The second objective is to compare the materials produced by using 6 pins and 8 pins in terms of various properties and the effect of some processing parameters on these properties.

The two materials are compared at two stages, the prepreg stage and the woven stage. At the prepreg stage, the properties evaluated are, weight fraction, density, void content, volume fraction tensile strength and flexural strength.

The woven composite, made from the prepreg tapes produced using 6 pins and 8 pins, were prepared according to desirable pattern of plain weave with gap sizes of 0, 0.7 and 1.4 cm.
cm. The effect of molding pressure and temperature on the tensile and flexural properties was evaluated and compare between the two systems.
CHAPTER 2

EXPERIMENTAL

2.1 Raw Material

2.1.1 Matrices: Acrylonitrile Butadiene Styrene (ABS)

General-purpose grade ABS, Polylac PA757 manufactured by Chi Mei Co. Ltd, Taiwan was used in this study. This resin was yellowish in color and was obtained in pellet form. Basically, ABS is a thermoplastic composed of three monomers i.e. acrylonitrile, butadiene and styrene in varying proportions. Due to this nature, it has a balance combination of good mechanical properties, wide service temperature range and easy of fabrication. The acrylonitrile component contributes to surface hardness, heat and chemical resistance whereas styrene gives rise to process ability, rigidity and strength. While the third component, butadiene provides toughness and impact strength. A general structure of ABS is shown below;

\[
\begin{align*}
\text{acrylonitrile} &\quad \text{butadiene} &\quad \text{styrene} \\
\end{align*}
\]

\[
\begin{array}{c}
\begin{array}{c}
H \\
H \\
C - C \\
H \\
CN \\
\end{array} \\
\begin{array}{c}
H \\
H \\
C - C \\
H \\
y \\
\end{array} \\
\begin{array}{c}
H \\
H \\
C - C \\
H \\
z \\
\end{array}
\end{array}
\]
At microscopic level, ABS is a two-phase matrix where styrene-acrylonitrile copolymers construct the continuous phase and the discrete phase is formed by polybutadiene. Styrene-acrylonitrile has thermoplastic nature whereas the discrete and dispersed phase (i.e. polybutadiene) possesses elastomeric characteristic. Hence, with the combination of these characteristics, ABS exhibits better dimensional stability and toughness.

Furthermore, the beauty of ABS is product flexibility, where the composition of the terpolymer or the proportion of each monomer can be tailored to fulfill specific product requirements. Because of its compositional versatility, ABS resin are manufactured in a wide range of grades including medium and high impact, heat resistance, plate able fire retardant and both low and high gloss varieties (Berins, 1991). This makes the range of applications for ABS materials extremely broad. Property rise, ABS falls in between commodity plastics and engineering resins and it fills the property requirements for many plastics parts at reasonable price. Therefore, due to the reasons above and it is easier to be purchased locally; ABS resin was selected for this study. Table 2.1 below shows the properties of ABS.
Table 2.1: Typical properties of ABS (Brydson, 1995)

<table>
<thead>
<tr>
<th>Properties</th>
<th>ABS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.02 – 1.06</td>
</tr>
<tr>
<td>Tensile Strength (at yield MPa)</td>
<td>45</td>
</tr>
<tr>
<td>Young's Modulus (GPa)</td>
<td>2.5</td>
</tr>
<tr>
<td>Flexural Strength (MPa)</td>
<td>76</td>
</tr>
<tr>
<td>Young's Modulus (GPa)</td>
<td>2.8</td>
</tr>
<tr>
<td>Coef. Of Thermal Expansion (10^-5/K)</td>
<td>9</td>
</tr>
<tr>
<td>Elongation at break, %</td>
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<tr>
<td>Izod Impact Strength (at 23°C)</td>
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</tr>
<tr>
<td>Tg(°C)</td>
<td>130</td>
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<tr>
<td>Tm(°C)</td>
<td>240</td>
</tr>
<tr>
<td>Viscosity* of 30% W/W solution (cP)</td>
<td>1305</td>
</tr>
</tbody>
</table>

*measured using Brookfield viscometer, spindle No. 5

2.1.2 E-Glass Reinforcement Fibers

The continuous E-glass fiber reinforcement was used in this research as shown in Figure 2.1. It was manufactured by Central Glass Ltd., Japan and was supplied by a local company, Euro-Chemo-Pharma (M) Sdn.Bhd. in form of roving and marketed as a pultrusion grade. In this research, E-glass fibers was chosen because of its lower cost,
superior dimensional stability, moisture resistance, excellent electrical properties and advocated for pultrusion (Schwartz, 1992; Hull & Clyne, 1996).

Table 2.2: The properties of E-Glass Fiber (Hull & Clyne, 1996)

<table>
<thead>
<tr>
<th>Properties</th>
<th>E-Glass Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>2.54</td>
</tr>
<tr>
<td>Tensile Stress (GPa)</td>
<td>2.0</td>
</tr>
<tr>
<td>Tensile Modulus (GPa)</td>
<td>76</td>
</tr>
<tr>
<td>Strain (%)</td>
<td>2.6</td>
</tr>
<tr>
<td>Poison Ratio</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Figure 2.1: E-Glass fiber was manufactured by Central Glass Ltd., Japan and was supplied by Euro-Chemo-Pharma (M) Sdn.Bhd. in form of roving.
2.1.3 Methyl Ethyl Ketone

Solution based method of pultrusion is utilized and Methyl Ethyl Ketone (MEK) was used as a solvent in this research. MEK was supplied by local supplier, Exxon Chemical (M) Sdn Bhd. MEK was selected because it has relatively low toxicity, inexpensive and capable of dissolving amorphous resins such as ABS readily (Bader, 1993). A general structure of MEK is shown below:

\[ \text{H}_3\text{C} \quad \text{C} \equiv \text{O} \quad \text{H}_2\text{C}_2 \]

2.2 Equipment

Two types of processing equipments were used in this study. The first equipment is the pre-pregging machine where Continuous Fiber Impregnated Thermoplastic (COFIT) was produced. This machine is actually a pultrusion line as shown in Figure 2.2, consist of several components which details will be explained in the next section. The second instrument is a compression-moulding machine it is where the woven laminate was molded at a pre-determined temperature.
2.2.1 Prepregging Machine

Throughout the experiment, the prepreg tapes were prepared by using a SIRNA pultrusion type prereger. The pultrusion equipment used was fabricated in School of Industrial Technology Universiti Sains Malaysia (Nasir et al., 1996). The pultrusion machine consists of different parts (see Figure 2.2). The process has been explained in Section 1.11.

Figure 2.2: The Pultrusion equipment

2.2.1 (a) Impregnation Tank

The impregnation tank consists of a rectangular metal block with a dimension of 46 cm x 10 cm x 10 cm and has a maximum capacity (ABS + MEK) of 4.5 liter (Ishak, 1995; Shahnong, 1996). The impregnation tank as shown in Figure 2.3, has several mortars to provide tension to the fibers during impregnation. The function of tension is to stretch the fibers so that the ABS solution can penetrate into the fibers. A doctor Blade that is situated
at the top end of the tank is used to control the extent of impregnation. This could be determined by the value of fibers weight fraction of the prepreg tape.

Direction of pulling

E-glass fibers inside

Pin

Figure 2.3: The Impregnation Tank with 8 pins

2.2.1 (b) Dryer

The function of the dryer is to evaporate the solvent in the prepreg tape after it exits the impregnation tank. The dimension of the dryer is 46 cm x 10 cm x 10 cm. The temperature of the dryer is maintained between 135°C-145°C using hot air.

2.2.1 (c) Die

The purpose of the die equipment is to control the width of the prepreg tape product and also to evaporate residual solvent (Ishak, 1995). The width and the length of the die equipment are factors that influence the properties of prepreg tape (Ishak, 1995; Shahnson, 1996). The die equipment has a dimension of about 46 cm x 10 cm x 10 cm, and has width of aperture of 2 mm x 5 mm. The temperature of the die equipment is fixed at 220°C.
2.2.1 (d) Cooler

The cooler equipment uses airflow from a compressor at room temperature. The cooler is used to cool the prepreg tape to room temperature after leaving the die and before it enters the puller. This is to ensure the temperature of the prepreg tape is below its T\text{g}.

2.2.1 (e) Puller

The function of the puller equipment is to pull the prepreg tape product at certain speed. The speed of the puller will determine the time of the prepreg tape in the other equipments. The factors that influence the performance of puller are the clamps system between the puller and the force of the motor. The puller system with two gripping system made up from rubber lining is used to decrease the damage of surface the prepreg tapes. In general, the speed of puller equipment can be increased until 0.75 meter/sec., and the power of the motor is 2 HP. As indicated by previous works (Ishak, 1995; Shahnon, 2000) the new puller (which was used in this study) was introduced to overcome the slippage problem of the prepreg.

2.2.2 Compression Molding Equipment

The appropriate prepreg tapes were used to prepare the woven laminated system. In this study, plain was chosen over other woven pattern like twill, basket and satin due to ease of handling and preparation (Mariatti, 1998). The laminate was compression molded with preheat temperature 220°C; preheat time, 15 minutes and molding time 5 minutes.
However in case where the effect of molding condition was to be identified, the preparation was carried out in similar manner, but with different pressure required. As shown in Figure 2.4 the compression molding equipment has two plates, the temperature of the plates is controlled by the controllers. In this study, plain weave with different size of gap was compression molded and followed by preparation of test coupons.

Figure 2.4: The Compression Molding Equipment

2.3 Experimental Procedure

In this study, experimental procedure has been divided into two parts. The first part of the study is to produce and to analyze the properties of prepreg tapes with the used of different number of pins. The various types of prepregs were then characterized by physical and mechanical properties. The second part involves the preparation of plain-woven system from the prepreg tapes, followed by analyzing of the properties.
2.3.1 Preparation of Matrix Solution

30 % w/w ABS solution was prepared by dissolving 3 kg of ABS with 7 kg of MEK. During the preparation large amounts of materials were used to ensure effective mixing since the mixing container is quite big. Furthermore the consumption of matrix solution during pultrusion process was relatively fast and to ensure continuous and adequate supply of solution in the impregnation tank, matrix solution was added when necessary (i.e. fiber roving were not fully submerged). 30 % ABS w/w matrix solution was chosen because it was an optimum solution concentration for better prepregs properties as reported by previous workers (Nasir, 1996; Sahnon, 1996; Ishak, 1995; Mariatti, 1998). Method of dissolving ABS in MEK is by using high-speed stirrer as shown in Figure 2.5. The first step, the container was filled with MEK. Then ABS was added slowly with the stirrer rotating at low speed. After fifteen minute, all ABS was charged into the container and the stirrer speed was increased to 1400 rpm, and the mixture was continuously stirred for 1 hour. During stirring process the hole which accommodate the stirrer should be close, to prevent solvent evaporation. Matrix solution was stored in a closed clean container for further use.
2.3.2 Preparation of the prepregs tape

Before carrying out the pultrusion process, the drying chamber and die has to be heated to operation temperature. Around ½ hour was required to obtain die temperature of 220 °C, while waiting the temperature to stabilize, 12 tow glass fibers were pulled through the impregnation tank and aligned on the die. Then the upper platen of the die was lowered to close the die. The ABS matrix solution was poured into the impregnation tank only after the temperature of the drying equipment was stable. This is to reduce solvent evaporation prior to the prepregging process that could affect the concentration of the solution. The lid of impregnation tank was then placed and the process pultrusion could be started at a predetermined puller speed. It was very difficult to achieved stability of prepregs product, because cracks often occurred when the prepregs came out from the die. Fixing a shape at the end at the die solved this problem. Nevertheless, the shape of prepregs was still not uniform. Another weakness of the process was at the die, where when prepregs go through at the die entrance some matrix stick to the thin slit entrance forming a blockage at the die. This phenomena if not monitored will obstruct the prepreg tape go through inside the die.
and the process will have to be stopped. In order to continue the process, the die cavity has to be cleaned. This subsequently will increase cost operation and spoiled the surrounding area of the die.

2.3.3 Preparation of Woven Prepreg

The prepregs tapes that were produced with fixed processing parameters are woven manually into plain weave form. In making plain weave, a few influential factors should be considered and taken care of:

- visual quality of the prepreg tape has to be good such as no crack, no break and uniform wetting of the resin on the surface of prepregs tape.
- try to get uniforms gap and interlace during weaving.

Several plain weaves were made, viz. plain weave without the gap and plain weave with varying gaps. In this study for varying the gap, two dimension of gaps were used i.e. 0.7 cm x 0.7 cm and 1.4 cm x 1.4 cm.

2.3.4 Preparation of Final Woven Laminated Composite

Here, the three types of plain weave were arranged on the compression-molding machine. To ensure the quality of the woven composite, only the prepreg tapes having acceptable properties such as dimension, density and weight fraction were chosen. They were woven manually according to desirable patterns as already mentioned.
Single plies laminated composite from each pattern was respectively put on to the compression molding machine and molded under the following conditions:

Preheat time: 15 ± 0.5 minutes
Pressure time: 5 ± 0.5 minutes
Preheat temperature: 220°C
Pressure: Zero and 12 MPa

Teflon sheets were placed on both surface of the prepregs tape to prevent sticking and assist remolding. After 20 minutes the molded woven composite was removed from the compression-molding machine and allowed to cool to room temperature under some pressure to prevent warping. In this case, where the influence factors of molding conditions were to be examined, the woven were molded in a similar manner but at different pressure. Portions of the woven composite were cut and the properties were analyzed.

2.3.5 Preparation of the Test Coupons

Test coupons with appropriate shapes and direction were cut out from the laminated woven composites using a band saw, model CB 75 F. For physical properties test coupon 50 mm x 50 mm were used. Meanwhile for mechanical properties the dimensions of test coupons were 220 mm x 50 mm as shown in Figure 2.6.
Figure 2.6: The Specimens Geometry for Plain Weave System

Where:

A = gage length
B = length of the specimen

2.4 Testing and Characterization

Common testing and characterization methods have been done to obtain the various properties of the prepregs tape and woven composite that has been examined. The tests can be broadly divided into different types. Several of generally standard tests have been recommended for most composites, such as the prepregs tape and the woven composite. For example the physical properties and mechanical properties to identify the fiber weight fraction, volume fraction, void content, density, diameter, width, tensile, flexural and the others.
2.4.1 Physical Properties

These tests provide very basic information that is necessary for characteristic and qualifying the various effects examined. The details of procedures and like for all types of tests are reviewed in the different specifications such as the ASTM standards. The tests could be used to assure product uniform, such as density and specific gravity tests. The physical properties tested are:

2.4.1 (a) Dimension

The uniformity dimensions of prepregs tape products were important to ensure uniform geometry of the woven product. By using of Vernier Peacock VM 150, the dimension of thickness and wideness were measured at the different location to get the average value of the thickness and width.

2.4.1 (b) Fiber Weight Fraction and Volume Fraction

Fiber weight fraction (Wf) is a composition that relates to the relative amount of the fiber and the matrix in a composite. It is an important factor that influences the mechanical properties of the composite according to Mc Crum et al., (1988). It can be measured by any of two methods, which is physical and chemical ashing.
Here, the physical ashing method described in ASTM D2584 was used to determine the weight fraction of the composite. It was done by placing a sample of known weight in a furnace at say 650°C until no weight change is noted. The weight fraction was calculated as follows:

\[
\text{Fiber weight fraction (Wf)} = \frac{W_c - W_a}{W_b - W_a} \times 100%
\]

Where:

\(W_c - W_a\) = weight of the samples after ashing
\(W_b - W_a\) = weight of the initial sample

From the above equation, we can relate Wf with fiber volume fraction (Vf) using the equation below:

\[
\text{Fiber volume fraction (Vf)} = \frac{W_f / \rho_f}{W_c / \rho_c}
\]

Where:

\(V_f\) = fiber volume fraction
\(W_f\) = fiber weight
\(W_c\) = composite weight
\(\rho_f\) = fiber density
\(\rho_c\) = composite density
2.4.1 (c) Density

The density ($\rho$) of the sample was determined according to ASTM D792 methods. Each cutting of the five samples was weighted in the air by using a Mettler AJ 150 balance up to four decimal points. After that the each sample was weighted on the aquadest by hanging the sample using yarn and the weight is noted. The density is determined as below:

\[
\text{Density (g cm}^{-3}\text{)} = \frac{A}{A - B} \times 0.9971
\]

$A =$ weight in air

$B =$ weight in water

The ASTM D792 standard provides the relationship of density to specific gravity (SG) at 23°C.

Density of any material (g cm$^{-3}$) = SG x 0.9971

Where 0.9971 is the density of water

2.4.1 (d) Void Content

The voids content (V%) of composites were measured according to ASTM 2734-70. First, the theoretical density is obtained according to:

\[
\text{Density theoretical} = \frac{1}{[(W_c/\rho_i) + (W_m/\rho_m)]}
\]
Where:

\( W_f \) = fiber weight fraction

\( W_m \) = matrix weight fraction

\( \rho_f \) = fiber density, 2.54 gm/cm\(^3\)

\( \rho_m \) = matrix density, 1.04 gm/cm\(^3\)

The void content then can be measured by using the equation below:

\[
\text{Void content} = \frac{\rho_{\text{theoretical}} - \rho_{\text{true}}}{\rho_{\text{theoretical}}} \times 100\%
\]

2.4.2 Mechanical properties

The mechanical properties of a material describe how it responds to the application of a force or load. Most composites are used because they have desirable mechanical properties at an economical cost (Rosato et al., 1989). For this reason, their mechanical properties may be considered the most important for most applications.

2.4.2 (a) Tensile Test

The tensile test is according to ASTM D-638 to evaluate the strength of product composite. In this test a sample is pulled to failure in a relatively short time at a constant rate. The type of sample used for the tensile test such as already mention before.
As shown in Figure 2.7 Testometric M500-25KN was used to measure the composite tensile strength and the crosshead rate was set at 0.2 cm/min. Five samples have been used and the average value was chosen to determine the tensile strength property. The test sample is positioned vertically in the grips of the testing machine. This tensile testing system includes a monitor, which displays stress-strain curves and numeric data and a printer for generating hard copies. The computer does mathematical calculations and stores data for quality control reports.

![Testometric equipment M500-25KN.](image)

Figure 2.7: Testometric equipment M500-25KN.

Tensile strength is measured in Pascals and is the ratio of the pulling force in Newton’s and the original cross-sectional area of the sample in square meters.

\[
\text{Tensile strength (Pa)} = \frac{\text{Pulling force (N)}}{\text{Cross-section (m}^2\text{)}}
\]

The force data obtained can be converted to stress data, and a plot of stress vs. strain can be constructed. A typical stress-strain diagram is shown in Figure 2.8.
Figure 2.8: A Typical stress-strain deformation behavior

Understanding stress-strain curves requires familiarity with a few technical terms.

Up to the yield point A, the resistance of the sample to the applied force was linear. After point A, the relation between stress and strain was no longer linear. Calculation can provide the strength at yield and the elongation to yield.

At the break point B, the material failed completely and broke into two pieces. Calculations can readily provide the strength at break and the elongation to break.
The ratio between the stress applied and the strain, within the linear range of the stress-strain curve is called tensile modulus or Young’s modulus. It is calculated by dividing the stress (load) in Pascals by the strain (mm/mm). Mathematically, Young’s modulus is identical to the slope of the linear portion of the stress-strain curve.

\[
\text{Young Modulus} = \frac{OD}{OC}
\]

2.4.2 (b) Flexural Properties

Flexural properties, such as flexural strength and modulus, are determined by ASTM test method D790-92. The stresses induced due to the flexural load are the combination of compressive and tensile stresses. The Testometric Tensometer was used to measure the three-point flexural properties of the composite at the crosshead speed of 0.5 cm/min.

Simple beam equation is used to determine the stresses on specimen at different levels of crosshead displacement. Significantly, a flexural specimen is not in a state of uniform stress. When a simply supported specimen is loaded, the side of the material opposite the loading undergoes the greatest tensile loading. The stress-strain behavior of plastic in flexure generally follows from the behavior observed in tension and compression for either unreinforced or reinforced plastic. The flexural strength for most plastics under standard ASTM bending test is typically somewhat higher than their ultimate tensile strength, but flexural strength itself may be either higher or lower than compressive strength.
There are several advantages of flexural strength test over tensile test: 1) to elimination of the clamping needed where the tight clamping of the test specimens in tensile test creates stress concentration points, 2) if a material used in the form of a beam and if the service failure occurs in bending, then a flexural test is more relevant for design or specification purpose than tensile test and 3) the specimen alignment is more difficult in tensile test.

A load-deflection curve is plotted if the determination of flexural modulus value is desired. Modulus is determined from the initial linear portion of the load-deflection curve where strains are usually small. In the three point flexural test, the test bar rests on two supports and is loaded at one point which is on equal distance from the adjacent support points. Consider a rectangular beam of span length, L; width, d and thickness, t were loaded in three-point flexural, as shown in Figure 2.9.

![Three-point flexural test geometry](image)

Figure 2.9: Three-point flexural test geometry

The maximum stress on the outer surface at the mid-span (σ) of the three-point flexural test was calculated by
Flexural strength \( (\sigma) = \frac{3 \, P \, L}{2 \, b \, d^2} \)

Where \( P \) is the applied load, \( L \) is the support or span length and \( b \) and \( d \) are the sample width and thickness, respectively. The maximum strain in the outer layer also occurs at midspan, and it may be calculated as follows:

Maximum strain in outer layer or \( r = \frac{6 \, D \, d}{L^2} \)

Where \( D \) is the maximum deflection of the center of the beam.

### 2.4.2 Statistical Quality Control

Quality control is the means by which every step in the production process receives the attention required to assure that all parts and end products meet the desired specifications (Shah, 1984; Shewhart, 1980).

In this study statistical quality control technique, through the use of control charts to statistically determine whether the dimension is in or out of control or to check reliability of dimension of the prepreg tapes. The centerline of the control chart represents the average of a series of dimension values. The top and the bottom lines of the chart represent the upper control limit (UCL) and the lower control limit (LCL), respectively. Generally, the control limits are three standard deviations (3\( \sigma \)) above and below the centerline. This means that the probability of measurements falling between \( \pm 3 \) standard deviation is 99.73%.
percent of the observed values. Or stated another way, between ±3 standard deviations from the mean, one expects to find 99.73 percent of all the observed values.

To elucidate the process, Figure 2.10 shows the schematic diagram all the processing of the prepreg and woven composite.

![Diagram](image)

**Figure 2.10:** The schematic diagram all the processing of the prepreg and woven composite this study
CHAPTER III
RESULTS AND DISCUSSION

3.1 Effect of pin number in Impregnation Tank.

3.1.1 Matrix loss

Direct melt impregnation method in which the fiber roving is pultruded through a polymer melt was first reported by Bradt (1962) in the production of injection molding pellets from continuously impregnated fiber tows. The aims of impregnation process are to achieve a high degree of fiber wetting, with a controllable resins volume fraction in the tow, along with the fastest possible throughput, without undue tension build-up in the fibers. Impregnation tank is generally necessary to have several pins to achieve the desired level of impregnation. Earlier studies, which were done by Ishak (1995), Shahnun (1996, 2000), Mariatti (1998) used 6 pins at the impregnation tank.

Here, an attempt was made to use 8 pins in the impregnation tank to study the effect of different number of pin. The increasing number of the pin was hoped to increase the impregnation of the matrix and to decrease the excess matrix loss at the die entrance. Because focus the study is on the effect number of pin hence, the same parameters such as temperature, pulling rate, number of tow, etc. (Leach, 1990; Ishak, 1995; Shahnun, 1997) were chosen for this study since some guidelines have already been established. The amount of the matrix loss was compared between processing using 6 pins and 8 pins, while maintaining the entire process variables (Ishak, 1995; Shahnun, 1996; Mariatti, 1998). The results of using 6 pins and 8 pins are shown in Table 3.1.
Table 3.1: Composition amount of matrix on the prepreg tape after impregnation tank and puller, with using 6 pins and 8 pins.

<table>
<thead>
<tr>
<th></th>
<th>6 pins</th>
<th></th>
<th>8 pins</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>After</td>
<td>After</td>
<td>After</td>
</tr>
<tr>
<td></td>
<td>Imp.</td>
<td>Puller</td>
<td>Imp.</td>
</tr>
<tr>
<td>Tank (%)</td>
<td></td>
<td>(%)</td>
<td>(%)</td>
</tr>
<tr>
<td>ABS (matrix)</td>
<td>18.88 ± 0.75</td>
<td>17.62 ± 0.65</td>
<td>13.70 ± 0.80</td>
</tr>
</tbody>
</table>

As shown in Table 3.1, amount of matrix using 6 pins is 18.88 % after impregnation tank, meanwhile after puller is 17.62 %. It means using 6 pins could result in matrix loss of about 1.26 %.

The earlier process using 6 pins in the impregnation tank show the inefficiency function of the pins (Ishak, 1995). For example it can not control perfectly the formation of the excess matrix. This phenomenon later on will obstruct the movement of the prepreg tape inside the die, hence decreases the speed and the effectiveness of the puller.

Table 3.1 also shows amount of matrix using 8 pins are 13.70 % after impregnation tank and puller. There was obviously no matrix loss in this process. Thus as expected, it is indicated that increasing number of pin to 8 pins could decrease the matrix volume fraction and resulted in no matrix loss.

Furthermore, the effect of using 8 pins could decrease the amount of matrix by 5.18% after impregnation tank and 3.92 % after puller.

Based on these results, it can be concluded that increasing number of pin could eliminate the matrix loss and decrease the amount of matrix.
3.1.2 Dimension

Prepregs, which were produced from pultrusion process, is a semi-finished product; they are also referred as a precursor or intermediate materials. Previous studies (Wiedemann & Rothe, 1990; Chandler et al., 1992; Hollaway, 1986) have shown that the dimension of the prepreg is one of the factors that influence the composite properties.

Thus, in order to ensure the quality of the final product, the prepregs should be chosen based on certain criteria, for example dimension, density, fiber weight fraction and so forth. Study by Mariatti (1998) has shown that the dimension of the prepreg is one of the factors that influence the woven composite properties. For example the dimension of prepreg such as the width and the thickness normally will influence the weave ability of the woven system, especially for a tight pattern like a plain weave. This subsequently will reduce the gap size at the interlacing point and this in return will increase the mechanical properties after system. A thinner prepreg will show a better ability to weave because of the flexibility. This phenomenon is similar with those using a small tow of prepreg; say 4 tows, which show better, weave ability than 12 tows prepreg (Mariatti, 1998). Perhaps the prepregs with a consistent dimension will produce a consistent gap size and also improve the woven end properties.

Based from the above information, the main purpose of the present study is to identify the effect using 8 pins in influencing the consistency in dimension of prepregs. SIRNA pultrusion type prepregging system is able to produce a consistent dimension of prepregs (Nasir, 1996; Ishak, 1995). In the pultrusion process, the dimension of the product is based on the space dimension of the die. The results are shown in Table 3.2.
Table 3.2: The averages dimension of the prepregs tape with using 6 and 8 pins.

<table>
<thead>
<tr>
<th>Properties</th>
<th>6 pins</th>
<th>8 pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width (cm)</td>
<td>2.61 ± 0.32</td>
<td>2.56 ± 0.11</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>1.25 ± 0.16</td>
<td>1.11 ± 0.08</td>
</tr>
</tbody>
</table>

Table 3.2 highlights the differences in width and thickness of the prepreg, which were produced by using 6 pins and 8 pins. As shown in Table 3.2 the width prepreg using 6 pins is 2.61 cm and using 8 pins is 2.56 cm while the thickness prepreg using 6 pins is 1.25 mm and using 8 pins is 1.11 mm. It is interesting to note that the average width of the prepregs, which were produced from the process with using 8 pins, is less than those of using 6 pins. Between the two systems, the difference in width is marginal but there is significant difference in thickness. The dimensional reliability of these two systems are more significant as shown in Figure 3.1, 3.2, 3.3 and 3.4. It is obvious that the process using 8 pins exhibits better reliability with more consistency in the width and thickness size.

Statistical Quality Controls (SQC) parameters were used to find the reliability of the width and the thickness. These parameters were using of 3- sigma method and fifty samples were measured to determine the width and the thickness of the prepreg composite. Generally, the control limits are three standard deviations (3σ) above and below the centerline. This means that the probability of measurements falling between ± 3 standard deviation is 99.73 percent of the observed values.
Figure 3.1: The reliability width of the prepregs tape using 6 pins.
Using 8 Pins

![Graph showing the reliability width of the prepregs tape using 8 pins](chart.png)

Figure 3.2: The reliability width of the prepregs tape using 8 pins
Using 6 Pins

Figure 3.3: The reliability thickness of prepregs tape using 6 pins.
Figure 3.4: The reliability thickness of prepregs tape using 8 pins.
Theoretically, the die is used to ensure better impregnation of the COFIT prepreg and at the same time it will give a stable dimension or shape of the prepreg (Ishak, 1995). In short, it is apparent that the using of 8 pins was able to produce more consistence prepregs dimension. However as mentioned before, the pultrusion process using 6 pins will produce excess resin at the die entrance. Instead of obstructing the movement of the prepreg, the excess matrix also will stick inside the die and thus reduce the dimension of the product. For example, this will reduce the width of the product. In order to maintain the dimension of the product, the space of the die has to be cleaned more frequently to remove excess matrix sticking to it. Therefore, if more time is used for removing the matrix inside the die, more inefficient the process will be, for example in term of energy and material waste.

It is also important to note that 8 pins could increase the efficiency of the pultrusion process by reducing the energy loss during the cleaning process or during the removal of sticky matrix inside the die. This is due to the frequency of cleaning process can be reduced by using this technique. Therefore, it is obvious when using 6 pins, the die is less efficient to produce consistent the width for a long period of processing time.

For example Figure 3.5 shows the inconsistency of the prepreg tape width using 6 pins. As shown the differences in width between both prepregs is very significant which is 2.8 cm for the narrower prepreg and 3.7 cm for the wider one.
3.1.3 Physical Properties

The physical properties basically indicate the morphologies or the bulk properties of the composite. Physical properties such as fiber weight fraction (Wf); fiber volume fraction (Vf), void content, density and etc. can be used to measure the quality of the product.

In the present study, the effect of using 6 and 8 pins on the physical properties of the prepregs was investigated. All were produced under similar prepregging conditions such as concentration, die temperature, pulling rate, etc.

Table 3.3: The physical properties of prepreg tape with using 6 pins and 8 pins.

<table>
<thead>
<tr>
<th>Properties</th>
<th>6 pins</th>
<th>8 pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wf (%)</td>
<td>82.38</td>
<td>86.30</td>
</tr>
<tr>
<td></td>
<td>± 0.50</td>
<td>± 0.75</td>
</tr>
<tr>
<td>Void (%)</td>
<td>18.4</td>
<td>22.2</td>
</tr>
<tr>
<td></td>
<td>± 0.87</td>
<td>± 0.76</td>
</tr>
<tr>
<td>Density</td>
<td>1.6515</td>
<td>1.6507</td>
</tr>
<tr>
<td></td>
<td>± 0.0015</td>
<td>± 0.0135</td>
</tr>
<tr>
<td>Vf</td>
<td>0.54</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>± 0.01</td>
<td>± 0.01</td>
</tr>
</tbody>
</table>
As shown in Table 3.3, the Wf prepreg using 6 pins is 82.38 % meanwhile the Wf prepreg using 8 pins is 86.30 %. It is obvious that the prepreg using 8 pins shows slightly higher Wf than those using 6 pins. Perhaps the value of Wf in the former system is higher due to the role of 8 pins. As discussed in the previous section, the using 8 pins allowed less matrix content presented in the prepreg system and hence resulted in higher Wf.

Previous studies (Ishak, 1995; Shahnon, 1997) have noted that the Wf has been used in measuring the consistency of the product. It was reported that the system was able to produce the Wf value in the range of 0.80 – 0.87 %. In other words, it is obvious that the process is able to produce a product with fiber dominant system. Studies by earlier workers (Ishak, 1995; Shahnon, 1997; Mariatti, 1998) have similar relationships, where, there was a slight increase in Wf with increasing the number of tow. In other word, it is obvious that decreasing amount of matrix could increase the Wf.

As shown in Table 3.3 the void content of the prepreg using of 6 pins is 18.4 % meanwhile the void content prepreg using 8 pins is 22.2 %. Void is one of the important factors, which influence the physical and mechanical properties of the composite system (Judd & Wright, 1989). Figure 3.6 shows the correlation between void content and Wf. It is apparent that an increase in Wf results in an increase in void content. For example the value of Wf and void content for the process with using 8 pins are 86.30 % and 22.2 %, respectively. Meanwhile the process using 6 pins shows the Wf value of 82.38 % and the void content of 18.4 %.

As mentioned before, the process using 8 pins was able to reduce the amount of matrix content and indirectly shows increasing value of Wf. As the matrix presence in the system reduced, thus this will result to a poor impregnation and subsequently increases the void content of the system.
It is interesting to note that the correlation between the thickness and the void content also can be made. For example for the system using 6 pins, it will produce a thicker prepreg. This subsequently resulted to better compaction and hence relate to a better impregnation and wetting inside the die. Thus this will reduce the number of void content in the system.

This generally corresponds with the previous study by Mariatti (1998) & Heng (1998) where it was noted that the void content increase with decreasing number of tow. This is because, the die is not fully occupied for the smaller size of towpreg, less compaction would occur due to the inadequate impregnation, this subsequently resulted to higher void content in the system.

As shown in Table 3.3 prepreg density value using 6 pins is 1.6515 higher than the value using 8 pins, which is 1.6507, this is due to the prepreg using 8 pins has bigger void content than using 6 pins. Moreover the volume fraction shows the value 0.54 for prepreg using 6 pins and 0.56 for prepreg using 8 pins. Theoretically, composite with a higher amount of void contents subsequently result in low density system (Mayer, 1985). As the density decrease, indirectly this will also reduce the Vf value. However, it is well known, apart from density and Vf, there are many other factors that influence the void content such as the matrix content, type of matrix, etc.

From the above information, it is apparent that the physical properties of the prepreg are governed by the used of 8 pins which in return influence the Wf and void content, density and volume fraction of the system.
3.1.4 Mechanical Properties

Mechanical properties are one of the factors, which used to measure the quality and performance of the product. Material selections for a variety of applications are quite often based on mechanical properties such as tensile, flexural and compression because they are well understood and most important provides the important information on the performance of any material in any mode of deformation. In the case of COFIT prepreg, the mechanical properties are strongly dependent on the strength of the components such as matrix and continuous fiber and also the quality interfacial bond in order to redistribute the stress (Leach, 1990; Stuart, 1990; Schwartz, 1996).

Moreover, the morphology of the prepreg such as void content, fiber distribution, density, and etc are able to determine the mechanical properties of the system. In the case of COFIT prepregs, it was noted that the tensile properties are
system. In the case of COFIT prepregs, it was noted that the tensile properties are strongly dependent on the fiber when they are parallel to the loading direction as in the case in this study (Caldwell & Cortez, 1988).

Based from the above information, the main purpose of the present study is to investigate the influence of introducing 8 pins into the pultrusion system. The mechanical properties of the prepreg using 6 pins and 8 pins are shown in Table 3.4.

Table 3.4: The mechanical properties of prepreg tape using 6 pins and 8 pins.

<table>
<thead>
<tr>
<th>Properties</th>
<th>6 pins</th>
<th>8 pins</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stress at peak (MPa)</td>
<td></td>
</tr>
<tr>
<td>Tensile</td>
<td>351 ± 9.71</td>
<td>298 ± 13.85</td>
</tr>
<tr>
<td></td>
<td>Strain at peak (%)</td>
<td>5.65 ± 0.10</td>
</tr>
<tr>
<td></td>
<td>Modulus (GPa)</td>
<td>5.98 ± 0.17</td>
</tr>
<tr>
<td></td>
<td>Toughness (MPa)</td>
<td>10.85 ± 0.95</td>
</tr>
<tr>
<td>Flexural</td>
<td>Stress at peak (MPa)</td>
<td>97 ± 4.60</td>
</tr>
<tr>
<td></td>
<td>Strain at peak (%)</td>
<td>0.95 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>Modulus (GPa)</td>
<td>12 ± 8</td>
</tr>
</tbody>
</table>

Table 3.4 and Figure 3.7 show the tensile properties for the prepregs, which were prepared by using 6 pins and 8 pins. The tensile strength of prepreg using 6 pins is 351 MPa, while prepreg using 8 pins is 298 MPa. It is apparent that the prepreg, which was prepared using 6 pins, showed higher tensile strength than those of using 8 pins. However, Young modulus of these two systems is more or less similar (5.98-5.80 Gpa).
As mentioned before, the differences in physical properties normally might influence the mechanical properties as well. Apparently, it is obvious that for the system using 6 pins shows higher tensile properties than those using 8 pins. This observation can be related to the higher amount of matrix present in the prepreg using 6 pins, which perhaps might improve the interface properties. This resulted in the reduction of void content and thus improved the tensile properties of the former system.

However, here the correlation between Wf and mechanical properties does not follow the trend reported in the previous studies (Crawford, 1987; Ishak, 1995; Mariatti, 1998). Theoretically, higher fiber content will increase the tensile properties because more fibers are able to share the force, which was applied to the system. In this case, perhaps the fiber content is not the only factor, which determined the properties of the prepreg system. Here it is thought to be a combination of amount of matrix content and also void content. According to Wiedemann and Rothe (1990) one important kind of surface defect, characterized by exposed reinforcement, occurs if the resin content is too low. It can occur that the prepreg can contain many pinholes and pinholes cannot be completely eliminated by subsequent pressing and the result is a void laminate.

As shown in Table 3.4 the toughness prepreg tape using 6 pins is 10.9 MPa, meanwhile the toughness of prepreg using 8 pins is 9.2 MPa. Moreover, the toughness, which was measured by the area under the stress-strain curve, also shows a difference as shown in Figure 3.7. It is obvious that the prepregs which were produced using 6 pins shows better toughness than those of using 8 pins. This perhaps might be explained by referring to the void content of the system whereby the system with fewer voids content is able to absorb more energy before failure. As mentioned before, the former system might exhibit a better interface property than the latter system, The interface properties are important in ensuring the toughness of the composite system (Leach, 1990).
Other than tensile properties, the studies on the flexural properties are also being carried out to determine the performance of these two systems. Perhaps, the flexural test can give additional information due to the different mode of deformation subjected to the sample, for example in measuring the ability in rolling the prepreg.

As shown in Table 3.4 the flexural stress prepreg tape using 6 pins is 97 MPa, meanwhile using 8 pins is 120 MPa. By referring to Table 3.4, and Figure 3.8 it is obvious that the flexural strength of the prepreg using 8 pins is higher than those using 6 pins. Perhaps it might be explained by referring to the thickness of the prepreg. In general, thin samples will show better rolling ability and thus this indirectly will increase the flexibility.

Thus as shown in Table 3.2, the prepreg with those using 8 pins showed less thickness compared to those of using 6 pins. This subsequently increases the flexural stress of the system eventhough these two prepreg show a different flexural strength and modulus.

The relationships between the flexural strength depend on the thickness of the prepreg may be explained by the following equation as mentioned in Chapter 2.

\[ S = \frac{3PL}{2bd^2} \]

Where:
- \( S \) = stress in the outer fibers at midspan, \( N/m^2 \) (psi),
- \( P \) = load at a given point on the load-deflection curve, \( N \) (lbf),
- \( L \) = support span, \( m \) (in.),
- \( B \) = width of beam tested, \( m \) (in.), and
- \( D \) = depth of beam tested, \( m \) (in.).

From the above equation, it is apparent that the flexural stress of the prepreg depends on the thickness. It is obvious that increase the thickness will decrease the
flexural properties. For example the prepreg using 6 pins has bigger thickness than using 8 pins exhibits lower flexural stress.

In short, from the discussion above, it is apparent that the prepreg using 6 pins showed a higher tensile strength with a more or less similar modulus. However, the prepreg, which was produced by using 8 pins, showed higher flexural strength. This indirectly indicates that the preregs, shows better weave ability and rolling ability, but displays lower tensile strength.
Figure 3.7: The stress-strain behaviors of prepregs tape using 6 pins and 8 pins
Figure 3.8: The flexural behaviors of prepregs tape prepared using 6 pins and 8 pins.
3.2 Effect of Pressure Molding on the Plain Weave Properties

Here, the prepreg tape produced using 6 pins and 8 pins were used to prepare the woven composite. They were woven manually according to desirable pattern of plain weave. A single laminated of the composite were molded using compression molding under a predetermined condition: viz. pressure molding of 0 MPa and temperature of 220°C. In short, an open mold was used throughout the experiment.

Temperature plays a significant role on the molding condition. Theoretically, if the molding temperature of the plain weave is higher than the melting points of the resin (Tp ABS = 240°C), the resin will degrade or resin failure. It is probably relates to increasing in molecular voids. To avoid it, the temperature process at the compression molding used was 220°C for both 6 pins and 8 pins systems. Previously, study done by Mariatti, (1998) reported that the molding temperature of 220°C would attribute to the highest tensile properties.

Based from the above information, the scope of the present study is to analyze the effect of compression molding pressure of 0 MPa and temperature of 220°C to the properties of the woven composite that was produced from the prepreg using of 6 pins and 8 pins. The physical and the mechanical properties of the woven using 6 pins and 8 pins are shown in Table 3.5.
Table 3.5: The physical and mechanical properties of the plain weave using 6 pins and 8 pins at pressure molding of 0 MPa, and molding temperature of 220°C.

<table>
<thead>
<tr>
<th>Properties</th>
<th>6 pins</th>
<th>8 pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wf (%)</td>
<td>84.27 ± 0.75</td>
<td>85.16 ± 1.00</td>
</tr>
<tr>
<td>Voids (%)</td>
<td>11.52 ± 0.47</td>
<td>13.28 ± 0.63</td>
</tr>
<tr>
<td>Tensile Stress (MPa)</td>
<td>120 ± 2.55</td>
<td>104 ± 10.3</td>
</tr>
<tr>
<td>Toughness (MPa)</td>
<td>3.15 ± 0.05</td>
<td>2.74 ± 0.13</td>
</tr>
</tbody>
</table>

Table 3.6: The physical and mechanical properties of the plain weave using 6 pins and 8 pins at molding pressure of 12 MPa and processing temperature of 220°C.

<table>
<thead>
<tr>
<th>Properties</th>
<th>6 pins</th>
<th>8 pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wf (%)</td>
<td>84.20 ± 0.65</td>
<td>83.76 ± 1.15</td>
</tr>
<tr>
<td>Voids (%)</td>
<td>14.23 ± 0.63</td>
<td>12.61 ± 0.49</td>
</tr>
<tr>
<td>Tensile Stress (MPa)</td>
<td>110 ± 8.76</td>
<td>130 ± 6.61</td>
</tr>
<tr>
<td>Toughness (MPa)</td>
<td>3.26 ± 0.08</td>
<td>3.99 ± 0.12</td>
</tr>
</tbody>
</table>

Table 3.5 shows that Wf for plain weave using 6 pins is 84.27 % meanwhile for plain weave using 8 pins is 85.16 %. However, the void content of the woven composite using 6 pins is lower than that using 8 pins. Void content of the woven using 6 pins is 11.52 %, while void content woven using 8 pins is 13.28 %. It indicates that the pressure molding can
influence the void content of the plain weave. The void content from Table 3.5 and Table 3.6 shows the different phenomenon. For example, the void content of the plain weave using 6 pins is smaller than using of 8 pins while processing without pressure on compression molding. Meanwhile the void content of the plain weave using 6 pins is bigger than using of 8 pins while processing at condition 12 MPa on the compression molding. It is obvious that pressure molding has some role in influencing the woven composite properties. According to Saunders et al., (1998) fiber deformation derived a relationship for the applied pressure on unidirectional fibers as a function of fiber volume fraction. They assumed that the externally applied pressure was split into two components, on the fiber reinforcement and the other on the resin. So while processing without compression, the viscous pressure component is negligible, the total applied pressure tends to be borne wholly by the fibers and the maximum extent of fiber deformation occurs. It is obvious that while processing without pressure in compression molding, the void content of the woven using 6 pins is less than using 8 pins because the woven using 6 pins has bigger amount of matrix. As mentioned before, one important kind of surface defect that decrease the properties, characterized by exposed reinforcement, occurs if the resin content is too low. It can occur either locally or generally, and is called weave exposure.

As expected, for both types of the woven, the tensile strength of the woven using 6 pins is higher than that using 8 pins. The tensile strength for woven using 6 pins is 120 MPa while woven using of 8 pins is 104 MPa. Here, it can be seen that the reduction of the tensile strength of the woven using 8 pins was caused by the higher void content.

The stress-strain deformation behaviors of the woven composite using 6 pins and 8 pins are given in Figure 3.9. In the case of using 6 pins on the woven composite, it results in increase maximum stress and toughness.
From above discussion it can be concluded that the woven composite prepared using 6 pins in 0 MPa compression molding pressure, shows higher stiffness, maximum stress, and bigger toughness than those using 8 pins. It is obvious that the molding process governed the mechanical properties of the composite system.
Figure 3.9: The stress-strain curve behaviors woven composite using of 6 and 8 pins at pressure molding 0 MPa and temperature 220°C on Compression Molding.
From the above discussion, it is clearly shown that the effect of the temperature molding on the woven composite properties. Here the molding condition used was 12 MPa of pressure and the others parameters remains the same with previous work done in this work.

A single laminated of the composite were molded by compression molding with molding pressure of 12 MPA and temperature of 220°C. In short, an open mold was used throughout. Consolidation of plies (between the prepreg) in the processing of polymer composite was achieved via a combination of compression. The compression of the composite results in changes of fiber fraction, porosity and pore dimension (Saunders et al., Bader, 1993). This has effects on processability by altering the permeability of the reinforcement to resin flow and on the mechanical properties of the composite product. The scope of the present study is to analyze the effect of 12 MPa compression molding pressure to the properties of the woven composite produced from the prepreg using 6 pins and 8 pins.

As shown in Table 3.6, the fiber contents (Wf) for woven composite produced using 6 pins is 84.20 % and that using 8 pins is 83.76 %. It is indicating that the process was insignificantly affected to the fiber content (Wf) for both 6 and 8 pins systems. However the differences to both of the system before and after entering to compression molding, the fiber weight fraction is quite similar.

As shown in Table 3.6 the void content of the woven composite prepared using 6 pins is 14.23 % meanwhile the void content of that produced using 8 pins is 12.61 %. In comparison between the void content of the prepreg and the plain weave (compare between Table 3.5 and Table 3.3), the void content of the prepreg using of 6 pins is lower than that using of 8 pins, where for the plain weave shows contradicting results. It indicates that the pressure and temperature on compression molding influenced the void content of the plain weave. Judging from the void content, perhaps different composite properties can be obtained by varying the molding conditions. Previous study by Mariatti (1998) basically relates that
The relationship between the void content and the tensile strength of woven composite prepared using 6 pins and 8 pins also can be seen from the Table 3.6. It shows that the tensile strength of the plain weave using of 6 pins is 110 MPa while using of 8 pins is 130 MPa. It indicates that the tensile strength of the plain weave using of 8 pins is higher than that using of 6 pins. It is clearly seen that the role of the molding pressure towards the composite properties. Where the prepreg produced using 6 pins has lower tensile strength compared to the prepreg produced using 8 pins. However, when both prepgregs were woven into a composite and compression molded, the tensile strength show a reverse trend.

Obviously, void is one of the important factors, which influence the physical and mechanical properties of the woven composite system (Judd & Wright, 1989). For example the thinner prepreg resulted in a tighter pattern of the plain weave and it will decrease the void content of the composite. Theoretically, decrease in void content will increase the tensile properties because more fibers are able to share the force, which was applied to the system (Kathryn, 1993). However in the case of the plain weave using of 6 pins, lower tensile properties can be explained by the weaving characteristics, which has bigger interlacing gaps than using 8 pins because of the thicker prepreg. Studies by earlier worker (Heng, 1998) has identified that the weaving characteristics of different woven geometry (because different thickness and the width) might influence the heat transfer, resin flow and penetration of the resin within the woven plies.

The stress-strain deformation behaviors of the woven using 6 and 8 pins are displayed in Figure 3.10. In the case of the woven composite, composite prepared using 8 pins shows higher stress and the toughness.

Obviously in the woven composite system, the mechanical properties of the system are governed by the nature of towpreg, weaving characteristic due to (the different width and thickness) and the molding process of the system.
Based on those results, it can be concluded that the plain weave using of 8 pins produce higher tensile strength than the plain weave using of 6 pins. This implies that the compression molding pressure influence the properties of the plain weave composite such as void content, fiber fraction, tensile strength and so forth.
Figure 3.10: The stress-strain curve behaviors woven composite using of 6 and 8 pins at pressure molding 12 MPa and temperature 220°C on Compression Molding
3.3 Effect of the interlace gap on the plain weave properties

Plain weave has a simple structure in which each warp and fill yarn over the end or pick and under the next. This construction gives a reinforcement that is widely used in general application.

Woven geometry basically refers to woven pattern, which exhibit dissimilarities in appearance and also performance (Edward, 1987; Heng, 1998). The dissimilarities of these different woven geometry basically attribute from the weave characteristics such as unit cell, interlace point, float length, etc, which are differed from one pattern to another. Meanwhile consistency is one of the main advantages of woven (Edward, 1987). The woven by its nature gives a reinforcement that is free from holes, and uniform in thickness and weight. For example, consistency in weight gives consistent laminates, which in turn means consistent properties. Susceptibility to high number of interlacing per square inch in plain weave significantly influences their performance. For example, tightly woven plain weaves are sometimes difficult to wet out quickly (fabric structure).

Based on the above information, the study was done to change interlace point of the plain weaves by spacing the weaves with the result that established gaps. It causes decrease high number of interlacing per square inch in plain weave. It is the intention of this study to observe the influence of interlace gap on the plain weave, molding temperature and molding pressure to the performance and the properties of the composite.

In order to find out the distance of the gap, the preliminary study was first investigated by using the gap 6 cm on the plain weave composite. This step is important to understand and assess the effect of pressure and temperature during compression molding process. After molding process with molding pressure of 12 MPa and temperature of 220°C
the width of the prepreg on the plain weave changes from 2.7 cm to 2.84 cm. The increases in
width are about 0.7 cm on both left and right side or a total 1.4 cm change.

Based on the above investigation the prepreg tape produced using 6 pins and 8 pins
were woven manually according to desirable pattern to the gap size of 0 cm, 0.7 cm and 1.4
cm as shown in Figure 3.11. The performance and the properties of the woven composite is
comparing with using 6 pins and 8 pins.

![Figure 3.11: The woven composite with the gap size 0 cm, 0.7 cm and 1.4 cm before entering
compression molding.](image)

3.3.1 Effect of temperature to the gap on the Plain Weave Properties with using 6 pins
and 8 pins

Figure 3.12 shows the effect of molding pressure of 0 MPa and molding temperature
of 220°C during compression molding towards 0 cm, 0.7 cm and 1.4 cm gap size of the
woven composite using 6 pins. The effect of molding temperature to the performance of all
the woven are quite similar with the woven composite using 8 pins as shown in Figure 3.13.
As seen, it is obvious the molding temperature with the presence of the gap insignificantly
influence the performance of the woven composite.
Figure 3.12: The woven composite using 6 pins at different of the gap size after molding processing at temperature 220°C.

Figure 3.13: The woven composite using 8 pins at different of the gap size after molding processing at temperature 220°C.
Table 3.7: The mechanical properties of the plain weave composite using 6 pins and 8 pins with the gap size 0 cm, 0.7 cm and 1.4 cm.

<table>
<thead>
<tr>
<th>Properties</th>
<th>6 pins (Gap)</th>
<th>8 pins (Gap)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 cm</td>
<td>0.7 cm</td>
</tr>
<tr>
<td>Tensile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress at peak (MPa)</td>
<td>120 ± 9</td>
<td>65 ± 8</td>
</tr>
<tr>
<td>Strain at peak (%)</td>
<td>2.40 ± 2.57</td>
<td>2.0</td>
</tr>
<tr>
<td>Modulus (GPa)</td>
<td>4.96 ± 3.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Toughness (MPa)</td>
<td>3.15 ± 2.22</td>
<td>1.33</td>
</tr>
</tbody>
</table>

Table 3.7 and Figure 3.14 highlight the relationship between weave characteristics and the tensile strength properties, obtained from specimens having varying gap without using pressure during compression molding and molding temperature of 220°C. As shown, the tensile strength for woven using of 6 pins are 120 MPa for 0 cm gap size, 94 MPa for 0.7 cm gap size and 65 MPa for 1.4 cm gap size. Meanwhile for the woven using 8 pins are 104 MPa, 83 MPa and 73 MPa respectively. It is apparent that the higher tensile strength is obtained for the entire gap size when using 6 pins. Obviously, that the role of molding temperature influence the tensile strength properties of the woven for both of the system. Here, processing without using pressure in compression molding. This generally corresponds with the different amount of matrix inside both of the system. It is indicates that the woven composite using 6 pins has more amount of matrix than woven composite using 8 pins. Obviously the woven composite which has more amount of matrix will produce smaller void content than the others. Thus as expected, smaller void content, result in increase tensile strength properties. As discussed earlier, temperature influences the distribution of the
matrix. However, since the differences amount of matrix inside both of the system is small, thus the effect to the tensile strength property is not really significant.

Figure 3.15 shows the stress-strain deformation behaviors of the different gap size woven composite system without using pressure and molding temperature of 220°C during compression molding. In general the modulus and strain between the woven composite systems using 6 pins at 0.7 cm and 1.4 cm gap size quite similar. It is indicates that the woven using 6 pins at 0.7 cm and 1.4 cm gap size could be used to produce composite system. For example, if the requirement of the composite is 62 MPA (as shown in Figure 3.15), then both composite with 0.7 cm and 1.4 cm can be used. For the sake of economics, composite with 1.4 cm gap size should be chose due to decrease in operation cost and material saving.

As shown in Figure 3.16 the toughness properties of the woven composite are not significantly affected influence by varying the gap size.
Figure 3.14: The relationship between Tensile stress Vs the gap size on the plain weave using 6 pins and 8 pins without pressure and molding temperature of 220°C during compression molding.
Figure 3.15: Stress-strain deformation behaviors of the woven using of 6 and 8 pins without pressure and molding temperature of 220°C during compression molding.
Figure 3.16: Graph of toughness Vs the gap size on the plain weave using 6 pins and 8 pins without pressure and molding temperature of 220°C during compression molding.
3.3.2 Effect of pressure molding 12 MPa to the gap size on woven composite properties produced using 6 pins and 8 pins

Figure 3.17 is shown the effect of pressure molding 12 MPa during compression molding to 0 cm, 0.7 cm and 1.4 cm gap size on woven composite prepared using 6 pins. The effect of pressure to the performance of all the woven are the less similar with the woven composite using 8 pins as shown in Figure 3.18. The differences are shown for the woven composite produced using 6 pins, all the form of the gap on the woven composite perfectly be one. This is because for woven composite using 6 pins has lower Wf than the woven composite using 8 pins. Obviously the woven using 6 pins has more matrix than the other one. Subsequently more matrix could fill in of the gap. This observation indicates that pressure and temperature during compression molding with and without presence of the gap could influence the performance of the woven composite.

![Figure 3.17: Woven composite using of 6 pins, molding pressure 12 MPa and temperature of 220°C after entering compression molding.](image-url)
Figure 3.18: Woven composite using 8 pins and molding pressure 12 MPa and temperature of 220°C after entering compression molding.

Table 3.8: The mechanical properties of the plain weave composite using 6 pins and 8 pins with the gap size 0 cm, 0.7 cm and 1.4 cm.

<table>
<thead>
<tr>
<th>Properties</th>
<th>6 pins (Gap size)</th>
<th>8 pins (Gap size)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 cm</td>
<td>0.7 cm</td>
</tr>
<tr>
<td>Tensile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress at peak (MPa)</td>
<td>110</td>
<td>52</td>
</tr>
<tr>
<td>Strain at peak (%)</td>
<td>2.67</td>
<td>2.50</td>
</tr>
<tr>
<td>Modulus (GPa)</td>
<td>4.08</td>
<td>3.20</td>
</tr>
<tr>
<td>Toughness (MPa)</td>
<td>3.26</td>
<td>0.67</td>
</tr>
<tr>
<td>Flexural</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress at peak (MPa)</td>
<td>75</td>
<td>1.60</td>
</tr>
<tr>
<td>Strain at peak (%)</td>
<td>1.98</td>
<td>0.93</td>
</tr>
<tr>
<td>Modulus (GPa)</td>
<td>6.13</td>
<td>4.75</td>
</tr>
</tbody>
</table>
Table 3.8 and Figure 3.19 highlights the relationships between weave characteristics and the tensile properties, obtained from specimens having varying gap size. As shown, the tensile strength for woven composite using 6 pins are 110 MPa for 0 cm gap size, 52 MPa for 0.7 cm gap size and 66 MPa for 1.4 cm gap size. Meanwhile for the woven using 8 pins are 130 MPa, 65 MPa and 68 MPa respectively.

It is apparent for all the woven processing, with 0.7 cm and 1.4 cm gap size, the tensile strength decrease and the value quite similar between both of the system. Thus as expected, with increase in gap size will result in decrease tensile strength. As seen, different of the gap size influence void content and tensile strength of the woven composite.

As already mentioned before void content is one of the important factors, which influence the physical and mechanical properties of the composite system. For example in the woven composite system, which has gap. In this composite, when gap size is increased, the higher void content will be. However amount of matrix has to fill in the gap on the composite system. Another factor that might contribute to this observation is the possibility using of the woven composite with 1.4 cm gap size hence saving the material.

From the experiment carried out, it has been proved that 0 cm, 0.7 cm and 1.4 cm gap size prepared using of 8 pins exhibit the highest tensile strength.

Figure 3.20 shows the stress-strain deformation behaviors of the different gap sizes in woven composite system. In general, tensile strength and stiffness decreases with increasing the gap sizes. For example 1.4 cm gap size using 6 pins show the lowest while the 0 cm gap size using 8 pins display the highest. The drop in tensile properties with the gap size is generally show similar trend with the previous studies (Naik et al., 1991; Hull, 1996; Boon, 2001), where the failure stress and strain at maximum stress are reduced as the gap diameter is increased. Theoretically, the presence of gap or macro voids also leads to increase in stress concentration effects near to the gap boundary. This will then influence the stress to be
transferred from one point to another point through the discontinuous fiber, higher stress concentration and presence of void content, thus resulting in a larger drop in tensile strength.

In the case of different the gap size in the woven composite system, it is apparent that the toughness between 0.7 cm and 1.4 cm gap size remain constant as seen in Figure 3.21. It is indicates that the 0.7 cm and 1.4 cm gap size insignificantly affected the toughness of both the system prepared through compression molding with molding pressure of 12 MPa.
Figure 3.19: Graph of tensile strength Vs Gap on the plain weave using 6 pins and 8 pins, molding pressure 12 MPa and molding temperature 220°C during compression molding.
Figure 3.20: The Stress-Strain deformation behaviors of the woven using 6 pins and 8 pins, molding pressure 12 MPa and molding temperature of 220°C during compression molding.
Figure 3.21: Graph of toughness Vs gap size on the woven composite using 6 pins and 8 pins, molding pressure 12 MPa and molding temperature of 220°C during compression molding.
Figure 3.22 highlights the flexural properties of the woven prepared using 6 pins and 8 pins with different gap size. As seen at 0.7 cm and 1.4 cm gap size for both of the woven composite system has similar value and with decrease in gap size flexural properties decrease. For 0.7 cm gap size using 8 pins, the flexural properties higher than that using 6 pins. This indicates that the woven using 8 pins is more flexible than that using 6 pins. As already mentioned before in chapter 3.1 this might be explained by referring to the thickness of the prepreg. In general the woven using 8 pins has lesser thickness compare to those using 6 pins and this subsequently increase the flexural stress of the system. Even though from Figure 3.23 these two-system show quite similar modulus.

In short from the discussion above, it is apparent that the woven composite prepared using 8 pins have higher flexural strength and quite similar flexural modulus than the woven using 6 pins. Meanwhile for 1.4 cm gap size the flexural properties of the woven composite using 6 pins is higher than that using 8 pins. This indicates that increase in the gap size could decrease the flexural properties, although it is not too significant. Obviously, amount of matrix and molding pressure still influence the properties of the composite. As seen the mechanical properties to both of the system with and without using pressure molding shows contradicting results.
Figure 3.22: Graph of flexural strength Vs Gap size on the plain weave using 6 pins and 8 pins, molding pressure 12 MPa and molding temperature 220°C during compression molding.
Figure 3.23: Flexural stress-strain behavior for woven using different gap at molding pressure 12 MPa and molding temperature 220°C during compression molding
CHAPTER IV
CONCLUSION AND FURTHER STUDIES

4.1 CONCLUSION

In general the effect of using 8 pins, as compared to 6 pins, in producing prepreg and woven composite influence the properties obtained. The conclusions can be summarized as follows:

- The higher number of pins could influence the physical properties of the prepreg composite. For examples, it could eliminate matrix loss, decrease amount of matrix, gives more consistence dimension but bigger void content. Meanwhile the mechanical properties, such as tensile strength and toughness are lower but the young modulus show similar value. Furthermore, the higher number of pin gave higher flexural strength.

- The woven composite prepared using 8 pins at 0 MPa compression molding pressure and temperature 220°C, showed lower stiffness, tensile strength and toughness. The effect of 12 MPa compression molding pressure to the properties are higher tensile strength and toughness.

- The tensile strength of the woven composite prepared using 8 pins for the gap size 0.7 cm x 0.7 cm and 1.4 cm x 1.4 cm is lower than those using 6 pins for the processing at compression molding 0 MPa pressure and 220°C temperatures. Meanwhile for the processing at 12 MPa compression molding pressure and 220°C temperatures, the tensile strength woven using 8 pins is bigger than that using 6 pins.
• The toughness properties of the woven composite are not significantly affected by varying the gap size when compression molded with and without pressure.

4.2 SUGGESTION FOR FURTHER STUDIES

• From the experiment, it is apparent that the prepreg and woven composite are strongly controlled by number of pins. Further work has to be conducted to study the effect of using different number of pins by varying the others parameters such as pulling rate, concentration of the solution, the length of the impregnation tank and etc.

• The studies of effect number of pins to the woven composite properties are restricted to a single ply plain weave. However there are still many areas need to be investigated. For example by using the similar approach to examine effect of multiple ply and different pattern of weave such as twill, satin and basket.
REFERENCES


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