VOL. 3, NO. 4, AUGUST 2008 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences


www.arpnjournals.com

DETERMINATION OF VOLUME FRACTION VALUES OF FILAMENT WOUND GLASS AND CARBON FIBER REINFORCED COMPOSITES

Abdalla F. H.[1], Megat M. H.[1], Sapuan M. S.[1] and B. B. Sahari[2]
[1]Department of Mechanical and Manufacturing Engineering, University Putra Malaysia, Serdang, Selangor, Malaysia
[2]Institute of Advanced Technology, ITMA, University Putra Malaysia, Serdang, Selangor, Malaysia
E-mail: awami67@yahoo.com

ABSTRACT

With the expansion of composites into application like pipes and pressure vessels, there exists a need for further studies on the properties of these materials. This paper presents the results from a series of tests on the physical properties of composite materials. Specimens cut from pipes made from composite materials to be tested under internal pressure loadings have been tested by using a series of ASTM D2584 (1968) standards test methods for glass fiber reinforced composites and the density method for carbon fiber reinforced composites. The results from this series of tests have been tabulated and presented. The volume fraction for the glass and carbon fibers were found to be 0.476 and 0.540, respectively.

Keywords: volume fraction**,** glass fibers, carbon fibers**,** burning, density, method.

INTRODUCTION

Composite materials in the context of high performance materials for structural applications have been used increasingly since the early 1960s; although materials such as glass fiber reinforced polymers were already being studied 20 years earlier. Initially conventional test methods originally developed for determining the physical and mechanical properties of metals and other homogenous and isotropic construction materials were used. It was soon recognized however that these new materials which are non homogenous and anisotropic (orthotropic) require special consideration for determining physical and mechanical properties [3]. In order to estimate the strength and stiffness, the structural materials are subjected to a number of tests. Tests aimed at evaluating the mechanical and physical characteristics of fibrous polymeric composites are the very foundation of technical specification of materials and of design efforts [4]. The uses of composite structures have proliferated recently to include a large number of new applications. Once only used for specialized parts or secondary members, composites are now considered to be competitive with other materials in many fields. The facts that composites in general can be custom tailored to suit individual requirements have desirable properties in corrosive environment; provide higher strength at a lower weight and have lower life-cycle costs has aided in their evolution. Also it provides a good combination in mechanical property, thermal and insulating protection. These qualities in addition to the ability to monitor the performance of the material in the field via embedded sensors give composites an edge over conventional materials. So to understand the behavior of the composite materials under different loading conditions and because composite materials are produced by different manufacturers studying of the mechanical and physical properties becomes vital [5,6]. The focus here is to expand the general understanding of these materials to illustrate the importance of knowing the mechanical and

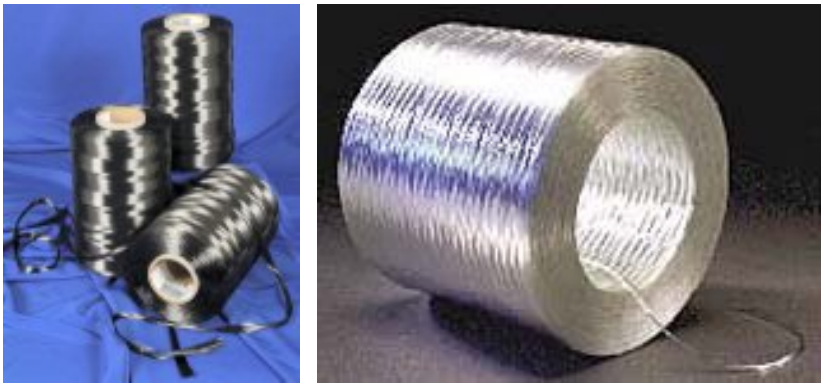
Physical properties and to show the ease with which this information can be obtained through simple laboratory tests. Specifications given by manufacturers are often average values for an entire product line and not a specific item. This is a source of error when considering small test samples cut from product sample. Further much of the specific information is not published in manufacturers literature which requires the user to conduct the tests himself to determine the exact information. Accurate mechanical properties of the composite materials are essentially important because they provide the fundamental materials parameters in the design composite structures under different loading modes.

The objective of this paper was to present the processing techniques of specimen preparation and analysis of test methods and test procedures to determine the physical properties of composite materials. The test methods presented are American Society for Testing and Materials (ASTM). These tests are useful for the experimental characterization of an isotropic material.

MATERIALS AND METHODS

Materials selected

The materials tested consisted of glass fiber reinforced composites with epoxy resin matrix and carbon fiber reinforced composites with epoxy matrix. The types of fiber used were E-glass fiber from PPG. Ind., Inc., USA and Pan-based carbon fiber from Zoltek Corporation, USA, and Figure-1 shows the roving creel of fibers. Table-1 shows the mechanical properties of the fibers. The matrix used in this study was epoxy resin and hardener types were of MW 215 TA and MW 215 TB, respectively. Table-2 shows the physical and mechanical properties of the matrix.



a **b**

Figure-1. Roving Creel for Fiber (a) Carbon Fiber (b) Class Fiber

Table-1. Mechanical properties of composite fibers.

Types of fiber	E_f (GPa)	ν_f	G_f (GPa)	ρ (g/cc)
Carbon fiber	228.0	0.31	41.16	1.81
Glass fiber	72.52	0.33	29.721	2.0

Table-2. Physical and mechanical properties of the Matrix.

Item	**Unit**	**WM-215 TA**	**WM-215 TB**	
Appearance	-	White viscous liquid	Colorless liquid	
Viscosity	Cps@ 30^o C	5500 ±1000	30 ± 20	
Mixing ration	-	100	25	
Mechanical Properties of Matrix				
E_m (GPa)	ν_m	G_m (GPa)	ρ_m (g/cc)	**Ultimate tensile stress** (MPa)
3.2	0.28	1.25	1.1	51

Determination of fiber volume fraction (v_f)

In the fiber reinforced material the fibers are distributed throughout the matrix in a pattern we could describe as somewhat repeating or periodic. There is randomness involved but as a first approximation the cross section could be idealized as square packed array or hexagonal packed array. The names of the arrays are derived from the shape of the polygons that describe the fiber packing pattern and generally the hexagonal array is the preferred model of the two. Assume that either of the two models represents to a reasonable degree of accuracy the microstructure of a fiber reinforced composite material as shown in Figure-2. By directing the attention to a unit cell of that model we easily see that the cross-sectional area of the fiber relative to the total cross sectional area of the unit cell is a measure of the volume of fiber relative to the total volume of the composite. This fraction is an important parameter in composite materials and is called fiber volume fraction and it is a number between 0 and 1 [7].

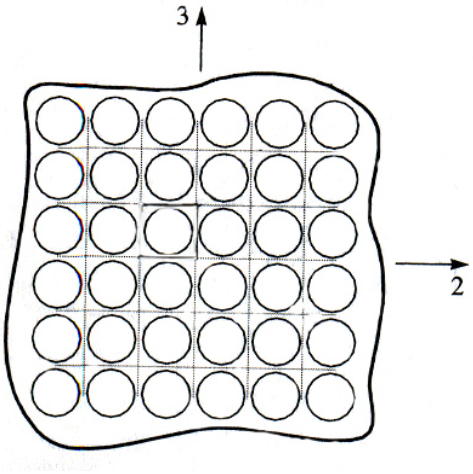


Figure-2. Unidirectional fiber square packing geometry[7]

Glass fiber volume fraction

Since fiber and resin content affect the material's mechanical response and properties, they should be measured for each material tested and accounted for in

predicting mechanical response. The fiber volume fraction v_f can be determined experimentally by weighing a lamina, then removing the matrix and weighing the fibers [8]. According to ASTM D2584 (1968) [1,5], four tubular specimens were prepared to find the volume fraction for glass fiber composite.

Test method

The specimen is contained in a crucible and is placed in a furnace degraded leaving only reinforcement and no filler was used. Once the resin is completely removed, analysis of the laminate is performed on the burn-out remains. This method is known as the ignition loss method or burn-out process. The burning method (ASTM D2548-68 [1]) has been considered a simple and effective way to determine the volume fraction of cured resin composite materials but in many cases it has shown some limitations when fillers have been added to the material. The fillers which may be partially burned out or not burned out at all by the burn-out process stay with the glass fiber. This causes difficulties in determining the fiber volume. Until now there has been no standard approach to separate fillers from the resin and glass fiber of structural composites [5]. In this work there was no fillers added to the composite structure produced.

Apparatus

1. Calipers used to measure the length and thickness of samples.
2. Electric furnace capable of maintaining a temperature of 565^0C for burning out specimens.
3. Weighing scale capable of determining mass to 0.01g.
4. Porcelain crucible approximately 30ml capacity.
5. Safety equipment such as heatproof gloves.

Test specimen

The test specimen composed of the entire cross-section of the profile is needed. The specimen should be large enough to minimize the error but small enough for the mass of the specimen to be determined on the weighing balance. In addition, the specimen after being cut should show ply orientation in the section.

Pre-test procedure

1. A table was prepared for recording of the data.
2. The specimen name and size.
3. The specimen was measured on each side with calipers (if the specimen was not uniform multiple points were measured and the average value were obtained) and the measurements recorded to the nearest mm.
4. The test method was recorded.

Test procedures

1. A crucible is heated to 600^0C for 10min or more. It was then cooled to room temperature and its mass was determined to the nearest 1.0mg. This was recorded in the data sheet.
2. The laboratory exhaust fan or ventilation system was turned on.
3. The mass of the specimen and the crucible together was determined to the nearest 1.0mg.
4. The crucible and the specimen were placed in the furnace. The heating element was turned on to 565^0C. The specimen is allowed to remain in the furnace for a minimum of two hours or until the entire matrix has disappeared (extra time is required for thicker laminates).
5. The crucible and the remains were removed from the furnace and cooled to room temperature. Then they were carefully placed on a gram scale and the post burn-out mass was determined.

Calculations of volume fraction of glass fiber are as follows: [9, 10]

(1) $$M_c = M_f + M_m$$

(2) $$V_f = \frac{M_f}{\rho_f}$$

(3) $$V_m = \frac{M_m}{\rho_m}$$

(4) $$V_c = V_f + V_m$$

(5) $$v_f = \frac{V_f}{V_c}$$

(6) $$v_m = \frac{V_m}{V_c}$$

Where

M_c: Mass of composite specimen, (g)
M_f Mass of glass fiber, (g)
M_m Mass of matrix, (g)
ρ_f Density of glass fiber, (g/cc)
ρ_m Density of matrix, (g/cc)
V_c Volume of composite specimen, (cm^3)
V_f Volume of glass fiber, (cm^3)
V_m Volume of matrix, (cm^3)
V_f Glass fiber volume fraction
V_m Matrix volume fraction

RESULTS AND DISCUSSIONS

Four specimens were tested and analyzed to determine the volume fraction values for glass fiber. The results are tabulated. Figure-3 shows the specimen before and after burning. As can be seen that the matrix completely removed from composite specimen after burning process and Figure-3b, depict typical fiber architecture lay-out for typical shape of tubular specimen. Table-3 shows the results of the volume fraction and it shows that the fiber volume fractions of the samples

ranged from 46.7% to 48.3%. The average value found for the glass fiber volume fractions was 47.6%.

a **b**

Figure-3. Specimen for volume fraction test (a) before burning (b) after burning.

Table-3. Volume fraction for glass fiber/epoxy composite.

Specimen No.	Mass of Matrix (M_m) (g)	Mass of fiber (M_f) (g)	M_f/M_c	M_m/M_c	V_c cm^3	V_f cm^3	V_m cm^3	v_f	v_m
1	0.6662	1.0602	61.411	38.589	1.136	0.530	0.606	0.467	0.533
2	0.632	1.0468	62.3541	37.646	1.098	0.523	0.575	0.477	0.523
3	0.6332	1.0494	62.3678	37.632	1.100	0.525	0.576	0.477	0.523
4	0.6312	1.0732	62.9664	37.034	1.110	0.537	0.574	0.483	0.517
Average								**0.476**	**0.524**

Carbon fiber volume fraction

Experimental measurements of the fiber content for carbon fiber composite were conducted by the density method [2]. This method is not recommended for materials with high porosity like ceramics. Assuming the porosity of the material is low the fiber volume fraction obtained by this method can give a quick and good estimate, and provide a lower bound for the fiber volume fraction value. The density used for carbon fiber was 1.80 g/cm^3, and for the resin were 1.1 g/cm^3 as obtained from Tables 1 and 2. The fiber volume fraction of the carbon fiber specimens used in this research is calculated by measuring the density of the composite in air and in 2-propanol (Alcohol). To determine the v_f, four specimens were cut from tensile composite specimen; each sample was dried and weighed in air. Each sample was then immersed in 2-propanol and weighed in the propanol fluid. The density of the composite was calculated by Archimedes' Principle using the following equation:

$$\rho_c = W_{air}\rho_{2-propanol} / (W_{air} - W_{2-prapanol}) \quad (7)$$

Where

ρ_c is the density of the composite.

$\rho_{2\text{-propanol}}$ is the density of 2-propanol = 0.782 g/cm^3.

W_{air} is the weight of the sample in air.

$W_{2\text{-propanol}}$ is the weight of the sample in 2-propanol.

The fiber volume fraction is then calculated by using the rule of mixtures:

$$v_f = (\rho_c - \rho_{resin}) / (\rho_{fiber} - \rho_{resin}) \quad (8)$$

Where

v_f is the fiber volume fraction.

ρ_{fiber} is the density of the carbon fiber = 1.8 g/cm^3.

ρ_{resin} is the cured resin density = 1.1 g/cm^3.

ρ_c is the composite density calculated from equation (7).

The fiber volume fractions of the samples ranged from 53.7% to 54.2% while the value obtained for the density of the composite was 1.483 g/cm^3 as shown in Table-4. The average value found for the carbon fiber volume fractions was 54.0%.

Table-4. Volume fraction of carbon fiber and density of carbon fiber composite.

Specimen No.	Weight in air W_{air} (g)	Weight in Propanol $W_{2\text{-propanol}}$ (g)	Composite density ρ_c (g/cc)	Volume fraction v_f
1	2.1738	1.0309	1.484	0.540
2	2.2777	1.0807	1.484	0.541
3	2.0877	0.9909	1.485	0.542
4	2.2616	1.0707	1.481	0.537
Average			**1.483**	**0.540**

CONCLUSIONS

Generally manufacturers provide only average volume fraction values for an entire line of products and it was found that these data can vary widely among samples from a particular manufacturer. And these variations are important to consider since mechanical properties depends on volume fraction value [5]. So it is necessary to conduct tests to evaluate the mass or volume fraction of the fiber when dealing with composite materials. No fillers have been used in this composite. Although the filler is typically added to improve the fire resistance and reduce the cost of a composite and also reduce the voids and improve the processing viscosity; the addition of the fillers can reduce the mechanical properties of the composites. Even small amounts of filler can deteriorate the impact performance of the material [5]. The volume fraction for the glass and carbon fibers produced by using filament winding method are found to be 0.476 and 0.540 respectively.

ACKNOWLEDGMENTS

The authors would like to express their gratitude and sincere appreciation to the Ministry of Science, Technology and Innovations, Malaysia (MOSTI, Project No. 09-02-04-0824-EA001) for the financial support, and the Department of Mechanical and Manufacturing Engineering of the University Putra Malaysia for supporting the group in undertaking the project.

REFERENCES

[1] ASTM D2584. 1968. Standard test method for ignition loss of cured reinforced resins. Annual book of ASTM standards, Vol. 8.01, American Society for Testing and Materials, Philadelphia. pp. 328-329.

[2] Broyles N. S., Verghese K. N. E., Davis S. V., Li H., Davis R. M., Lesko J. J. and Riffle J. S. 1998. Fatigue performance of carbon fiber/vinyl ester composites: the effect of two dissimilar polymeric sizing agents. Polymer. 39(15): 3417-3424.

[3] Donald F. Adams, Leif A. Carlsson and R. Byron Pipes. 2003. Experimental characterization of advanced composite materials. 3rd Ed. by CRC PRESS LLC.

[4] George Lubin. 1985. Static Test Methods for Composites. Van Nostrand Reinhold Company Inc. New York, USA.

[5] Binshan S. Y., Alrik L. Svenson and Lawrence C. Bank. 1995. Mass and Volume Fraction Properties of Pultruded Glass Fiber-Reinforced Composites. Research Report, Composites Volume 26 Number 10, Elsevier Science Limited, U.K.

[6] Sun W. and Tzeng J. T. 2002. Effective Mechanical Properties of EM Composite Conductors: an Analytical and Finite Element Modeling Approach. Composite Structures. 58: 411-421.

[7] Hyer M. W. 1998. Stress Analysis of Fiber Reinforced Composite Materials. The McGraw-Hill Companies Inc. USA.

[8] D. Hull, M. J. Legg and B. Spencer. 1978. Failure of Glass/Polyester Filament Wound Pipe. Composites.

[9] Jones R. M. 1998. Mechanics of composite materials. 2nd Ed. Edwards Brothers, Ann Arbor.

[10] Barbero E. J. 1998. Introduction to composite materials design. Taylor & Francis, Philadelphia, USA.