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Effect of Multiaxial Testing on Polymeric Foams Performance for Shear-Compressive Loading

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Abstract—**Polymeric foams are widely used as core materials in sandwich structures. The polymeric foams have complex geometry shapes with various density but good as energy absorption devices. The industry has continually developed new type of polymeric foams with have different types of mechanical properties. For this purpose, a standard testing method is required to evaluate the mechanical properties of foams. The basic testing methods are uniaxial tension, compression and shear tests. The purpose of this paper is to develop the multiaxial test method as well as to contrast with the current test method. A multiaxial test rig was designed and fabricated in the project. The forces are applied to the core in form of compressive and shear. The acquired results for the multiaxial test found that the mechanical properties are slightly varied with the basic test methods. The surface failure of foams where more clear failure surface locus is also investigated.**

Keywords: polymeric foams, failure surface, multiaxial test

I. Introduction

Polymeric foam materials have a cellular structure with a three-dimensional array of cells and they are being used increasingly in engineering applications (see figure 1). The four major areas of application for cellular materials are thermal insulation, packaging, structural use and buoyancy. In many of these applications, interest has been focusing in structural use where many of researchers gain to improve the performance and capability of the structures, which is called sandwich structure. However, their mechanical behaviours are complex due to their cellular structure [1]. More materials tests are required to determine their mechanical properties for structural design and numerical simulation purposes [2]. Due to the interest of polymeric foams, many researchers had done several studies to determine the mechanics, behaviours and properties of the foams [3, 4, 5]. In order to understand the basic mechanical behaviour of polymeric foam in general loading case, experimental and theoretical studies have been conducted in three basic loading conditions; tension, compression and shear tests.

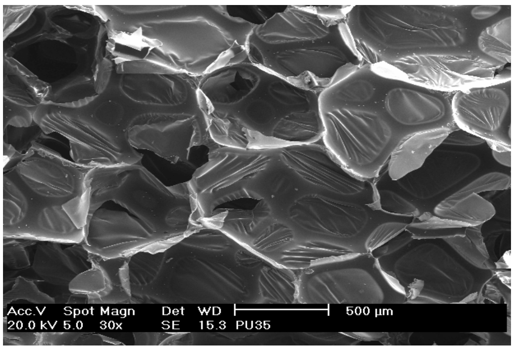

Figure 1. Three-dimensional array of cells of polymeric foam

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This paper is an effort in showing the basic tests of polymeric foam in three different conditions e.g. tension, compression and shear tests and presenting the multiaxial test as an additional test to study the polymeric foam behaviours. The focuses are more on multiaxial testing and the construction of failure surface locus of polymeric foam.

II. MATERIAL PREPARATION

In this study, rigid polyurethane (PUR) foam was used as the specimen. The foam system is 529B/3, supplied by Maskimi Polyol Sdn. Bhd. PUR foam is produced by reaction of a polyol and an isocyanate, required formulation, in the presence of appropriate blowing agent, catalyst and surfactant. The foam was manufactured to get slab stock foam by using injection foaming process in special *in-situ* mould [6]. The PUR chemicals used were based on ratio 50% of component A (isocyanate) and 50% of component B (polyol blend). This ratio was chosen because of the ratio gave uniform and consistency microstructure for this structural foam. The samples were prepared from slab stock foam into cubes with dimensions of 25mm x 25mm x 25mm as shown in figure 2(a). The foam weight was determined by using electronic weighting scale (see figure 2(b)). The density of foam, ρ was measured according to standard ASTM D1622-98.

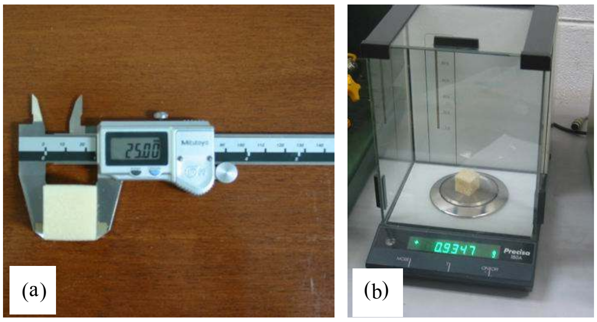

Figure 2. (a) Specimen dimension, (b) Measuring foam weight.

Table 1 shows the density of PUR was measured. Based on table 1, the average apparent density of the PUR foam was 64.01± 0.2 kg/m^3.

Table 1. Density of PUR foam was measured.

Sample	Weight (g)	Height (mm)	Length (mm)	Width (mm)	Volume (mm^3) x10^3	Density, ρ (kg/m^3)
1	1.0056	25.09	24.91	25.11	15.69	64.07
2	1.0094	25.04	25.12	25.04	15.75	64.09
3	1.0135	25.13	25.10	25.12	15.84	63.96
4	1.0084	25.14	25.05	25.09	15.80	63.82
5	1.0117	25.06	25.11	25.07	15.78	64.13
					Average:	64.01

III. EXPERIMENTAL WORK

In this project, four types of tests have been considered and experimental tests were accomplished to collect the appropriate data for this PUR foam.

IV. COMPRESSION TEST

Compression test was conducted in an INSTRON 100kN series 4206 testing machine according to standards ASTM D1621-1987. The specimens were 25mm thick, and other dimensions were same, 25mm by 25mm. As shown in figure 3, the specimen was placed between the platens of the machine and was deformed at a quasi-static loading rate 1mm per minute, which gives an engineering strain rate of 6.7 x 10^{-4}s^{-1}. The compression stress is calculated by using simple compression calculation;

$$\sigma_c = F/A \qquad (1)$$

where: σ_c = core compression strength (MPa)
F = load (N)
A = cross-section area (mm^2)

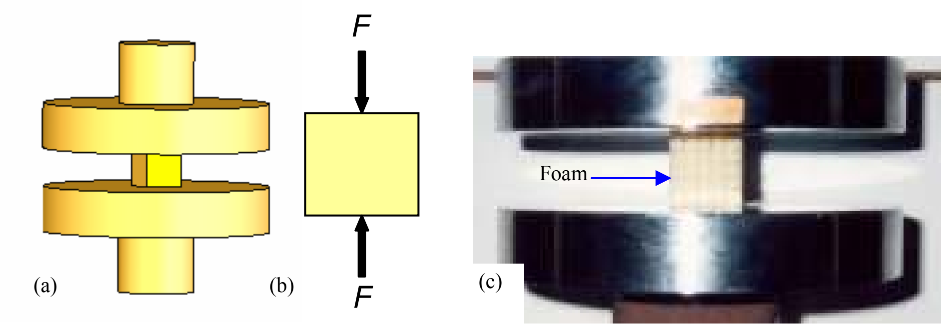

Figure 3. Compression test (a) setup, (b) free-body diagram of compression loading (c) picture of specimen before compression test.

V. Tension Test

The foam tension test was conducted on an INSTRON 100kN series 4206 testing machine to the relevant standard ASTM C297-1961. The specimens were 25mm thick and the other dimensions were 25mm by 25mm. The blocks of the foam were bonded to aluminium blocks using Araldite glue. The curing time was 3 hours at 40°C. The testing rig is designed to allow for both forward and lateral deflections which eliminate bending effect as shown in figure 4. The stiffness of the testing machine was compensated for by replacing the foam with an aluminium block. The crosshead speed was 1mm per minute, which gives an engineering strain rate of 6.7×10^{-4} s^{-1}. The tension stress is calculated by using simple tensile calculation;

$$\sigma_t = F/A \qquad (2)$$

where: σ_t = core tensile strength (MPa)
F = load (N)
A = cross-section area (mm^2)

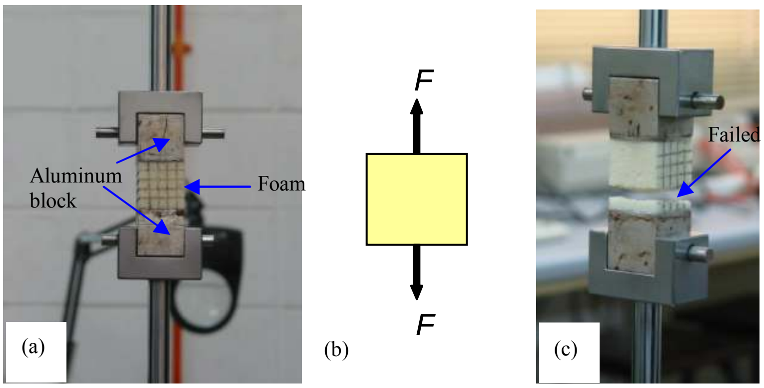

Figure 4. Tension test (a) setup, (b) free-body diagram of tensile loading (c) specimen failed in tension mode.

VI. Shear Test

The foam shear test is defined in ASTM standard C273-1961. There are two versions of the test, namely tensile and compression loading. The compression version was used. The specimen geometry was 25mm thick with the other dimensions being 240mm by 50mm. It was then tested on the INSTRON 100kN series 4206 testing machine. The load line should act through the opposite corners of the foam specimen. The foam was bonded to the platens using Araldite glue as shown in figure 5. The bonding between rigid and the foam was important because if not failure would occur at the bonding of the foam and the platen. If this occurs so the shear data was not accurately. The shear stress is calculated by using simple shear calculation;

$$\tau_f = F/(L \times b) \qquad (3)$$

where: τ_f = core shear strength (MPa)
F = load (N)
L x b = A = cross-section area (mm^2)

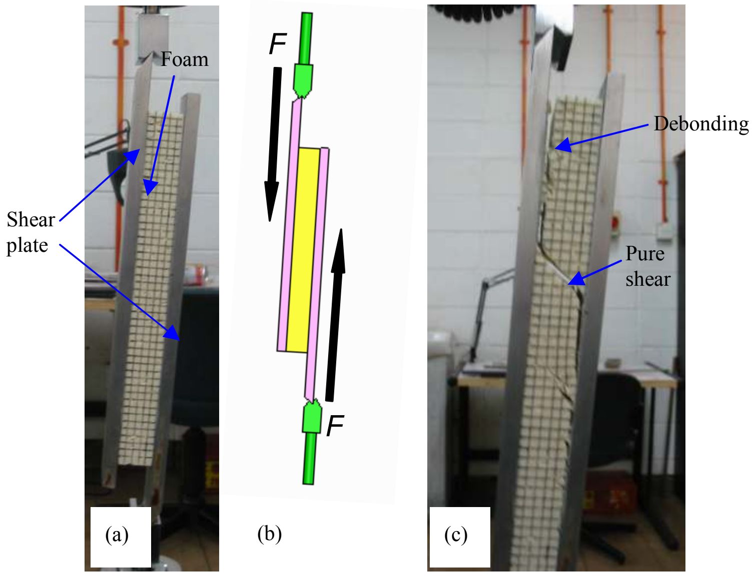

Figure 5. Shear test (a) setup, (b) shear force acting on the shear plates (c) pure shear failure mode at 45°.

VII. Multiaxial Test

In order to get the accurate mechanical properties of polymeric foam, a special rig is designed to verify the behaviour of foam under compressive and shear stresses. The purpose of this test is because of transverse shear effects on the compressive behaviour of core foam become an important issue in modelling the impact response of a sandwich structure. It was found that the core material underneath the impact loading area is subjected to multiaxial stresses, where the foam material response and failure depend on its interactive behaviour under compressive and shear stresses. In their elastic-plastic analysis model, it used a linear interaction criterion to describe shear effects on compressive yielding.

$$\frac{\sigma}{\sigma_y} + \frac{\tau}{\tau_f} = 1 \qquad (4)$$

Where σ_y is the yield or plateau stress from the compression test, and τ_f is the shear-failure stress.

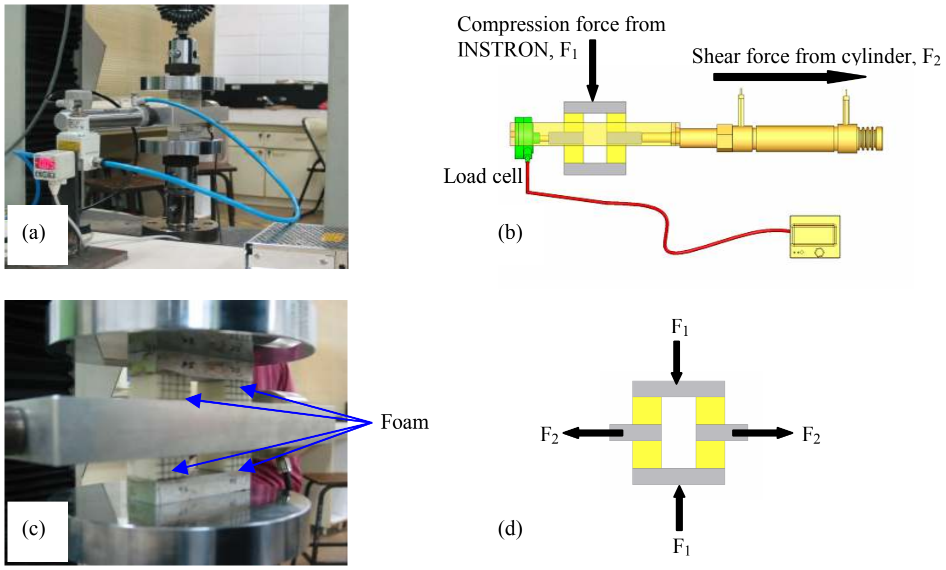

Figure 6. Multiaxial foam test. (a) Picture of multiaxial test setup, (b) Assembly drawing, (c) Picture of foam is loaded with compressive and shear forces, (d) Free-body diagram of forces acting at foam.

The foam specimen which is a cube with the dimensions of $25mm^3$ is used for this test. Four cubic specimens of foam are prepared and glued on the steel plate using Araldite glue. The glued cubic specimen was putted in an oven for 4 hours at 40°C for the curing process. The prepared specimen was then placed between loading platen of the INSTRON machine. The experimental multiaxial test rig is shown in figure 6. In the vertical direction, the compressive load, F_1 is applied by INSTRON platens to the steel plates. Initial compressive quasi-static loading rate was set at 1mm per minute. A constant transverse force, F_2 was monitored by a load cell-data logger.

The transverse force was applied at two middle plates and then to supply shear force on the foam specimens. This force was supplied by a piston using high pressure gas from an air compressor. The air pressure can be adjusted to give a constant force through a direction control valve. A rigid aluminium frame of 8mm thickness was used around the specimen block for supplying an equal right and left transverse tension force. The load-displacement from INSTRON machine was recorded to calculate the engineering stress and strain. The same steps were repeated for different transverse forces. The initial transverse force was obtained from previous pure shear experiment test. The equation to calculate the compression and shear stresses is shown below.

Effective compressive stress, $\sigma = F_1$ / (Effective Area) (5)

Effective shear stress, $\tau = F_2$ / (Effective Area) (6)

This multiaxial test can be conducted under different shear rate, compressive loading rate, compressive strain rate with other types of polymeric foam cores.

VIII. Results And Discussion

In figure 7 shows the graphs of multiaxial tests under different shear loading. Table 2 shows the mechanical properties of PUR foam under compressive-shear test. In figure 8, relationship between dimensionless compressive stress and shear stress ratios is plotted and verifies the equation (4).

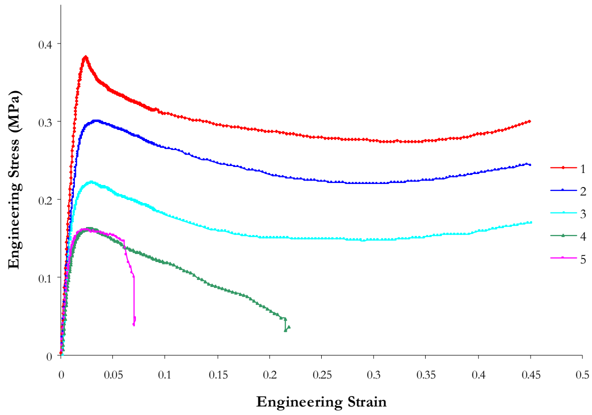

Figure 7. Graphs from mutiaxial tests in different loading rate.

Table 2. Mechanical properties of PUR foam under multiaxial test.

Specimen	Shear Stress Ratio, τ / τ_f	Shear Stress, τ (MPa)	Shear Force, F_2 (N)	Yield Stress, σ_y (MPa)	Yield Strain, ε_{cy} (%)	Modulus Young, E (MPa)
1	0.10	0.030	38	0.383	3.4	24.80
2	0.20	0.060	75	0.300	3.1	23.40
3	0.30	0.090	113	0.222	2.9	20.50
4	0.35	0.105	130	0.163	2.8	17.95
5	0.40	0.120	150	0.161	2.3	18.92

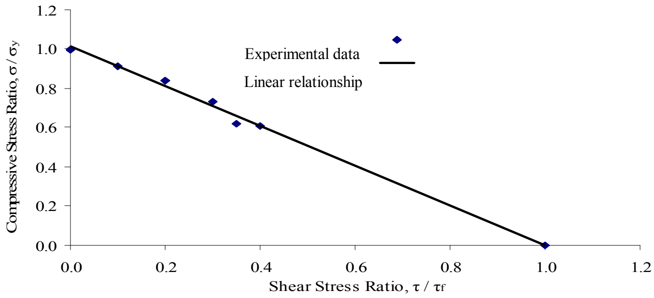

Figure 8. Relationship between non-dimensional compressive stress and shear stress ratios.

From the all tests, the data can represent the yield stress locus or failure surface diagram. The details of yield stress locus are presented in figure 9. In figure 9, the data are plotted in two dimensional principal stress states and are dimensionless with respect to the tension failure stress, σ_{tf}. Point A corresponds to tension, point B to shear, point C to compression and point D is approximate to hydrostatic compression where it is shown in dotted line. The only quadrant (quadrant I) with no data is the all tension made. The dashed line is represented the failure surface without multiaxial test data where it is in straight line, not smooth compared with including mutiaxial test data.

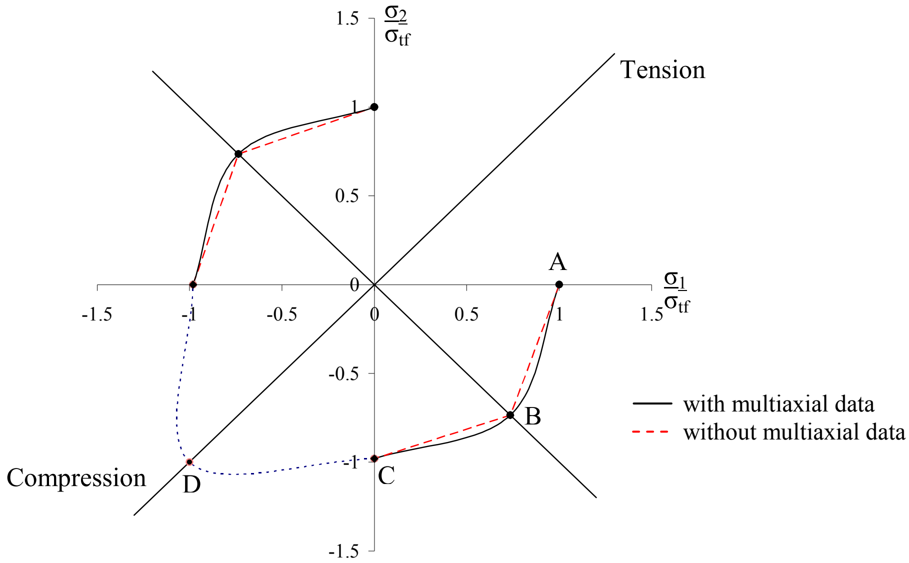

Figure 9. Failure surface locus of PUR foam.

IX. CONCLUSION

A test rig is developed in the paper to study the polymeric foams response under multiaxial stress state. In the present case, the compressive response of PUR foam under shear forces is verified to be used in different polymeric foam studies. The multiaxial foam test gives an effect to the yield surface of foam where more clear and smooth failure surface locus is constructed. The material test results can be used to determine parameters in material models and the compressive-shear results may be used to examine the validity of material models through the FE method.

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REFERENCES

[1] J.L. Gibson and M.F. Ashby, *Cellular Solids*. Cambridge University Press, 1997.

[2] Q.M. Li, R.A.W. Mines and R.S. Birch, "The crush behaviour of Rohacell-51WF structural foam", *International Journal of Solids and Structures*, vol. 37, pp. 6321 – 6341, 2000.

[3] T.C. Triantafillou, J. Zhang, T.L. Shercliff, J.L. Gibson and M.F. Ashby, "Failure surface for cellular materials under multiaxial loading-II Comparison of model with experimental", *International Journal of Mechanical Science*, vol. 31, pp. 665 – 678, 1989.

[4] A. Alias and R.A.W. Mines, "Experimental results and techniques on the crush behaviour of structural foam", *The 3rd International Symposium on Impact Engineering*, Singapore, pp. 379 – 384, 1998.

[5] R.A.W. Mines, Q.M. Li, A. Alias, R.S. Birch and J.A. Close, "On the measurement of the crush behaviour of structural foams", *The 11th International Conference on Experimental Mechanics*, Oxford, 1998.

[6] M.R.M.Rejab, A. Alias and Y.S. Ismail, "*In-situ* technique in manufacturing structural sandwich beams", *Research Seminar on Materials and Constructions*, UTM Skudai, October 2002.