TENSILE PROPERTY OF HAND LAY-UP PLAIN-WEAVE WOVEN E-GLASS/POLYESTER COMPOSITE: CURING PRESSURE AND PLY ARRANGEMENT EFFECT

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ABSTRACT. *This paper describes an experimental study on the tensile properties of hand lay-up plain-weave woven GFRP panels. Tests are conducted on the GFRP specimens fabricated at different curing pressure of 35.8kg/m^2, 70.1kg/m^2, 104kg/m^2 and 138.2kg/m^2. Two types of woven GFRP lay-up are designed with symmetrically and non-symmetrically arrangement at the center-plane of the composite are also investigated. The rectangular straight sided tensile samples are fabricated and tested with reference to British Standard. Uni-axial tensile deformation behaviors are then investigated with respect to the different curing pressures and lay-up arrangements. The results obtained have demonstrated the convergence of both elastic tensile stiffness and ductility with increasing curing pressure. This has consistently illustrated that the structural integrity of the composite will eventually achieve a threshold performance in its stiffness and ductility, irrespective of further increasing curing pressure for a particular fiber lay-up arrangement. Increasing the curing pressure has also shown to be detrimental to the tensile stiffness of woven GFRP.*

KEYWORDS. Curing pressure, Lay-up arrangement, Mechanical properties, Plain-weave woven GFRP.

INTRODUCTION

Composite materials are ingenious invention that provided immense benefits in the application of engineering design and structure. The development of composite materials brought about huge impact on material revolution that faces the fast growing needs of commercial exploitation. Nowadays, these materials are used in a very wide range of industrial applications. Laminated fiber-reinforced composite materials are commonly used in the marine industry, ducting and piping industries and many others due to their good environmental resistance, better damage tolerance for impact loading, and at the same time having a high specific strength and stiffness (Sutherland and Soares, 2004). Fiber woven fabrics are probably the most commonly used textiles in structural applications. In superconducting magnets application, Glass Fiber Reinforced Polymer (GFRP) woven laminate are successfully used as electrical insulation, thermal insulation and permeability barrier, which provided minimal structural support (Kumagai et.al., 2005). It can also offer a low cost composite manufacturing.

Mechanical properties can be considered the most important of all the physical and chemical properties for most application (Nielsen et.al., 1994). The mechanical properties of woven fabric composites, such as strength and stiffness, are strongly determined by the weave parameters (weave geometry, yarn size, yarn spacing and yarn crimp), the laminate parameters (fiber orientations and overall fiber volume fraction), and the inherent material properties of fiber and matrix. Previous work by (Pandita et al., 2004) has shown that the tensile properties such as strength and stiffness decrease drastically when woven fabric composite are subjected to an off-axis tensile loading. In the bias direction, the tensile strength and stiffness of woven fabric composites are comparable to those knitted fabric composites. (Srivastava and Hogg, 1998) studied on particles filled quasi-isotropic glass-fiber reinforced polyester resin composites, reported that fiber-reinforced polymeric composite laminates have traditionally suffered poor resistance to interlaminar fracture caused during out of-plane impact. In the work of (Nielsen et. al., 1994), the tensile strength of composite can be greatly affected by such factor as the perfection of alignment of the fiber and by imperfections such as voids.

Viscoelastic behavior of polymer base composite material offer pronounced effects to the stress-strain characteristics. Consequently, the values of the tangent modulus of tough materials taken from the initial part of the stress/strain curves often depend strongly on the scales used (BS, 1997). (Pegoretti et. al., 2006) carried out the research on unidirectional liquid crystalline single-polymer composites, and the tensile modulus is identified using a secant value between two strain level of 0.05% and 0.25%, as suggested by the ISO standard 527 (BS, 1997). (Belmonte et. al., 2001) has also investigated on the tensile modulus of woven quasi-isotropic GFRP laminates by taking a linear regression of stress against strain between 0.05% and 0.30% strain, which was within the linear portion of the stress-strain curve (ASTM, 2001).

The objective of this study is to investigate the tensile behavior of woven GFRP, which is hand lay-up plane-weave woven E-glass/Polyester laminate, in order to determine the tensile strength, tensile modulus and other characteristics with respect to changing curing pressure and lay-up arrangements. The tensile tests are performed on rectangular straight samples without end tabs at room temperature (23^{o}C/297.15K) in accordance with British Standard, BS EN ISO 527-4/BS 2782-3 Method 362F (BS, 1997), and also ASTM (American Society for Testing Materials) D 3039 (ASTM, 2001) test standards are referenced for better understanding.

EXPERIMENTAL METHOD

The experimental method describes in details the materials and its fundamental constituents, the specimen preparation for the fabrication of GFRP composite panels, and the experimental test methods and facilities according to standards.

Material

Plain-weave type woven glass fiber, commercial code: NISER-600, has been used as the GFRP material for the purpose of this investigation. The basis of NISER-600 is the glass fabric of E-glass. The E-glass has a round cross sectional shape approximately 9µm and chemically contains less than 1% alkali. The NISER-600 consist of a chemical composition of SiO_2 55.2%, Al_2O_3 14.8%, B_2O_3 7.3%, MgO 3.3%, CaO 18.7% and Na_2+K_2O 0.5%. The E-glass plain weave has been produced by interlacing warp thread and fill thread as illustrated in Figure 1. The matrix resin has Polyester mixed up with catalyst hardener, Butanox M-50 (methyl ethyl ketone peroxide, solution in dymethyl phthalate) acquiring a density of 1.21g/cm^3.

The E-glass plain weave woven roving reinforcement used has specific mass of 600gm^{-2} with approximately 2.5 warp ends per cm, 2.4 weft picks per cm and having a density of 2.6g/cm^3. Panels of 10 layers of glass woven fabric has been laminated using different curing pressure of 35.8kg/m^2, 70.1kg/m^2, 104kg/m^2 and 138.2kg/m^2, respectively. Curing of the polyester resin has been achieved using 0.74% by mass of catalyst. The resin has been mixed with the hardener in the ratio of 400: 3 by mass.

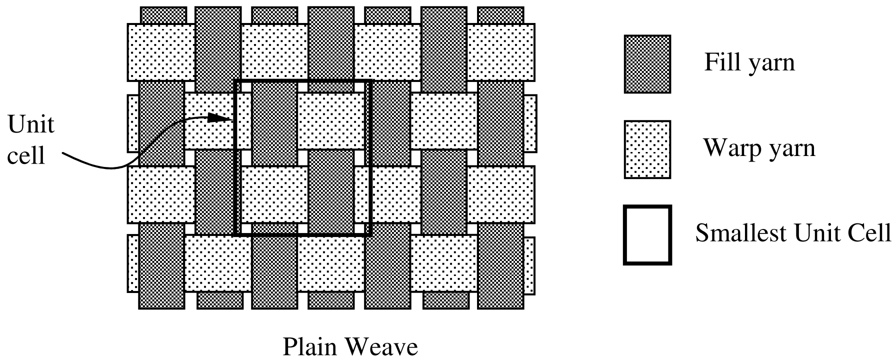

Figure 1. Fill yarn, warp yarn and smallest unit cells for plain weave.

Sample Preparation

The Type-2 tensile test specimen based on British Standard BS EN ISO 527-4/BS 2782-3 Method 362F (BS, 1997) had been reproduced. The Figure 2 illustrates the plane geometry and dimensions of the Type-2 test specimen. Eight experimental composites panels were fabricated with two arrangement of E-glass fiber cloth/ply. A plain weave woven roving with glass fibers at 0^o and 90^o directions, layered-up with symmetrically and non-symmetrically arrangement about the center-plane of the laminate can be illustrated in the Figure 3. Flat panel were formed using a hand layup technique. The 300mm length and 430mm width in dimension having average mass of 71g woven roving ply was positioned manually in the open rectangular mold with base dimension of 305mm length and 435mm width. The resin was then poured into the mold and the ply flattens using brush and roller. Large entrapped air pockets were removed manually with squeegees. Room-temperature curing polyester had been used as a matrix resin. The plain weave woven E-glass fabric was used in the ten plies of stacking for two different stacking arrangements as mention earlier. Stacked plies of laminates were allowed to cure for 24 hours at room temperature of $23^oC/297.15K$ between pressure plate and mold for different sets of pressure applied. The pressure squeezed out any excess resin and also eliminates further air entrapment (Dyer and Isaac, 1998). The overall dimensions of the panels fabricated were 300mm × 400mm for series of groups of thicknesses. All samples were cut using a diamond circular saw. The mechanical damages caused by the cutting were removed from the straight edges by polishing before testing. The geometric dimension and tolerance of the different groups of samples were obtained using the digital venire caliper and micrometer and found with percentage coefficient of variation well below 3%.

Testing Method

All the tests were conducted using a 100kN axial loading servo-hydraulic testing machine, Instron Series 8801, at room temperature $23^oC/297.15K$. The procedures outlined in the BS test method for determination of tensile properties of isotropic and orthotropic fiber-reinforced plastic composites (BS, 1997) and also the ASTM test method for tensile properties of polymer matrix composite materials (ASTM, 2001) were referenced for the tensile test. The in-plane uniaxial tensile tests were conducted under displacement control with a crosshead speed of 2mm/min for quantifying the test (BS, 1997) through measuring the Young's modulus. During the measurements, load, extension, stress and strain data were automatically logged on and collected by the computer through the load cell and transducer. The Young's Modulus values were determined by considering a linear regression of stress against strain between 0.05 and 0.25% strain, which was within the linear portion of the stress-strain curve (BS, 1997).

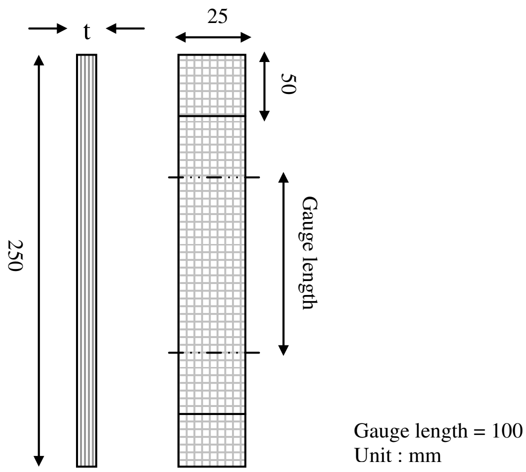

Figure 2. Specimen geometry and dimensions.

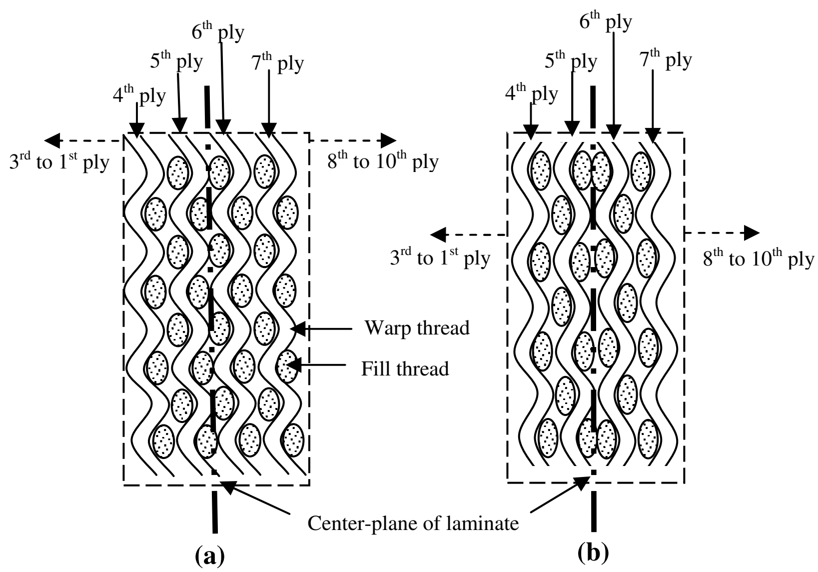

Figure 3. Stacking sequence of plain weave E-glass fiber ply; (a) Non symmetrical and (b) Symmetrical.

The stress calculation was defined based on the nominal cross-sectional of the test specimen, such that

$$\sigma = \frac{F}{A} \tag{1}$$

where σ the tensile stress (MPa), F the measure force (N), and A initial cross-sectional of the specimen. While the nominal stain values had been defined on the basis of the gauge length, given by

$$\varepsilon = \frac{\Delta L_o}{L_o} \tag{2}$$

where, ε the strain value (dimensionless), ΔL_o the increase in the specimen length between the gauge mark (mm), and L the gauge length of the specimen (mm). As a result, the modulus of elasticity (Young's modulus) was calculated on the basis of two specified strain values,

$$E = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1} \tag{3}$$

where E the Young's modulus of elasticity (MPa), σ_1 the stress (MPa) measured at the strain value $\varepsilon_1 = 0.0005$, and σ_2 the stress (MPa) measured at the strain value $\varepsilon_2 = 0.0025$.

RESULTS AND DISCUSSION

The tensile characteristic curves are typically shown in the Figure 4 for the four different types of curing pressure in the two types of lay-up arrangements, group-A symmetrical and group-B non-symmetrical. The characteristic stress-strain results for each lay-up arrangements and curing pressure all have shown a similarity in trend growing from non-linearity and eventually develops into linear slops after about 0.015 amount of strain. The initial non-linearity is basically attributed to the deformation of the matrix resin. Thereafter, the characteristic linear slope predominantly reflects the deformation of the glass fibers. In all the tensile fracture, the characteristics are also very distinct and abrupt, signifying little or no plastic strain throughout the failure deformation. This behavior is characterized by the Curve-D type of tough materials failing without yield point as classified under the British Standard (BS, 1997). Essentially, during the tensile fracture, the entire load is carried by the fibers that are parallel to the nominal stress. The strain to failure is also found to fall over a range between 0.055 to 0.067 amount of strain, which can be explained as due to the curing pressure and lay-up arrangement effects.

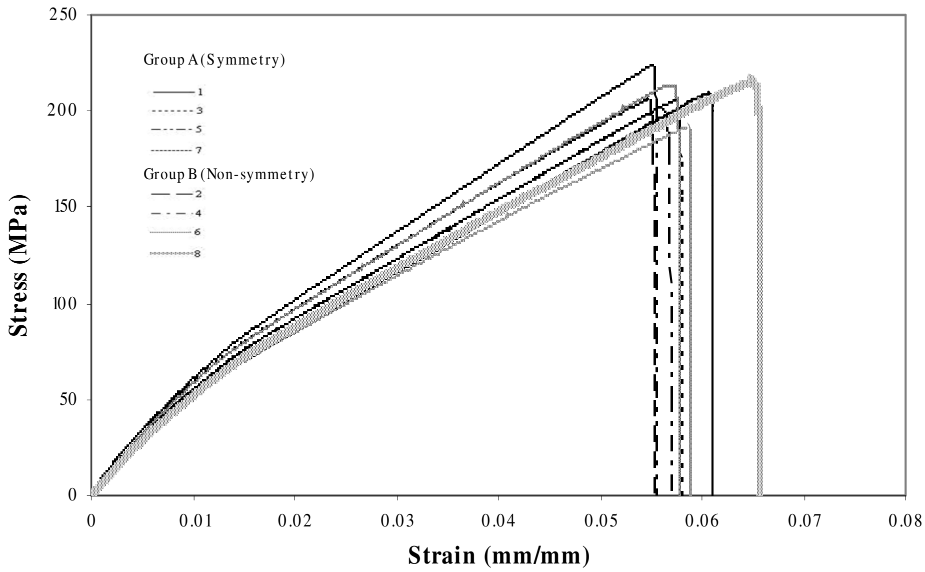

Figure 4. Stress versus Strain of tested specimens.

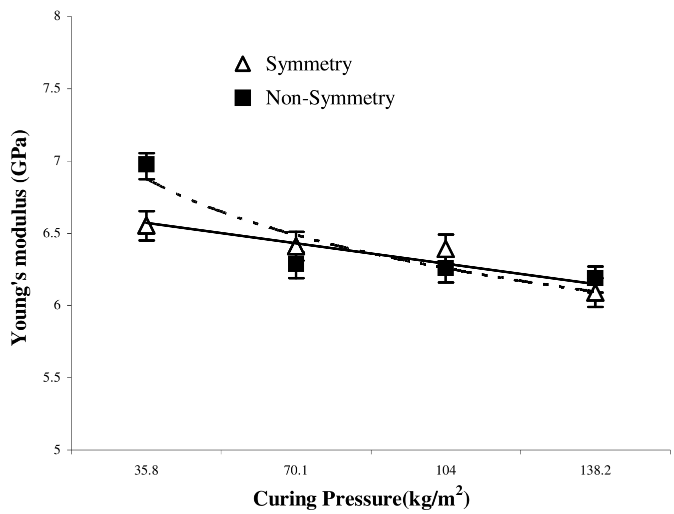

Figure 5. Young's modulus versus Curing pressure.

The behavior of Young's modulus value for each symmetrical and non-symmetrical lay-up arrangement, with respect to the curing pressure, is shown in the Figure 5. In symmetrical lay-up, the tensile Young's modulus with respect to increasing curing pressure is approximately a linear decreasing characteristic behavior. However, in non-symmetrical lay-up, the tensile modulus illustrates an inversely decreasing trend with increasing curing pressure. Therefore, in the similar range of curing pressure used, the lay-up arrangements for the woven glass fiber composite panel have responded with significant characteristics to the tensile structural stiffness. In both cases the increasing curing pressure is detrimental to tensile stiffness integrity of this woven GFRP type, although the symmetrical lay-up has a much lesser effect of stiffness losses. At higher curing pressure, both types of lay-ups appeared to converge to a common tensile stiffness, which is expected. A common stiffness characteristic, irrespective of the lay-up arrangements, can also be identified with a curing pressure of about 87.1kg/m^2.

The tensile ductility of woven GFRP with respect to changing curing pressure and lay-up arrangement effects are also compared in the Figure 6. In symmetrical lay-up arrangement, ductility has a clear inverse behavior with increasing curing pressure. While in the ductility behavior of non-symmetrical arrangement, it is increasing with increasing curing pressure. Their ductility characteristic is almost a mirror to each other, which could be attributed to the differences in the structural deformation due to the composite lay-up arrangements. However, in both cases ductility appears to converge to constant values at higher curing pressure. This is reasonable to the fact that increasing the curing pressure further will not change the fiber-fraction volume, thus, the related ductility of the system.

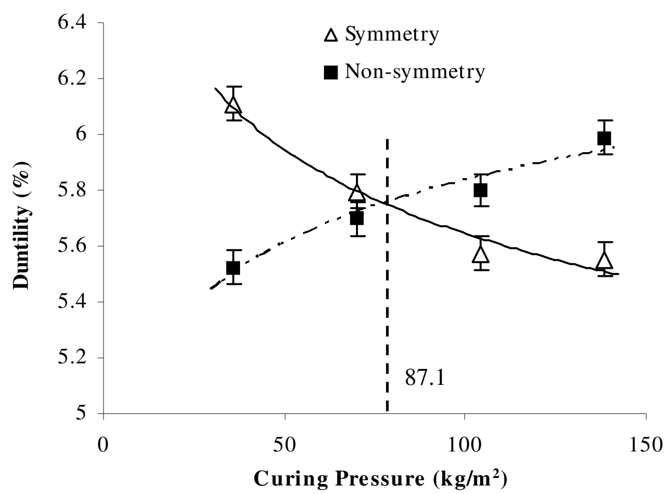

Figure 6. Percentage of ductility versus Curing pressure.

CONCLUSIONS

Tensile property of hand lay-up plane-weave woven E-glass/polyester laminate has been investigated. The characteristic tensile deformation from the different lay-up arrangements and curing pressure has shown a relative significant. The elastic tensile stiffness and ductility parameters has been investigated and compared with the variations in the curing pressure and fiber lay-up arrangements. Their characteristic effects are consistent, and the structural arrangements of the fiber lay-ups have shown to adversely affect the ductility behavior of the glass GFRP composite. Therefore, the findings of these tensile characteristic dependence of E-glass woven GFRP composite can contribute to a better understanding in its applications.

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REFERENCES

ASTM Standard D3039-01, Standard Test Method for Tensile properties of polymer matrix composite materials. American Society for Testing Materials, West Conshohocken, PA, 2001.

Belmonte, H.M.S, Manger, C.I.C, Ogin, S.L, Smith, P.A, Lewin, R. Characterization and modeling of the notched tensile fracture of woven quasi-isotropic GFRP laminates. Compos Sci Technol 2001;61:585-597.

BS EN ISO 527-4/BS 2782-3 Method 362F. Plastics-Determination of tensile properties-Part 4: Test conditions for isotropic and orthotropic fiber-reinforced plastic composites.. United Kingdom: British Standard, 1997.

Dyer, K.P, Isaac, D.H. 1998. Fatigue behavior of continuous glass fiber reinforced composites. Composites: Part B 1998;29: 725-733.

Kumagai, S, Shindo, Y, Inamoto, A. Tension-tension fatigue behavior of GFRP laminates at low temperature. Cryogenics 2005;45:123-128.

Nielsen, L.E, Landel, R.F, Faulkner, L.L, editor. Mechanical properties of polymers and composites. 2nd ed. New York: Marcel Dekker Inc.; 1994.

Pandita, S.D, Huysmans, G, Wevers, M, Verpoest, I. Tensile fatigue behavior of glass plain-weave fabric composites in on-and off-axis directions. Composites: Part A 2004;32:1533-1539.

Pegoretti, A, Zanolli, A, Migliaresi, C. Preparation and tensile mechanical properties of unidirectional liquid crystalline single-polymer composites. Compos Sci Technol 2006;66(3-4):361-372.

Srivastava, V.K, Hogg, P.J. 1998. Damage performance of particles filled quasi-isotropic glass-fiber reinforced polyester resin composites. J Mater Sci 1998;33:1119-1128.

Sutherland, L.S, Soares, C.G. Effect of laminate thickness and of matrix resin on the impact of low fiber-volume, woven roving e-glass composites. Compos Sci Technol 2004;64:1691-1700.