

A description on deformation and failure of hybrid composite under static loading

Open
Access

Ahmad Fuad Ab Ghani^{1,2,*}, Jamaluddin Mahmud²

¹ Fakulti Teknologi Kejuruteraan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

² Fakulti Kejuruteraan Mekanikal, Menara 1, Kompleks Kejuruteraan, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

ARTICLE INFO

ABSTRACT

Article history:

Received 6 July 2017

Received in revised form 28 August 2017

Accepted 25 September 2017

Available online 8 October 2017

A description on deformation and failure study of hybrid composite under static loading is given. Numerous advantages in terms of mechanical properties obtained by using hybrid composite are observed from literatures and expected from this research project. Lacks of experimental techniques and finite element modeling (FEM) at micro and macro level have limits the findings and explanation on mechanics and material science of hybrid composite under static loading. The use of Scanning Electron Microscope (SEM) is proposed to view precisely the microstructure behavior pre and after loading. Hybrid composite will be formed by unidirectional prepreg Carbon fiber reinforced polymer (CFRP) and Glass fiber reinforced polymer (GFRP) cured under high temperature and high pressure. Micro hardness test is proposed as a measure of hardness between different arrangements of hybrid composite. The framework of relation between elasticity, tensile characterization, shear properties, microstructure study and hardness test of hybrid composite is formulated for this research project.

Keywords:

Hybrid Composite; Tensile Properties;
Shear Properties Static Loading; Micro
hardness

Copyright © 2017 PENERBIT AKADEMIABARU - All rights reserved

1. Introduction

Hybrid composite is formed by reinforcement of two or more types of fiber bound with matrix. It is an improved composite in terms of mechanical properties as compared to conventional Fiber Reinforced Polymer (FRP) composite such as Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP). Hybrids composite normally have more than one reinforcing sections or multiple reinforcing and multiple matrix section or single reinforcing phase with multiple matrix phases. The deformation and stress analysis of hybrid composites is a result of compromise between individual components forming the hybrid composite, where each constituent has its own advantages and disadvantages with respect to mechanical properties [1]. The study of mechanical properties of hybrid composite with induce and yield results that could be of parameters for composite designers, engineers and practitioners to opt for hybrid composite for their structural

* Corresponding author.

E-mail address: ahmadfuad@utem.edu.my (Ahmad Fuad Ab Ghani)

parts or components. There is still a lack of research and development in terms of findings from hybrid composite and its relation in terms of material properties and mechanical behavior especially for promising composite Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) which used widely in aerospace, marine, infrastructure industry [2].

2. Tensile Properties of Hybrid Composite

Tensile properties are of critical parameters differentiating stiff and strong materials from tensile perspective either static or dynamic loading and uniaxial loading or multiaxial loading. It is interesting and of researchers' as well as industrial practitioners' inquiry as how does it behaves under tensile loading as compared to conventional composite (single type of fiber). Is it worth the cost saving from monetary point of view with respect to tensile properties such as tensile modulus in longitudinal/transverse direction, tensile strength in longitudinal/transverse direction, failure strain in longitudinal/transverse direction which are more important. Hybrid composite consists of more than one type of fiber where the advantages of one type of fiber in terms of mechanical properties could assist with the other. The mechanical properties of a hybrid composite depend on its fiber content, orientation, dimension of constituent fibers (diameter), level of intermixing of fibers, interface bonding between fiber and matrix and fibers arrangement between different type of fibers. The strength of hybrid composite also depends on the failure strain of each fibers where higher failure strain on a type of fiber could complement the other [2]. The mechanical properties of hybrid composite such as modulus of elasticity and improved tensile strength which lead to the beneficial on applications in aerospace, automotive, marine etc. Tensile properties of hybrid composite are able to surpass the properties of single composite but it was found that interfacial interaction between the fiber and matrix was relatively weak based on SEM image of the fractured surface [3]. It was observed that the measured tensile strength of the hybrid composite lies in between that of the solid CFRP and solid GFRP. This means that the mechanical properties of GFRP are improved on the modulus of elasticity and the tensile strength [4].

3. Shear Properties of Hybrid Composite

In real engineering scenario, part or structural component will be subjected to multiaxial loading that includes shear loading. It is complex in terms of shear field obtained for conventional unidirectional composite and it is even more difficult for hybrid composite shear stress and strain computation due to nature of loading as well as fiber orientation in hybrid composite. Different techniques performed by scholars to measure the shear strength of unidirectional carbon fiber composites. The results of the shear modulus can be predicted with sufficient accuracy via experimental method using off axis shear stress testing and Iosipescu shear test method which able to produce perfect shear field on v notch region to determine shear strength as well [5]. The computation of the shear modulus and the shear strength of composite material using Iosipescu V Notch Shear Test is suitable due to perfect shear field generated. Literature shows that the Iosipescu V Notch shear test with a modified Wyoming test fixture (ATSM D5379) was performed experimentally and compared theoretically to determine the in plane shear modulus and strength of unidirectional hybrid composites [6]. In this research project, both off axis shear test and Iosipescu V Notch shear test will be employed to study the deformation and strength behaviour of hybrid composite at different layup and arrangement between carbon fiber and glass fiber material.

4. Microstructure Study of Hybrid Composite

In order to understand the structure and failure mode of hybrid composite as compared to each single constituent of composite, microstructure study of preloading and after loading on hybrid composite is proposed. Failure will happen based on many modes such as cracking between fiber and matrix when subjected to load (e.g. tensile, compression, shear). The study of microstructure on hybrid composite material is essential in understanding the causes of failures and failure modes. Another research observed that during service life, composite structures will experience high stresses resulting in crack propagation through fiber matrix interfaces [7]. Reason of forming hybrid composite is to enhance each constituent's composite strength, toughness, as well as its reliability towards failure. The area where CFRP and GFRP composite placed together in hybrid composite is the interface region. Most of hybrid composite failures are reportedly occurring at this interface region. Another interesting study observed that weak point in hybrid composite materials lies on the interface area [8]. Figure 1 shows the cross sectional view of CFRP unidirectional prepreg after curing, as observed using SEM at 500 times magnification at 50 μ m. The diameter of CFRP as observed is around 6.7 μ m to 7.5 μ m observed at 5000 times magnification.

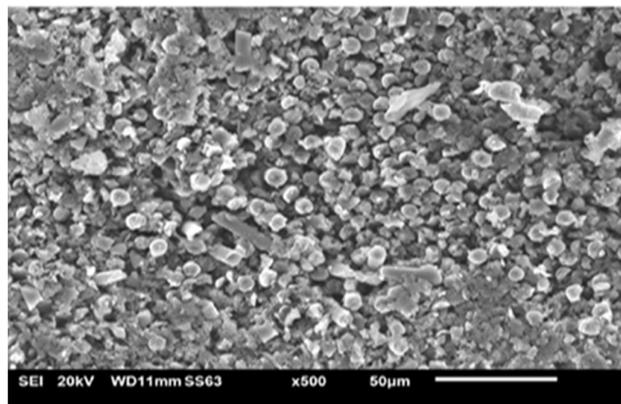


Fig. 1. CFRP unidirectional SEM cross sectional view

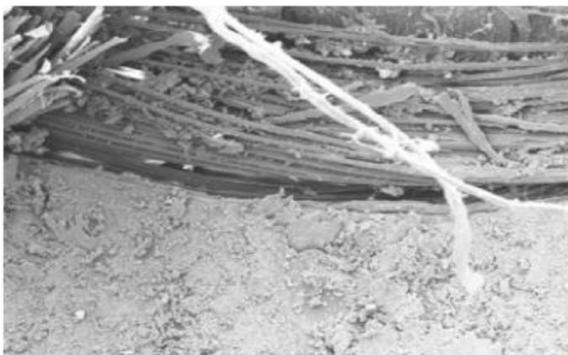


Fig.2. Interlayer cracking in unidirectional kevlar hybrid composite [9]

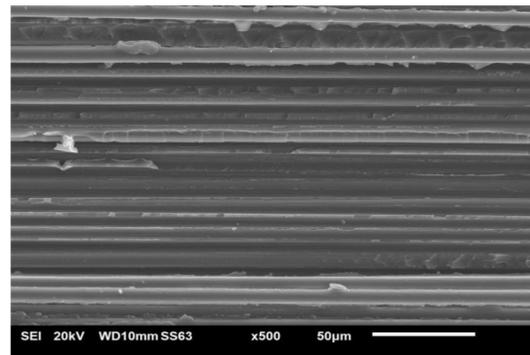


Fig.3. Microstructural longitudinal view of unidirectional CFRP using SEM

Macroscopic view is a view that can be observed by the eye. An example of macroscopic view of composite failure is when human can see the composite cracking or ruptured of composite.

Microscopic view is a view that cannot be observed by naked eye and in need of assistance for image magnification. An article [1] on hybrid composite microstructural study observed the failure mode of the hybrid composite by analyzing the morphology using Scanning Electron Microscope (SEM). They analyzed the cross sectional observation of untested samples which focussing on the fibre/matrix interface and matrix's void contents. The interstitial regions which serve as crack initiators are observed in woven and UD samples [9]. Meanwhile, Figure 2 shows the cracking observed in UD kevlar sample [9]. Interlayer delamination and interlayer cracking are two most common failure modes. Fiber pull-out is another failure mode occurs in CFRP and GFRP. Figure 3 depicts longitudinal view of unidirectional CFRP using SEM at 500 times magnification performed at material science lab in Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia, Melaka. It depicts the layup longitudinal view of composite material that opens to the possibility of visualizing the fiber deformation, failure mode, characteristic of hybrid composite which is the research interest under study.

5. Hardness Study of Hybrid Composite

The research also encompasses the study of hardness of hybrid composite and its relation to tensile strength and possibly other mechanical properties. Hardness is defined as resistance of a material to localized deformation. The deformation can happen due to indentation mode, bending or cutting [10]. Hybrid composite is expected to have better flexibility due to the combined fiber reinforced composites as compared to the flexibility of each constituent of the composite. For instance CFRP/GFRP hybrid composite consists of high modulus of elasticity fiber in CFRP and low modulus of elasticity fiber in GFRP. The higher modulus of elasticity fiber offers stiffness and load holding capability while the low elasticity fiber makes the hybrid composite more resilient and more cost effective. Relation of hardness to other properties of composite such as strength in longitudinal and transverse direction has not been studied widely by researchers. This makes research in this area promising and has served as part of the motivation for this project to be conducted. During micro hardness test experiment, the indentations are minimal and computed using a microscope. Hardness of different micro constituents can be measured together with hardness gradients as experienced in the case of hardening behavior [11]. Conversions from micro hardness values to tensile strength and other hardness scales such as HB, HR etc. are available for many metals and alloys but not for composite material. It is a challenge for this proposed research project to explore the possible relation in regards to hardness and tensile deformation behavior of hybrid composite.

5.1 Hardness Test on Hybrid Composite

A research discussed on the hardness of specimens tested using micro hardness Vickers test and the hardness was computed at three different locations of the specimen where the average value was taken [12]. Several researches tested specimen using Barcol hardness test. It was measured using a HPE Bareiss Durometer based on ASTM D2583 and produced an average out of 20 measurements [13]. They concluded that carbon fiber reinforced epoxy (CFRP) experienced higher tensile strength than GFRP and Hybrid composite (GFRP + CFRP) as shown in Figure 4. They also found that tensile strength increased when the hardness increased proportionately [12]. Micro hardness value also increases proportionately with incremental amount of carbon fiber content as per Figure 5.

5.2 Relation of Hardness and Tensile Strength

It is of interest to study and synthesize the relation of one material properties to another. It perhaps could bring to significant findings for better performance prediction and optimization. Hardness encompasses other mechanical properties such as the resistance to friction and abrasion that occur at micro scale in hybrid composite material [13]. The phenomenon associates hardness with tensile strength and resistance to deformation is relying on the modulus of elasticity level [14].

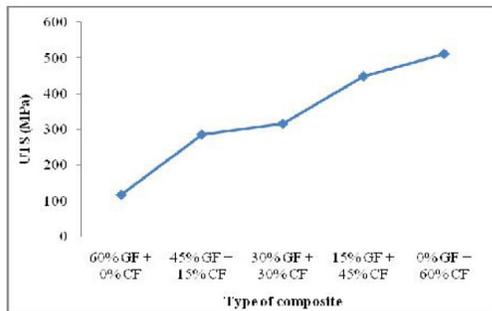


Fig.4. The effect of reinforcements on UTS of the fibers reinforced composite [12]

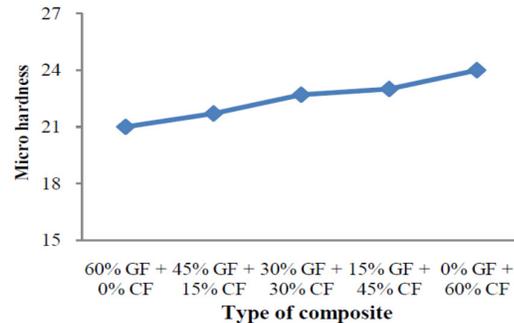


Fig.5. The effect of reinforcement on micro hardness of the fibers reinforced composites [12]

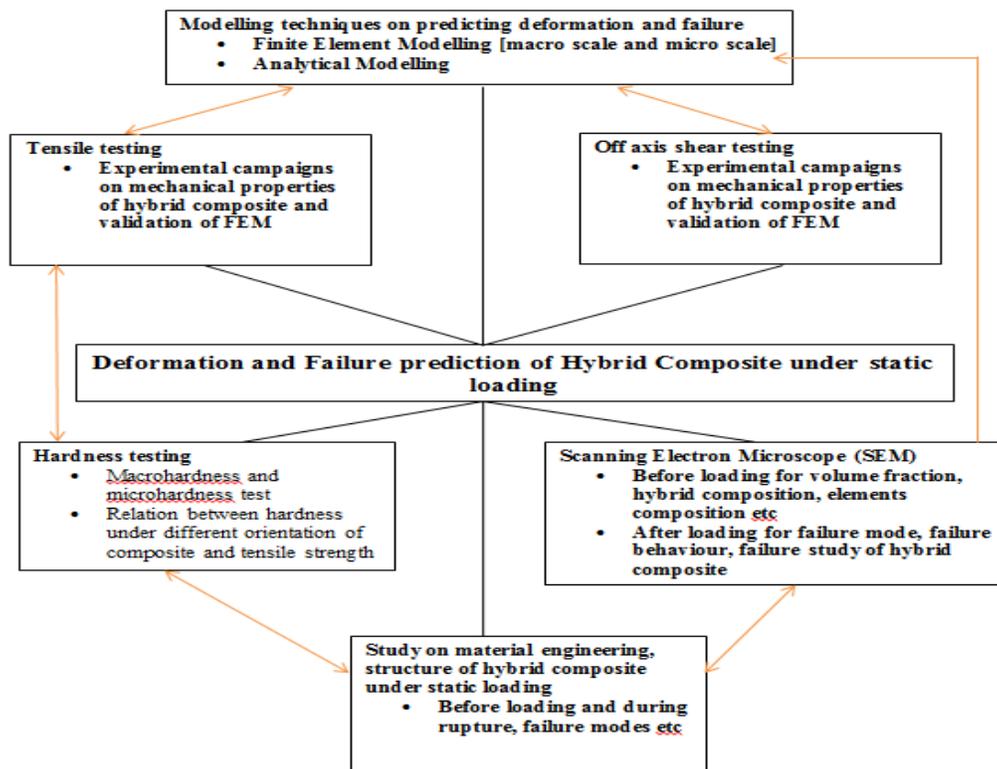


Fig. 6. The Framework on Hybrid Composite Deformation and Failure Study

Research shows that estimation of yield strength in tension is approximately 1/3 of the material hardness [10]. An approximate relationship between the hardness and the tensile strength of steel for instance is,

$$TS \text{ (MPa)} = 3.55 \times HB \text{ [HB equal or less than 175]} \quad (1)$$

$$= 3.38 \times HB \text{ [HB more than 175]} \quad (2)$$

where HB is the Brinnell Hardness of the material measured with a standard indenter using 3000 kgf load [10]. Figure 6 shows the framework of studying deformation and failure characterization of hybrid composite via experimental and finite element method. Tensile strength is associated with many factors during tensile, shear and fatigue loading such as matrix cracking, fretting, fiber bridging, delamination etc. Problem of matrix cracking in composite has been reviewed under fatigue loading, tensile loading, and flexural loading condition by several scholars [15, 16]. The introduction combination of low modulus and high modulus of hybrid composite constituents will bring to advantage of degrading of load transfer between matrices and fibre [17].

6. Conclusion

The rationale for studying the characteristic of hybrid composite is discussed. Methodology of tensile test, shear test, microstructure test and micro hardness test are elaborated in terms of principle and application on hybrid composite. The relation between different compositions of hybrid composite was studied from tensile properties perspective, shear properties characterization and microstructure field. Micro hardness findings are expected to contribute significantly in terms of its relation with other mechanical properties of hybrid composite such as tensile strength obtained from experimental campaigns. The proposed research project is suggested for experimentally and supported by findings to be obtained from Finite Element Modelling which are not discussed in this paper.

ACKNOWLEDGEMENT

Author would like to thank Fakulti Kejuruteraan Mekanikal (FKM), Universiti Teknikal Malaysia Melaka (UTeM) for the equipment and professional technical support during test at material science lab for this research project.

References

- [1] Moravčík, M., P. Kotula, and F. Bahleda. "Experimental and FEM analysis of hybrid composite structures with GFRP elements." *Procedia Engineering* 40 (2012): 268-273.
- [2] Panse, Prachi, Anoop Anand, Vinod Murkute, Avinash Ecka, Rahul Harshe, and Makarand Joshi. "Mechanical properties of hybrid structural composites reinforced with nanosilica." *Polymer Composites* 37, no. 4 (2016): 1216-1222.
- [3] Isa, Mohd, and Muhammad Rafiq. "Processing and characterisation of aramid/carbon hybrid fibre reinforced polypropylene composites/Muhammad Rafiq bin Mohd Isa." PhD diss., University of Malaya, 2014.
- [4] Pazhanivel, K., N. Ramadoss, K. Poyyathappan, P. Anandan, and G. B. Bhaskar. "Flexural analysis on GFRP composites subjected to cyclic gradual load and cyclic impact." In *Advanced Materials Research*, vol. 685, pp. 35-39. Trans Tech Publications, 2013.
- [5] Purslow, D. *The shear properties of unidirectional carbon fibre reinforced plastics and their experimental determination*. No. 1381. HM Stationery Office, 1977.
- [6] He, Jianmei, Martin YM Chiang, Donald L. Hunston, and Charles C. Han. "Application of the V-notch shear test for unidirectional hybrid composites." *Journal of composite materials* 36, no. 23 (2002): 2653-2666.
- [7] Mohammad Kamal Hossain, "Scanning Electron Microscopy Study of Fiber Reinforced Polymeric Nanocomposites", Scanning Electron Microscopy, InTech Publisher, 2012.

- [8] Gan, Yong X. "Effect of interface structure on mechanical properties of advanced composite materials." *International journal of molecular sciences* 10, no. 12 (2009): 5115-5134.
- [9] Yahaya, R., S. M. Sapuan, M. Jawaid, Z. Leman, and E. S. Zainudin. "Effect of fibre orientations on the mechanical properties of kenaf–aramid hybrid composites for spall-liner application." *Defence Technology* 12, no. 1 (2016): 52-58.
- [10] Alam, Shahzad, Farzana Habib, Muhammad Irfan, Waas Iqbal, and Khuram Khalid. "Effect of orientation of glass fiber on mechanical properties of GRP composites." *Journal of the Chemical Society Pakistan* 32, no. 3 (2010): 265-269.
- [11] Choudhary, D., "Hardness Testing on Composites, "Mechanical Properties of Epoxy Based Hybrid Composite of Glass and Banana Fibers", *Journal of Manufacturing Engineering*, Vol. 9, pp. 49, 2014.
- [12] T.D. Jagannatha and G. Harish, "Influence of Carbon and Glass Fiber Reinforced on Flexural Strength of Epoxy Matrix Polymer Hybrid Composite", *Int. Journal of Engineering Research and Applications* Vol. 5, pp. 109, 2015.
- [13] Júnior, José Humberto Santos Almeida, Heitor Luiz Ornaghi Júnior, Sandro Campos Amico, and Franco Dani Rico Amado. "Study of hybrid intralaminar curaua/glass composites." *Materials & Design* 42 (2012): 111-117.
- [14] Baba, N. B., Suhaimi, A. S., Mohd Amin, M. A., and Mohd, A., Study on Mechanical and Physical Behavior of Hybrid GFRP, *Advances in Materials Science and Engineering*, vol., pp 1, 2015.
- [15] Ilham, K. Muhammad, H. Anuar, M. S. Norhashimah, I. Idris Yaacob, and S. M. Sapuan. "Matrix Cracking in Reinforced Polymer Nanocomposites: A Review." *Journal of Advanced Review on Scientific Research* 11 (2015): 13-36.
- [16] Loh, X. H., M. Ahadlin M. Daud, M. Zulkefli Selamat, and UniversitiTeknikal Malaysia Melaka. "Study on Fibre Length and Composition of Kenaf-Polypropylene (K-PP) Composite for Automobile Interior Parts." *Applied Mechanics and Materials* 695 (2014): 36. X
- [17] Siti Nadia Mohd Bakhori, Siti Nur Fatin Zuikafly, Fauzan Ahmad, Mohamad Zaki Hassan, Tensile properties for MWCNT filled jute-Epoxy composites, *Journal of Advanced Research in Applied Mechanics* 31, Issue 1 (2017) 16-21