Experimentally Shear behaviour comparison between woven glass fiber/Polyester and Polyester

*Thamir A. D. M. S. Almul**
Engineering Technical College / Mosul, Northern Technical University NTU, 41002 Mosul, Iraq
**thamir_own@yahoo.com, thamir_own@ntu.edu.iq*

ABSTRACT

Composite woven E-glass/polyester panels had demonstrated better mechanical properties compared to metallic or pure polymers. Their high strength to weight ratios, corrosion and erosion resistance as well as other properties had been shown in studies to be better in contrast to metallic or pure polymers. However, vital information on the performance of composite woven E-glass/polyester under service conditions is scarce. There is the need to investigate its mechanical stability and shear behavior under stressful service-like conditions in order to determine its performance limits. The current research examines the mechanical behavior of woven glass fiber/polyester and polyester resin. The method subjects butterfly shape specimens, using the Arcan test fixture, to pure shear by tensile load conditions to obtain the shear strength, and shear modulus, G of the test specimens. The results show stress strain curves linearly propagated on each ±45 degree direction from the loading axis although the different recorded strain value between strains gauges +45° and -45° is about 7%, which may be caused by the effect of porosity (i.e. air bubbles) in the specimens. Eglass/polyester showed strengthens shear properties structure than polyester resin.

Keywords: *Composites; Woven E-Glass fiber; Arcan test; Shear Modulus; Polyester resin.*

Introduction

Normally, most of the different materials laminated contain planes weakness. In shear, the plate's strength will be dominated by these weaknesses unless the stress direction intersects the thickness. Shear stress at the interfaces across the thickness can seldom be avoided by casting design because of varying of the

ISSN 1823- 5514, eISSN 2550-164X

Received for review: 2019-06-15
Accepted for publication: 2019-07-01
Published: 2020-06-30

third direction of plane thickness mechanical properties [1]. In most engineering application, it is necessary to test the plate to obtain the shear and stress properties and also determining the failure criteria. In 1978, Arcan et al. introduced a new method of testing shear properties of material under uniform plane-stress conditions. Arcan et al. designed a special test fixture with a special shape of butterfly specimen as shown in Figure 1(a) [2].

Because of the manufacturing efforts to reduce the necessity of metallic source and high weight as well as cost products, there is large demand for investigating more composite and new advanced resources for substituting the current products of glass fibers reinforced polyester resin structures. Currently, many studies have recently investigated on manufacturing and testing of the properties for this new advanced replacement, and their constituents. The aerospace and automotive investigations have both displayed a great deal of consideration in utilizing additional composite reinforcements [3].

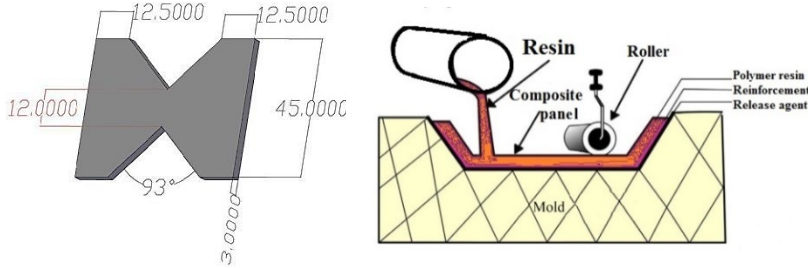
Various types of materials such as Aluminum and solid polymer can be tested using this fixture to determine the shear properties. Using the photo elastic analysis, it shown that in the significant section of the specimen is possible to produced uniform plane stress with high degree of accuracy. To improve of the shear stress testing, Arcan et al. (1978) has been developed a method for testing mechanical properties of isotropic and also orthotropic materials under uniform plane stress conditions. The compact nature of the Arcan fixture offers advantages to obtain the shear properties in all in-plane directions in a relative simple manner. The Arcan fixture can be used to apply both shear and axial forces to the test specimen and this special case of loading produces pure shear on the significant section and the experimental results are encouraging and acceptable with high degree of confident [2]. A special butterfly-shaped specimen has been designed to achieve a better test result especially in shear test. The method includes pure shear as a special case, when the angle equal to zero. The principle behind the geometry of the specimen is that in the pure shear zone, the isostatics will intersect the sheared cross-section (AB in Figure1(a)) at an angle of ± 45° [2]. Voloshin and Arcan (1980) used this method to determine a failure envelope for unidirectional fiber-reinforced materials and Jurf and Pipes (1982) used this method to investigate the inter-laminar fracture characteristics of graphite-polyester composite material with satisfactory result. A picture of the test rig used due to the testing is shown in Figure 1(a). The specimen is plane circular with antisymmetric cutouts. The significant section of the specimen is AB and the specimen must be designed in such a manner that the state of stress on AB shall be as uniform as possible [4-14].

In general, typical shear test method used to determine the shear properties of most materials is the cylinder-torsion test. However, this method has disadvantage which is unable to produced significant section on the sample and the grips strongly influence the state of stress, and there is the need to investigate and get a vital information on the performance of composite woven

E-glass/polyester under service conditions is scarce mechanical stability and shear behavior under stressful service-like conditions in order to determine its performance limits. The current research examines the mechanical behavior of woven glass fiber/polyester and polyester resin. The method subjects butterfly shape specimens, using the Arcan test fixture, to pure shear by tensile load conditions to obtain the shear strength, and shear modulus, G of the test specimens, the apparatus consist of specimen with butterfly shape and Arcan test fixture (test rig). The shear properties obtained due to the volume of the usage and forms.

Materials

The woven E-glass/polyester composite sample configuration that has been used in this investigation is shown in Figure 1(a). The composite woven E-glass/polyester panel has been manufactured using hand layup with six layers of E-glass fiber woven form (which supplied by INCOTELOGY GmbH Co.), then impregnated with polyester resin (Polyethylene terephthalate PET) supplied by Wee Tree Tong Chemicals Pte Ltd, Sungei Kadut-Singapore using rolling Procedure, Figure 1(b) shows the hand layup fabrication characters. Mechanical behavior investigations of the E-glass/polyester composite and polyester resin only will be analyzed analytically by employing a Moher circle. This research is adopted the classical mechanics of laminated and mechanical shell theory composite by assume that the behavior of the materials is elastic and linearly. The steps for solving the problems analytically will be presented in the next section.



(a) (b)

Figure 1: (a) Dimensions and geometry of the butterfly sample. (b) hand-layup fabrication characters

The main independent four characteristics are G_{12}, E_1, E_2 and υ_{12}, These independent characteristics can be determined from the known fiber and resin characteristics. The elastic factors for the panel can be determined with considerable accuracy which is using the expressions usually symbolized as the Halpin-Tsai formula. The axial elasticity modulus E_1 is predictable by the equation of mixtures creation [15-25]. And the mechanical properties of the composite panel can be determined via equations (1-8) depending on the volume fraction of about 0.59-60 % E-glass fibre.

$$E_1 = E_f .V_f + E_m .V_m . \tag{1}$$

where the prefixes f and m present the fibre and resin respectively. Fiber volume fraction and matrix volume fraction are symbolized by V_m and V_f While volume fraction can be determined by:

$$M_c = M_f + M_m ; v_f = M_f / \rho_f ; v_m = M_m / \rho_m ;$$
$$v_c = v_f + v_m ; V_f = v_f / v_c ; V_m = v_m / v_c \tag{2}$$

The woven fibre and resin matrix densities can be determined by:

$$\rho_c = \rho_f .V_f + \rho_m .V_m \tag{3}$$

where the density for the woven fibre and the matrix are symbolized by ρ_f and ρ_m respectively, and the mass for matrix and fibre are symbolized by M_m and M_f respectively. The main Poisson ratio can be determined by:

$$\upsilon_{12} = \upsilon_{13} = \upsilon_f .V_f + \upsilon_m .V_m . \tag{4}$$

where the Poisson ratios of resin and fiber are symbolized by v_m and v_f respectively. The shear modulus G_{12} and the transfers elasticity modulus E_2 can be found from:

$$E_2 = (1 + \xi \eta_c V_f)/(1 - \eta_c V_f) \tag{5}$$

where $\eta_c = (\frac{E_f}{E_m} - 1)/(\frac{E_f}{E_m} + \xi)$; $\xi = 2$ for calculations of E_2

$$G_{12} = (1 + \xi \eta_g V_f)/(1 - \eta_g V_f) \tag{6}$$

where $\eta_g = (\frac{G_f}{G_m} - 1)/(\frac{G_f}{G_m} + \xi)$; $\xi = 1$ for calculations of G_{12}

$$G_f = (E_f)/(2(1+\upsilon_f)) \tag{7.1}$$

$$G_m = (E_m)/(2(1+\upsilon_m)) \tag{7.2}$$

with assumption of $G_{12} = G_{13}$.

The other value of Poisson ratio can be determined by :

$$\nu_{21} = (\nu_{12} E_2)/E_1 \tag{8}$$

where E_1 is represent the woven fibre elastic modulus; E_2 is the matrix elastic modulus; E_3 is matrix elastic modulus in the another direction; υ_{12} = resin Poison ratio; υ_{13} = resin Poison ratio in the another direction; υ_{23} is the fibre Poison ratio; G_{12} is the resin modulus of rigidity; G_{13} is the resin modulus of rigidity in the another direction; G_{23} is the fibre modulus of rigidity; θ is woven ply orientation of fibre. The properties for the constituent material with engineering properties are arranged in Tables 1 and Table 2 respectively.

Table 1: The properties for the used constituent material

	E [GPa]	G [GPa]	ρ [Kg/cm^3]	υ	Mass[g]
Woven E-glass fiber	72.4	29.7	2.54	0.33	540
Polyester resin	2.0 – 4.4	0.7 - 2	(1.1 – 1.46) *10^{-3}	0.28	160-

Table 2: Material properties of constituents

Material	E_1 [GPa]	E_2 [GPa]	E_3 [GPa]	G_{12} GPa]	G_{23} [GPa]	G_{13} [GPa]	ν_{12}	ν_{23}	ν_{13}
Woven Eglass/ polyester	2.13	2.2	2.2	1.00	1.00	1.00	0.2540	0.25	0.25

Analytical Investigation

The shear stress for every sample is the main data that should be obtained in this testing. For each type of specimens, the shear strength, shear strain and the shear modulus has been recorded to compare with the analytical value. In this calculation, we assumed that the shear stress distribution along significant section is uniform. Figure 2 shows the specimen geometry. The result for the samples can be calculated as follows;

Specimen: woven glass fiber/polyester
Specimen's thickness, t =2.70 mm
Specimen's significant gauge length, h = 11.70 mm

Load carried by the specimen at the moment, F = 500 N
Principal strain in +45° direction, ε +45° = 48266 με
Principal strain in -45° direction, ε -45° = -48169με

The average shear stress, τavg and shear strain, γ can be determined as follows;

Specimen cross sectional area, Ao = t x h
Ao = (2.70 x 11.70) mm
Ao = 31.59 mm

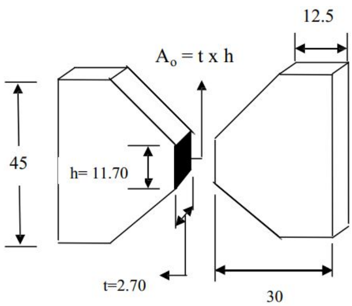


Figure 2: Specimen geometry

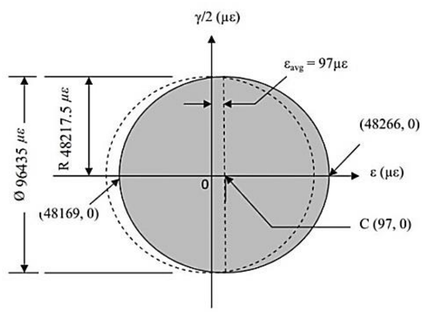


Figure 3: Mohr's circle constructed for loading woven glass fiber/polyester at 500N

<u>Calculation for Woven glass Fiber/Polyester Specimen using Moher Circle:</u>

i. Average shear stress, τavg

$\tau_{avg} = F/A_o$ = 500 N/23.76 mm^2 = 21.04 MPa

ii. Shear Strain, γ

$\gamma = \varepsilon_{45^o} - \varepsilon_{-45^o}$

= 48266 με – (-48169 με) = 96435 με

iii. Centre of Mohr's circle

C = ($\varepsilon_{45^o} + \varepsilon_{-45^o}$) /2 = [48266 + (-48169)] / 2 = 97 με

iv. Radius of Mohr's circle

R = γ / 2 = (96435 με) / 2 = 48217.5 με

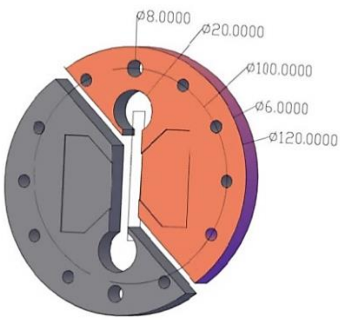
v. Diameter of Mohr's circle

Ø = 2R = 96435 με

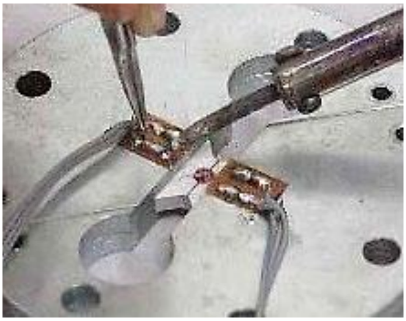
Result and Discussion

Mechanical shear characterizations have been determined from Arcan tests; the main applied load in this research is the subjection of the shear force to measure the capability for woven E-glass fibre to enhance the shear properties over the polyester resin to be used as a suitable replacement to metallic for high strength to weight ratio advanced materials. Arcan test has been applied with two type samples of woven E-glass/polyester and polyester resin. Three specimens have been taken among five tested specimens for each sample for the subjection of pure shear force.

The Arcan test rig consists of a pair of male and female sides as shown in Figure 4(a). The exact size and shape of specimen has been riding into the female part according by the male part. Both sides were constricted by screws to ensure the specimen has been tightly gripped between the two sides to avoid misalignment and slippage during the subjection of tension load. The complete assembly of the test rig has been hanged to the holder at lower and upper part consequently to the Tensile Testing Machine, the speed rate is 1mm/minute and using 5 kN load cell. The tensile load has been applied through holder before loading structure changed to shear mode that lastly imposed onto the sample. The direction of principal shear stress then will act in the direction of ± 45° as referred to the horizontal axis of sample significant section [2]. The details of Arcan test rig set-up are shown in Figure 4 (a). TML FCA-1-11 strain gauge with 13 mm gauge-length was fixed onto the side of the butterfly sample at the center of the gauge length area (refer Figure 4 (b)).



(a)



(b)

Figure 4: (a) Arcan test rig (b) Fixing for TML FCA-1-11 strain gauge

Table 3 shows the collected data of an experimental result for all types of specimens in which all the specimens tested up to failed completely.

Table 3: Experiment result for Woven E-glass fiber/polyester and polyester

Sample	Maximum yield load P(*kN*)	Strain approach yield limit		Shear stress at yield load τ (MPa)	Shear Modulus G (GPa)	Shear strain at yield load γ (με)
		+45°	**-45 °**			
Woven E-glass fiber/polyester	0.50	48266	-48169	25.09	0.27	96435
Polyester Resin	2.00	23245	-23185	38.90	0.60	46430

Referring to Table 2, maximum load For Woven is 0.55 *kN* and shear modulus is 0.27 GPa and for polyester resin where the maximum loading is 2 *kN* and shear modulus is 0.6 GPa.

Figure 5 shows the relationship between shear stress and shear strain is directly proportional. All the two types of samples analysed until failure.

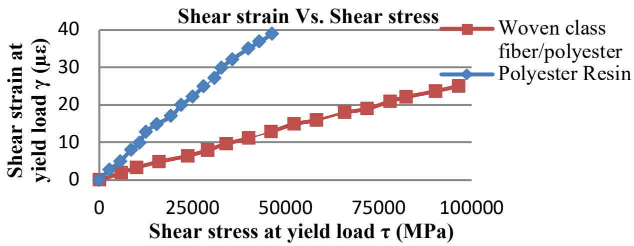


Figure 5: Relationship between shear stress and shear strain for each sample

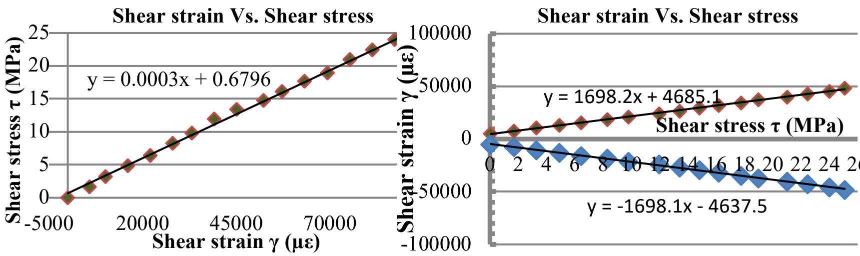
a) Woven glass fiber/polyester

Table 4: Raw experiment data for woven sample (woven 4)

Load	Strain		Average	Shear	Shear Stress
(N)	ε+45 (με)	ε-45 (με)	εavg (με)	γ	τmax (Pa)
0	5165	-5068	48.5	0	0
34.375	7802.813	-7761.81	41	5927.188	1.696813
68.75	10498.13	-10455.6	42.5	10054.38	3.2862
103.125	13192.74	-13149.4	43.3	16081.56	4.904375
137.5	15882.85	-15843.3	39.6	22108.75	6.4225
171.875	18571.86	-18537.1	34.8	28135.94	8.299063
206.25	21271.38	-21230.9	40.5	33163.13	9.80875
240.625	23972.39	-23924.7	47.7	39190.31	11.97688
275	26671.8	-26618.5	53.3	45217.5	13.395
309.375	29351.01	-29312.3	38.7	52244.69	14.81313
343.75	32046.33	-32006.1	40.2	57271.88	16.18125
378.125	34745.54	-34699.9	45.6	63299.06	17.74938
412.5	37443.95	-37393.8	50.2	69326.25	18.9975
446.875	40127.86	-40087.6	40.3	75353.44	20.99563
481.25	42832.68	-42781.4	51.3	81380.63	22.45375
515.625	45522.99	-45475.2	47.8	87407.81	23.99188
500	48266	-48169	48.5	96435	25.09

The maximum shear stress of each sample was determined by dividing the maximum load with the significant area of the samples. The results showed that the shear stress for different fiber forms and different fiber volume fractions were totally different. For the brittle specimens, the fracture line occurred at about 45° angle measured from the specimen principal axis to the gauge length vertical line. By visual inspection on the specimens cracked surface, it can be seen that the failure occurs almost at 45° angle. Therefore, the failure occurs in the direction of principal stresses which is same as the failure characteristic of brittle material. However, the failure characteristic for woven specimens showed that it was not totally brittle but it has some ductile behavior during loading test.

For each specimen, the principal strains in the +45° and -45° angle were used in order to calculate the shear strain. Then, the shear stresses versus shear strains graph can be obtained. Therefore, the elastic shear modulus was determined using the curve gradient of the earlier stage of the shear-strains curve. Next, Table 4 and Table 5 shows the data and result for each sample.



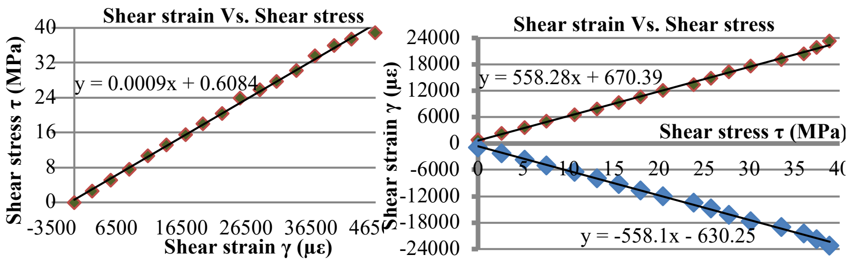
(a) (b)

Figure 6:(a) Relationship between Shear Stress-strain for Woven glass fibre/polyester sample
(b) Strain profiles measured at significant area for woven glass fibre/polyester sample

b) Polyester resin

Table 5: Raw experiment data for woven sample (woven 4)

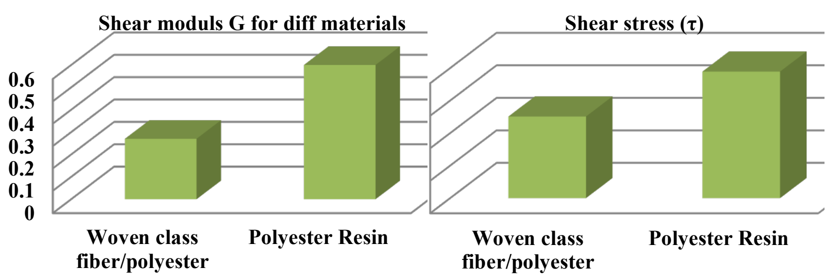
Load	Strain		Average	Shear Strain	Shear Stress
(N)	ε+45 (με)	ε-45 (με)	ε_{ave} (με)	γ	τmax (Pa)
0	913	-855	32	0	0
80	2286.6875	-2250.6875	36	2701.875	2.63125
160	3687.375	-3646.375	41	5603.75	5.1625
240	5083.3625	-5042.0625	41.3	8505.625	7.59375
320	6475.75	-6437.75	38	11307.5	10.725
400	7870.4375	-7833.4375	37	14209.375	13.15625
480	9266.925	-9229.125	37.8	17111.25	15.5875
560	10665.4125	-10624.8125	40.6	19813.125	18.01875
640	12065.3	-12020.5	44.8	22815	20.45
720	13454.8875	-13416.1875	38.7	25516.875	23.88125
800	14855.475	-14811.875	43.6	28618.75	25.8125
880	16249.9625	-16207.5625	42.4	31220.625	27.74375
960	17650.95	-17603.25	47.7	34222.5	30.175
1040	19042.1375	-18998.9375	43.2	37124.375	33.60625
1120	20442.525	-20394.625	47.9	40126.25	36.0375
1200	21835.8125	-21790.3125	45.5	42728.125	37.46875
1290	23245	-23186	47.8	46430	38.9



(a) (b)

Figure 7: (a) Relationship between Shear Stress-strain for Woven glass fibre/polyester sample
(b) Strain profiles measured at significant area for woven glass fibre/polyester sample

Figure 5, 6(a) and 7(a) displays the relationship between stress and strain. In general, the result illustrates a direct proportional for the changes of shear stress with shear strain when shear force has been subjected. This is occurring because the nature of the brittleness mechanical properties of composite materials. The value of shear modulus (G) for all specimens has been evaluated in regard to the slope of the curves. Shear modulus of woven glass fiber/polyester is 0.27 GPa while for polyester resin is 0.6 GPa. The slope inclination detected good agreement with previous related researches.



(a) (b)

Figure 8: (a): Shear modulus (*G)* for woven glass fibre/polyester and polyester resin;
(b): Shear stress (τ) for woven glass fibre/polyester and polyester resin

Figure 6(b) and 7(b) shows strain relation at significant area. The strain profile for +45 and -45 is same with principle and literature where the profile always symmetry for each side even though a small variation can be detected on the incline of the graph. This variation occurs because the specimens with Arcan fixture during the test run. It can be realized on the Mohr's-circle. Figure 6(a), and 6(b) shows that there is a direct proportional relationship between shear stress (τ) and shear modulus (G). The result shows when shear stress is increase, the shear modulus is also increased

Conclusion

In this investigation between the woven E-glass/polyester and polyester resin has been implemented experimentally and numerically under pure shear load according to ASTM D5379. From the results, it can be concluded that:

• The range of fibre volume fraction in the woven glass fiber/polyester specimens is 0.4648 up to 0.4853, means the percentage of the fibre consists in the specimens is 46.48% to 48.53%. Because the resin content in the specimens is small compared to the other specimen types.

• Woven glass fibre/polyester specimen can only produce the shear stress between 16.89 MPa to 26.12 MPa.

• Resin plays an important role if compared to the fibre in shear testing.

• The significant section of the butterfly specimen had proved that the Arcan Test Method is reliable.

• The shear stress strain relation is linear by propagated. Even though the strain in both directions was not perfectly symmetry.

• Main factor that influenced the test data is the production method of the specimens (hand lay-up) resulting the porosity inside the specimens (i.e., air bubbles).

• This study recommended that the porosity occurred in the specimens due to hand layup can be avoided by improving this process of fabrication.

• With refer to the strain's data printed by the data logger; the shifting of strain value increases as the loading onto the specimen was increased. The misalignment of the pure shear is still less than 9%.

• A good agreement has been recorded for E-glass/polyester that showed strengthens shear properties structure than polyester resin.

References

[1] Ayal De and Jayatilaka (1979). 'Fracture of Engineering Brittle Materials', Applied Science Publisher, London

[2] Fahis bin Tumin. (2005), 'The Determination of Shear Properties of Brittle Materials Using Arcan Test Method', Tesis Sarjana Muda, Universiti Teknologi Malaysia, Johor.

[3] Mohanty, A., Drzal, L., & Misra, M. (2002). Novel hybrid coupling agent as an adhesion promoter in natural fiber reinforced powder polypropylene composites. Journal of materials science letters, 21(23), 1885-1888.

[4] M. Arcan, Z. Hashin and A Voloshin (1978). 'A Method to Produce Uniform Plane-stress States with Applications to Fiber-reinforced

Materials', Experimental Mechanics, April.
[5] D. Mohr and M. Doyoyo (2003). 'A New Method for the Biaxial Testing of Cellular Solids' Experimental Mechanics, June.
[6] Mayer, R.M.(1992). 'Design with Reinforced Plastics'. Bourne Press Ltd. 1- 46 United Kingdom.
[7] Marini Sawawi (2005). 'Evaluation of Adhesive Epoxy Materials in a Composite / Concrete System Under Shear Loading'. Tesis Sarjana, Universiti Teknologi Malaysia, Johor.
[8] McQuillien, E. J. and Gau (1976). 'Low Velocity Transverse Normal Impact of Graphite Epoxy Composite Laminates'. Journal Composite Materials, Vol. 10, January.
[9] M. J. Robert (1975). 'Mechanics of Composite Materials', Institute of Technology Southern Methodist University, Texas.
[10] N. Choupani, Lin Ye and M. Yiu-Wing (2006). 'Mixed-Mode Fracture of Adhesively Bonded Joints', The University of Sydney, Sydney.
[11] Rani El-Hajjar and Rami Haj-Ali (2004). 'In Plane Shear Testing of Thick Pultruded FRP Composites Using Modified Arcan Fixture Composites Part B', Volume 35: page 421-428, Experimental Mechanics.
[12] R. C. Stephens (1978). 'Strength of Materials', Edward Arnold (Publishers) Limited, London.
[13] Schwartz Mel M. (1997) 'Composite materials (properties, nondestructive, testing and repair)' Prentice Hall Inc, New Jersey.
[14] Shamsul Izwari Nawawi (2005) 'Determination of CFRP Pultruded Plate Shear Modulus by Arcan Test Method', Tesis Sarjana Muda, Universiti Teknologi Malaysia, Johor.
[15] Almula, T. A. D. M. S., Sharifi, S., Sharifishourabi, G., Gohari, S., Ayob, A. B., & Yahya, M. Y. (2013). Static Analysis of Stitched Sandwich Beams with Functionally Graded Foam Core. Applied Mechanics and Materials, 393, 381-386.
[16] Almula, T. A. D. M. S., Yahya, M. Y., Ayob, A., Makhtar, I., & Alias, A. (2015). Mechanical Behavior of Composite Multilayered Basalt/E-Glass/Epoxy Pipe under Internal Pressure. Paper presented at the Advanced Materials Research.
[17] H Sosiati, YA Shofie, AW Nugroho, Tensile Properties of Kenaf/E-glass Reinforced Hybrid Polypropylene (PP) Composites with Different Fiber Loading, EVERGREEN 5(2)1-5-2018-HS., URL: http://repository.umy.ac.id/handle/123456789/21622
[18] P. E. Bourban, N. Bernet, J. E. Zanetto, J. Anders and E. Månson, Compos. Part A, 32, 8, 1045 (2001). 2) A. John and S. Alex, Int. J. Eng. Manag. Res., 4 (4) 98 (2014).
[19] J. Holbery and D. Houston, JOM, 58, 80 (2006).
[20] M. Jawaid and H. abdul Khalil, Carbohydrate Polymers, 86 (1) 1 (2011).
[21] I.A.S. Salem, A.R. Rozyanty, B.O. Betar, T. Adam, M. Mohammed, and

A.M. Mohammed, J. Physics: Conf. Series, 908, 012001 (2017).
[22] J. Kamal, M. Zharif Thirmizir, E. Beyer, M.J. Saad, N.A. Abdul Rashid, and Y. Abdul Kadir, J. Sci. Technol, Available in: file:///C:/Users/ASUS/Downloads/796-3588-1- PB%20(1).pdf
[23] Z. Öztürk, J. Comp. Mater., 44, 2265 (2010).
[24] M. Ramesh and S. Nijanthan, Bull. Mater. Sci., 39, 1, 147 (2016).
[25] M. R. Mansor, S. M. Sapuan, E. S. Zainudin, A. A. Nuraini and A. Hambali, *J. Polym. Mater*., **30**, 3, 321 (2013).