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DETERMINATION OF MECHANICAL PROPERTIES OF PULTRUDED GRP BOX SECTION USING A "SHORT" TENSILE COUPON

Mehmet SARIBIYIK*
University of Sakarya, Faculty of Technical Education, Department of Structural Education, Adapazarı, TÜRKİYE
Naci ÇAĞLAR
University of Sakarya, Faculty of Engineering,Department of Civil Engineering, Adapazarı, TÜRKİYE

ABSTRACT

Glass fibre reinforced plastic (GRP) structural members are currently being produced successfully by pultrusion and are now used in an increasing number of civil engineering applications. Measurements of the orthotropic mechanical properties of the GRP box section are necessary for use in the numerical modelling of connection. Pultruded GRP structural sections may not possess the dimensions necessary for the extraction of standard length coupons for tensile testing. In this study, initial experimental tests have been conducted using ASTM D3039 specimens to provide the experimental longitudinal tensile properties (elastic modulus, Poisson's ratio, strength) of pultruded GRP box section. The transverse tensile properties have been determined using the proposed short coupon following validation against the ASTM D3039 data.

Key Words : Glass fibre reinforced plastic, tensile test, material Properties,short coupon

KISA ÇEKME KUPONU KULLANILARAK ÇEKİLMİŞ CTP PROFİL MALZEMENİN MEKANİK ÖZELLİKLERİNİN BELİRLENMESİ

ÖZET

Cam fiber takviyeli plastik (CTP) yapı elemanları ön gerilmeli olarak üretilmekte ve birçok inşaat mühendisliği alanında kullanılmaktadır. Birleştirmelerin nümerik analiz ve dizaynları için bu malzemelerin ortotropik mekanik özelliklerinin bilinmesi gerekir. Çekilmiş cam fiber takviyeli yapı profilleri çekme deneyi için gerekli standart numune boyunu vermeyebilir. Bu çalışmada, ilk olarak ASTM D3039 numuneleri kullanılarak çekilmiş CTP malzemenin boyuna olan mekanik özellikleri (elastik modülü, poisson oranı ve dayanım) deneysel olarak belirlendi. Enine olan mekanik özellikler ise belirlenmiş olan boyuna kısa kuponların ASTM D3039 kuponları ile uyumu sağlandıktan sonra bulundu.

Anahtar Kelimeler : Cam takviyeli plastik, çekme testi, malzeme özellikleri, kısa kupon

1. INTRODUCTION

In the continuing quest for improved performance of structural materials, (which may be specified by various criteria including reduced weight, higher strength, improved corrosion resistance and lower costs) materials scientists and engineers strive to produce either improved traditional or completely new materials. Within the past four decades there has been a rapid increase in the development of advanced composites incorporating fine fibres. These materials, depending on the matrix used, may be classified as a polymer, metal, or ceramic matrix composites. The high cost of metal and ceramic matrix composite materials prevents their normal use in construction. The majority of composites used in the construction industry are therefore based on polymeric matrix materials with E-glass, which is known as Glass Reinforced Plastic (GRP). Additional factors in choosing polymeric composite materials for structural engineering applications are: the materials having lightweight, non corrosive, chemically resistant, possessing good fatigue strength, non- magnetic and subject to the materials selected, can provide electrical and flame resistance. Material surfaces are also durable and require little maintenance (1, 2).

Assuming a state of plane stress, measurement of the mechanical properties of the composite material is necessary for numerical structural analysis and design. The tensile test method has proved invaluable in the determination of fundamental mechanical properties of composite materials (3-8). However, geometry of many structural GRP sections prevent the extraction of a standard length specimen (typically in excess of 250mm) for the evaluation of elastic properties as defined by the most commonly used standards (BS 2782, ASTM D638 and ASTM D3039). Some researchers (4, 8, 9,10) have used non-standard shaped specimens to determine experimentally the elastic properties of shorter length GRP materials. A short coupon has been developed using a combination of micro-mechanics with classical lamination theory, numerical modelling and experimental validation and verification. The justification for this approach is given in reference (11).

In this study, an experimental investigation has been carried out to characterise the orthotropic elastic properties of the pultruded GRP box section using the "short" coupon specification for use in the numerical representation of the connection assembly. Potential linear and non-linear behaviours are admitted. Strength measures are also included.

2. CONSTRUCTION OF GRP BOX SECTION

The pultruded GRP box section (Figure 1) (obtained from Lionweld Kennedy, Middlesborough, UK) is commercially available and currently used in secondary structural applications (i.e. small frames, stairways, etc.). It has average external dimensions of 51mm and wall thickness of 3.1mm. The box section composition includes the following four types of layers (Figure 2):

1. A veil, which is a resin-rich layer primarily used as a protective coating against erosion and surface damage to the main fibre reinforcement and to provide a smooth surface for handling.

2. Continuous Filament Mats (CFM) of different weights consist of randomly orientated fibres. CFM serves to improve the transverse mechanical properties of the pultruded section.

3. Plain Roving (PR) comprising continuous unidirectional fibre bundles, which contribute most significantly to the stiffness and strength of the section in the longitudinal direction.

4. Mock Spun Roving (MSR), which is crimped to guide the inner CFM.

This construction of the box leads to a strongly orthrotopic material, which, when thin, may be assumed to behave under plane-stress conditions. Owing to the high percentage of fibres in the longitudinal direction, both corresponding axial and bending stiffnesses are high. Conversely, transverse and shear stiffnesses are both relatively low, leading to anisotropic characteristics.

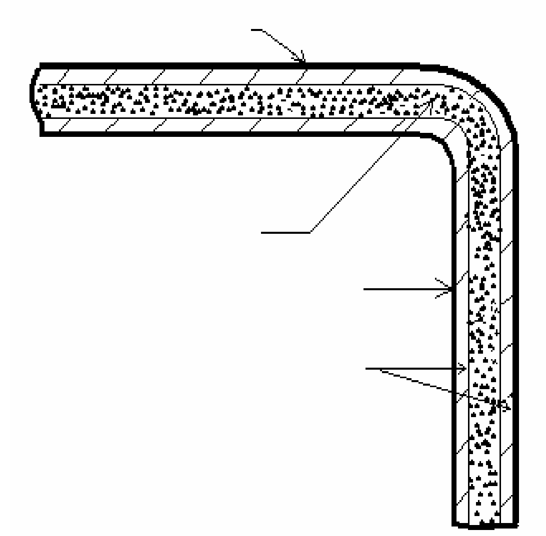

Figure 1. A perspective view of the Pultruded GRP box section.

Figure 2. Typical construction of the Pultruded GRP box section.

3. SPECIMEN PREPERATION

Longitudinal standard ASTM D3039 coupons (250mm by 15mm) were cut from the uniformly thick sides of the box section (see Figure 1) in all cases. Plain rovings (contributing significant to the material properties) were assumed to be parallel to the central axis and subjected to edge effects. Therefore, the longitudinal specimens (Figure 3) were extracted parallel to the member axis and remote from the edges of the box. A milling machine was used to ensure geometric consistency in plan. Aluminium tabs with dimensions of 1mm by 15mm by 50mm were bonded to the gripping areas with Araldite.

Equivalent longitudinal short coupons (47.5mm1 by 10mm) have been cut from the box section (Figure 4) to compare with the ASTM D3039. Correspondingly, smaller aluminium tabs (1mm by 9mm by 10mm) were used. In addition, coupons were cut in the orthogonal direction (Figure 5) to establish the transverse material properties.

4. TEST SET-UP

Axial tensile load has been applied to the coupons at a rate of 2mm/min (12) using self-clamping jaws with rotational freedom about two axes. An electronic data acquisition system recorded the load/strain data at a rate of one reading per second. Any bending contributions to the coupon strain state have been negated by the use of strain gauges located on both sides of the coupon at the geometric centre (i.e. back to back). This is consistent with standard test methods, where, for example, when determining the elastic properties it is recommended (12) that averaged strains from the back-to-back strain gauges be used to determine elastic properties when bending strains are greater than 3% of the axial values. A three pattern rosette (-45, 0, +45) and single gauge have been used on opposite sides for each coupon. All coupons have been loaded to failure, enabling a determination of tensile strength and to assess any elasto-plastic characteristics.

Figure 3. ASTM coupon - failure modes.

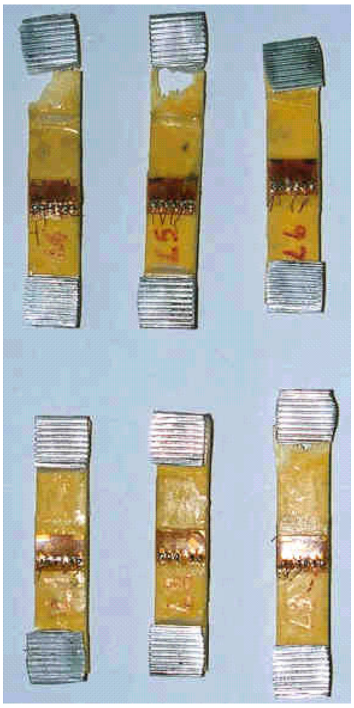

Figure 4. Short coupon -failure modes (longitudinal direction).

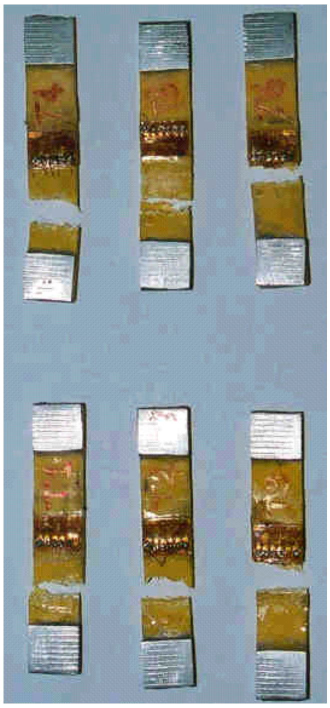

Figure 5. Short coupon - failure modes (transverse direction).

5. MEASUREMENT OF TENSILE PROPERTIES

The equation for calculating principal strains from three pattern rosette is derived from a strain-transformation relationship, which expresses the normal strain in any direction on a test surface in terms of the two principal strains.

The principal strains can be expressed in terms of the three measured strains as:

$$\varepsilon_{P,Q} = \frac{\varepsilon_1 + \varepsilon_3}{2} \pm \frac{1}{\sqrt{2}}\sqrt{(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2} \quad [1]$$

The plus and minus alternatives in (Eq. 1) yield the algebraically maximum and minimum principal strains, respectively. Principal longitudinal strains have been calculated from the measured strains of the three-terminal-rosette from (Eq. 1) averaged with the strain measured on the opposite side of the coupon. This procedure, as recommended by ASTM D3039, has been implemented in a short Fortran program, including the applied stress measures.

6. RESULTS AND DISCUSSION

6.1. Longitudinal Directio

From the test record of each specimen, the elastic modulus has been calculated from the

chord to the stress–strain curve between 1000 and 3000 micro-strain (με) (or the closest available data points) (see Table 3 of reference 12). Using this approach, the average modulus from five coupons is 26.7 kN/mm^2 with a standard deviation of 0.12 kN/mm^2. The maximum strength has been calculated with a range of 385 to 394 N/mm^2 (mean of 388 N/mm^2; standard deviation of 3 N/mm^2). Typical stress-strain curve is shown in Figure 6. The aluminium tabs prevented gripping damage to the specimen as expected when using the standard test method (12). The specimens failed in the gauge area as shown in Figure 3. Table 1 summarises the test results for the ASTM D3039 specimens.

6.2. Validity of the Short Coupon

Short coupons in longitudinal directions have been validated using experimental results of coupons specified from the ASTM D3039. The elastic properties have been computed from the chord in the region between 500 and 1500 micro strain (με) (or closest available data points) on the stress–strain curve. This strain range has been assumed by recognising that the breaking strain of the ASTM D3039 coupon has been determined experimentally to be approximately 15000 με, whilst that of the short coupon is around 7000με (i.e. a ratio of approximately 1:2). The strain range for the linear estimation of the elastic modulus of the short coupon has been obtained by applying the factor ½ to the standard limits and rounding to the nearest multiple of 500 με. This procedure is consistent with ASTM D3039 (12). Measured "short coupon" strains have been divided by the correction factor 1.0045 as calculated from the finite element analysis (11). The mean (from six specimens) longitudinal tensile modulus has been calculated as 26.4 kN/mm^2 with a standard deviation of 0.3 kN/mm^2. Table 2 summarises the test results for the short coupons in the longitudinal direction.

The statistical "Student's t test" [13] has been used to establish if the short coupon outcomes are representative of those obtained from the coupon geometry defined by the ASTM D3039. The results of the ASTM D3039 test results and short coupon results have been compared using (Eq. 8a-c) in order to determine whether there is a significant difference between both data sets.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{S_d} \quad [2a]$$

$$S_d = S_c \sqrt{\frac{n_1 + n_2}{n_1 \times n_2}} \quad [2b]$$

$$S_c^2 = \frac{SD_1^2(n_1 - 1) + SD_2^2(n_2 - 1)}{(n_1 - 1) + (n_2 - 1)} \quad [2c]$$

where t is the significance of the difference, Sc is the combined variance and Sd is the standard deviation of the difference of the means, n1 and n2 are the number of specimens in each data set.

The elastic modulus from the ASTM D3039 methodology has a mean of 26.7 kN / mm^2 ($\bar{x}_1$) and a standard deviation of 0.12 kN/mm^2 (SD_1). The corresponding values for the short coupon in the longitudinal direction are 26.4 kN/mm^2 ($\bar{x}_2$) and 0.3 kN/mm^2 (SD_2). Substituting these values into (Eq. 2), then,

$$S_c^2 = \frac{0.12^2(4) + 0.30^2(5)}{4 + 5} \Rightarrow S_c = 0.24$$

$$S_d = 0.24\sqrt{\frac{5+6}{5 \times 6}} = 0.15 kN/mm^2$$

$$t = \frac{26.7 - 26.4}{0.15} = 2.07$$

The number of degrees of freedom is [(5+6)-2] = 9. The 't' value given in Table A-8 in Kennedy and Neville (13), for a 5 percent level of significance (in the difference of the two data sets) is 2.262. As the tabulated value of 't' is greater than the calculated value, it is inferred that the difference between the ASTM D3039 and the short coupon data is significant to less than 5% (t = 2.07). Alternatively, it can be stated that there is at least 95% confidence that the short coupon is able to mimic the behaviour of the ASTM D3039 coupon in determining the tensile elastic material properties. Furthermore, it may be noted that the coefficient of variation of the ASTM D3039 (0.5%) and the "short" coupon (1.1%) results compare favourably. Similarly, the "t" value for the Poisson's ratio has been calculated by using the SD and values of Poisson's ratios (Tables 1 and 2; evaluated from the ASTM D3039 and short coupon in the longitudinal direction test results) substituting into to the (Eq. 2a-c). As in the previous (elastic modulus) case, the calculated value (t = 1.08) is smaller than the tabulated 't' value (2.262). It is concluded, therefore, that the short coupon results are valid. These results imply that the short coupon can be used to evaluate the material properties (Elastic modulus and Poisson's ratio) in the longitudinal direction where a long ASTM D3039 coupon would normally be used.

Though the tensile elastic properties of the box section in the longitudinal direction have been determined effectively, the transverse (through thickness) compressive stresses introduced by the jaws caused the premature failure of the short coupon (extracted from the longitudinal direction). Consequently, the results of the strength calculations have been found to be unreliable. The compressive stress from the jaws acting on the short coupon gripping area is approximately 8 times higher when compared with the ASTM D3039 specimen (i.e. the gripping area of the ASTM D3039 specimen is 15x50 = 750 mm^2 while that of the "short" coupon is 10 x10 = 100 mm^2). This increased stress causes the crushing of the specimen in clamping area which reduces its longitudinal integrity and strength leading to an underestimate of the ultimate tensile stress by a factor of two (i.e. 388 N/mm^2 (ASTM D3039) compared with 161N/mm^2 ("short" coupon). The "splaying" of the aluminium tabs (see Figure 4) indicates the presence of high compressive stresses in the clamping area. The long (ASTM D3039) coupons (see Figure 3) do not display this type of failure. It is concluded that the short coupon is able to predict the elastic material properties but should not be used to determine the ultimate strength of the box section material in the longitudinal direction.

Table 1. Box section ASTM D3039 coupon results

Specimen Code	$E_x^{initial}$ (kN/mm^2)	Polynomial $E_x^{tangent} = \partial\sigma/\partial\varepsilon$ (kN/mm^2)	Poisson's Ratio (ν)	Strength (N/mm^2)	Location of Failure
ASTM-1	26.8	$\sigma = -204.74\varepsilon^2 + 27.93\varepsilon$ $E_x = -409.48\varepsilon + 27.93$	0.30	389	near tab
ASTM-2	26.6	$\sigma = -146.52\varepsilon^2 + 27.50\varepsilon$ $E_x = -293.04\varepsilon + 27.50$	0.28	394	near centre
ASTM-3	26.7	$\sigma = -177.14\varepsilon^2 + 27.53\varepsilon$ $E_x = -354.28\varepsilon + 27.53$	0.28	386	near centre
ASTM-4	26.5	$\sigma = -191.96\varepsilon^2 + 27.26\varepsilon$ $E_x = -383.92\varepsilon + 27.26$	0.28	387	near centre
ASTM-5	26.7	$\sigma = -175.59\varepsilon^2 + 27.51\varepsilon$ $E_x = -351.18\,\varepsilon + 27.51$	0.30	385	near centre
Average	26.7	$\sigma = -179.19\varepsilon^2 + 27.55\varepsilon$ $E_x = -358.38\varepsilon + 27.55$	0.29	388	-
SD	0.12	-	0.02	3.0	-
CV	0.5%	-	6.4%	0.7%	-

Table 2. Box section short coupon results (longitudinal properties).

Specimen Code	E_x^{chord} (kN/mm^2)	Polynomial $E_x^{tangent} = \partial\sigma/\partial\varepsilon$ (kN/mm^2)	Poisson's Ratio (ν)	Strength (N/mm^2)	Location of Failure
L1	26.5	$\sigma = -455.73\varepsilon^2 + 26.99\varepsilon$ $E_x = -911.46\varepsilon + 26.99$	0.30	175	at grips
L2	26.6	$\sigma = -472.05\varepsilon^2 + 27.41\varepsilon$ $E_x = -944.10\varepsilon + 27.41$	0.30	144	at grips
L3	26.4	$\sigma = -455.53\varepsilon^2 + 27.61\varepsilon$ $E_x = -911.06\varepsilon + 27.61$	0.29	174	at grips
L4	26.3	$\sigma = -205.76\varepsilon^2 + 26.40\varepsilon$ $E_x = -411.52\varepsilon + 26.40$	0.31	135	at grips
L5	25.8	$\sigma = -191.72\varepsilon^2 + 26.39\varepsilon$ $E_x = -383.44\varepsilon + 26.39$	0.31	168	at grips
L6	26.6	$\sigma = -414.11\varepsilon^2 + 27.18\varepsilon$ $E_x = -828.22\varepsilon + 27.18$	0.30	168	at grips
Average	26.4	$\sigma = -365.82\varepsilon^2 + 27.00\varepsilon$ $E_x = -731.64\varepsilon + 27.00$	0.30	161	-
SD	0.30	-	0.01	15.8	-
CV	1.1%	-	2.6%	9.9%	-

6.3. Transverse Direction

Six short coupons in transverse direction have been tested to determine the transverse elastic properties of the box section. From the test record of each specimen, the elastic properties were computed from the chord in the region between 500 and 1500 (or closest available data points) on the stress-strain curve2. From six coupons, the mean transverse elastic modulus has been determined to be 9.2 kN/mm^2 with a standard deviation of 0.45 kN/mm^2.

Tensile failure of short coupons in the transverse direction is shown in Figure 5. All the specimens failed in the gauge area in contrast to the failure mode of the longitudinal "short" coupons. The maximum principal stress applied to the transverse coupons is orthogonal to the plain rovings (PR) (and not colinear as in the case of the longitudinal coupon), with the CFM and MSR contributing to the strength of the composite. The transverse strength of the composite is, therefore, significantly lower than the longitudinal equivalent (given predominantly by the PR). The coupon clamping stresses are clearly proportional to the applied tensile load and, by definition, to the tensile strength of the material. In the case of the "transverse coupon" the axial load required to induce tensile failure does not induce clamping stresses sufficient to cause degradation of the combined aluminium/GRP material and premature failure in this area. Consequently, it is suggested that the short coupon be used to establish both the elastic modulus and strength values in the transverse direction (i.e. orthogonal to the PR or principal reinforcement). The transverse strength of the box section has been determined within the range of 38-46 N/mm^2 (0.038-0.046 kN/mm^2) with a standard deviation of 2.72 N/mm^2 (0.0027 kN/mm^2) and coefficient of variation of 6.6%. The relatively high CV (6.6%) may reflect the effect of using a narrow (10mm) coupon on a material with a strength (in the tested direction) characterised by randomly distributed fibres. Stress-strain curve is shown in Figure 7.

Table 3. Box section short coupon test results (transverse properties).

Specimen Code	E_y^{chord} (kN/mm^2)	Polynomial $E_y^{tangent} = \partial\sigma/\partial\varepsilon$ (kN/mm^2)	Poisson's Ratio (ν)	Strength (N/mm^2)	Location of Failure
T1	9.1	$\sigma = -1054.7\varepsilon^2 + 10.99\varepsilon$ $E_y = -2109.4\varepsilon + 10.99$	0.17	42	near centre
T2	9.1	$\sigma = -636.59\varepsilon^2 + 10.89\varepsilon$ $E_y = -1273.18\varepsilon + 10.89$	0.14	40	near centre
T3	8.6	$\sigma = -1138.3\varepsilon^2 + 11.56\varepsilon$ $E_y = -2276.6\varepsilon + 11.56$	0.17	46	at centre
T4	9.5	$\sigma = -715.58\varepsilon^2 + 11.51\varepsilon$ $E_y = -1431.16\varepsilon + 11.51$	0.14	38	near centre
T5	9.9	$\sigma = -891.95\varepsilon^2 + 11.94\varepsilon$ $E_y = -1783.9\ \varepsilon + 11.94$	0.14	41	near centre
T6	9.0	$\sigma = -824.65\varepsilon^2 + 10.62\varepsilon$ $E_y = -1653.3\varepsilon + 10.62$	0.16	40	at centre
Average	**9.2**	$\boldsymbol{\sigma = -876.96\varepsilon^2 + 11.25\varepsilon}$ $\boldsymbol{E_y = -1753.92\varepsilon + 11.25}$	**0.15**	**41**	-
SD	0.45	-	0.015	2.72	-
CV	4.8%	-	10.0%	6.6%	-

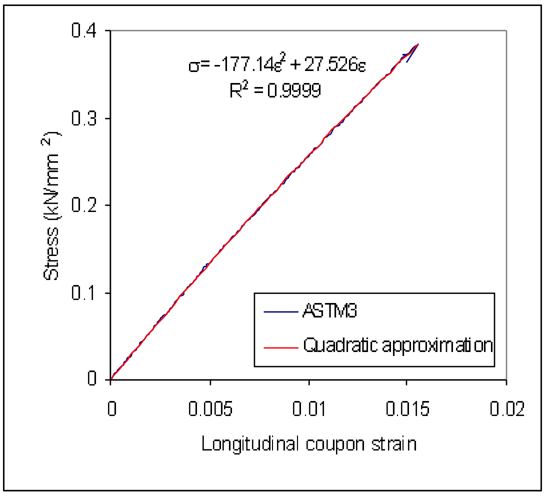

Figure 6. ASTM D3039 coupon stress-strain curve.

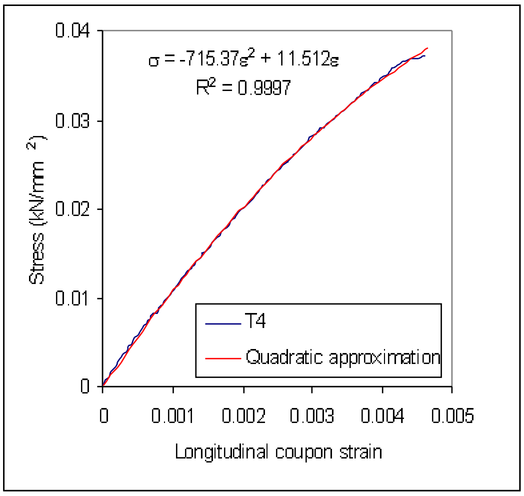

Figure 7. Short coupon (transverse direction) stress-strain curve.

7. CONCLUSION

An experimental program has been carried out to characterise the tensile behaviour of pultruded GRP box section using an ASTM D3039 and short coupon specification. The following conclusions have been drawn from this investigation:

- The mean longitudinal elastic modulus is obtained as 26.7 kN/mm^2 with a standard deviation of 0.12 kN/mm^2. All the specimens failed in the gauge area. The maximum strength has been determined with a range of 385 to 394 N/mm^2 (mean of 388 N/mm^2); with standard deviation of 3 N/mm^2 and coefficient of variation of 0.7 %.

- Experimental results of ASTM D3039 coupons and short coupons have been shown to exhibit consistent results. The statistical "Student's t test" has demonstrated that the short coupon data is representative of that obtained from an ASTM D3039 standard coupon. Test results have indicated that the short coupon is capable of measuring the elastic modulus, and Poisson's ratio where a long ASTM D3039 coupon would normally be used. However, the short coupon is not recommended for the use in determining the longitudinal strength of pultruded GRP.

- The mean transverse elastic modulus is determined to be 9.2 kN/mm^2 with a standard deviation of 0.45 kN/mm^2. All the specimens failed in the gauge area in contrast to the failure mode of the longitudinal "short" coupons. The transverse strength of the box section has been determined within the range of 38-46 N/mm^2 with a standard deviation of 2.72 N/mm^2 and coefficient of variation of 6.6%.

- For the purpose of the numerical studies undertaken on the connection assembly, the box material properties have been recommended to be linear (with perfectly plastic behaviour at the ultimate longitudinal and transverse stresses, σ_L and σ_T, respectively: i.e. no hardening) with mean values of: longitudinal elastic modulus, E_x = 26.7 kN/mm^2 transverse elastic modulus E_y = 9.2 kN/mm^2 longitudinal ultimate stresses, σ_L = 388 N/mm^2 transverse ultimate stresses σ_T = 41 N/mm^2 Poisson's ratio, ν = 0.29; shear modulus, G_{xy} = 3.8 kN/mm^2.

8. REFERENCES

1. EXTREN Fibre- "Glass structural shapes design manual", ***Strongwell,*** Bristol, Virginia (1989).

2.Hutchinson, A.R., Ed., "Joining of fibre reinforced polymer composite materials", ***CIRIA Project Report 46***, Westminster, London (1997).

3.Mottram, J.T., "Structural properties of pultruded E-glass fibre-reinforced polymeric I-beam", Composite Structures, 6, (Edited by Marshall, I. H.), Int. Conf. on Composite Structures, Paisley Collage of Technology, ***Elsevier***, 1-28 (1991).

4.Abd-El-Naby, S.F.M., "Experimental and theoretical investigation of bolted joints for pultruded composite structures", Ph.D Thesis, ***Dep. of Civil Engineering, University of Surrey*** (1992).

5.Chatterjee, S., Adams, D.F. and Oplinger, D.W., "Test methods for composites: A status report", ***FAA Technical Centre***, Atlantic City International Airport (1993).

6.Wang, Y. and Zureick, A., "Characterisation of the longitudinal tensile behaviour of pultruded I-shape structural members using coupon specimens", ***Composite Structures***, 29: 463-472 (1994).

7.Rosner, C.N. and Rizkalla, S.H., "Bolted connection for fibre reinforced composite structural members: experimental program", ***Journal of Materials in Civil Engineering***, 7(4): 223-231 (1995).

8.Sonti, S.S. and Barbero, E.J., "Material characterisation of pultruded laminates and shapes", ***Journal of Reinforced Plastic and Composites***, 15: 701-717 (1996).

9.Davalos, J.F., Salim, H.A., Qiao, P., Lopez-Anido, R. and Barbero, E.J., "Analysis and design of pultruded FRP shapes under bending", ***Composites: Part B***, 27B: 295-305 (1996).

10.Sarıbıyık, M., "Analysis of a bonded connector for pultruded G.R.P. structural elements", Ph.D. Thesis, ***University of Newcastle***, U.K. (2000).

11.Sarıbıyık, M. "Determination of material properties of moulded GRP connector using a" Short " Tensile coupon", ***Journal of the Institute of Science and Technology of Gazi University***, 15(1): 333-338 (2002).

12.Castro, J. and Griffith, R.M., "Press moulding processes", in Composite Engineering Handbook, Edited by Mallick, P. K., ***Marcel Dekker***, 9: 481-513, New York (1997).

13.ASTM D3039, "Standard test method for tensile properties of polymeric composite materials", ***Annual Book of ASTM Standards***, 14:02 (1996).

14.Kennedy, J. B. and Newille, A. M., "Basic statistical methods for engineer and scientist", 2nd Edition, ***Harper and Row Publishers***, New York (1976).

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