Available online at www.sciencedirect.com

Science Direct

Materials Today: Proceedings00 (2016) 000–000

materialstoday: PROCEEDINGS

www.materialstoday.com/proceedings

PMME 2016

Review on Testing of Polymer Fasteners*

S. Rajesh [a,]*, B. Vijaya Ramnath[b], C.Elanchezhian [c], Akash Chowdhury [d], R. Ashwin Sathya [e]
and
K.R. Deepak [f]

[a] *Research Scholar, Department of Mechanical Engineering, St. Peter's University, Chennai- 600 054, India.*
[a] *Department of Mechanical Engineering, Sri Sai Ram Engineering College, Chennai- 600 044, India.*
[b,c] *Professor, Department of Mechanical Engineering, Sri Sai Ram Engineering College, Chennai- 600 044, India.*
[e,f,g] *Department of Mechanical Engineering, Sri Sai Ram Engineering College, Chennai- 600 044, India.*
[a] *rajeshsri02@gmail.com,* [b] *vijayaramnathb@gmail.com*

Abstract

Fasteners play a very vital role in all engineering applications mainly in automobile and aerospace industries. In these industries it is very important to reduce the weight of the components in order to increase the performance. Therefore, the role of polymer fasteners, which are lighter in weight, becomes significant. The polymers which are generally used to make fasteners are black glass reinforced nylon, Victrex peek polymer, highly kinked rigid-rod polyarylene, Nylon, PVC, Polypropylene, Phenolic, PTFE, G10, Kel-F, Delrin/Acetal, Neoprene, Mylar, Glass-filled nylon, Peek, CPVCABS, PVDF / Kynar, Isoplast, Nomex, Kapton, Polycarbonate, Polyethylene, Ultem. There is a need to understand the mechanics of mechanically fastened structures which will be very important in design specification of the polymer fasteners. The paper begins with the testing methodologies and modes to failure analysis, followed by prevention of failure and future trends.

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

Keywords: *Fasteners; Polymer; Tests; Failure.*

* Corresponding author. Tel.: +0-994-474-2180
**E-mail address:* rajeshsri02@gmail.com

Selection and Peer-review under responsibility ofthe Committee Members of International Conference on Advancements in Aeromechanical Materials for Manufacturing (ICAAMM-2016).

1. Introduction

Experimentally obtained data and analytical models are the key components for the design of the polymer fasteners. The standard test procedures are devised by American Society for Testing and Materials (ASTM) and National Aeronautical and Space Administration (NASA). The aim of these tests is to develop a cost effective polymer fasteners which are light in weight as well as with sufficient strength. Fasteners are used in places which have holes that are fastened together hence ASTM committee has developed standard test procedure to determine the tensile and compressive strengths. These standard test procedures are open and filled hole test, bearing test, pull through test, fatigue response test. All these tests are well suited for both metal and polymer fasteners. Before testing the specimen is maintained at a temperature of 25 ± 2 ℃ and a relative humidity of 50 ± 5 % for about 3 days and the same condition is maintained during the tests. Five specimens are usually tested in different directions in order to get accurate results.

2. Types of Test

2.1. Open hole test and filled hole test

The standard test method to determine the open hole tensile strength (OHT) of a polymer matrix is ASTM D 5766/5766 M-02 a [2] . The data obtained from the test is significant for choosing the material specifications and the design allowable. The test specimen is similar to the one used in the standard test method for tensile properties of polymer – matrix composites materials (ASTM D3039 /D 3039 M) [3] expect in the fact that it has a centrally located hole as shown in figure1. The ultimate strength results are affected by factors such as bolt- hole preparation, specimen geometry etc. Hence it is desirable to have a specimen with a width to bolt hole diameter ratio of (w/d)= 6, edge distance to bolt hole diameter ration (e/d)= 3 and a bolt hole diameter to thickness ratio (d/t) in the range of 1.5. to 3.

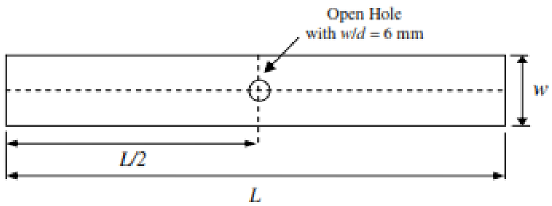

Figure 1. ASTM D 5766/D 5766M-03 standard test

The ultimate OHT strength .$F_x^{OHTu} = P_{max} / A$ [1] is calculated based on the gross cross sectional area (A=wt). In this test the bolt hole dimension is neglected and P_{max} is the maximum load before which the failure occurs in the composite. The results are recorded only for those specimen in which the fracture occurs through the hole, other specimens in which the fracture occurs at some other place is rejected. ASTM D 6484 / 6484 M 04 is used to determine the Open Hole Compressive (OHC) strength of the composite [4]. Two test procedures namely procedure A and procedure B are used for this method. In procedure A, the specimen is directly clamped on the hydraulic wedge grips and in procedure B the specimen is end loaded by sandwiching it between the end platens. In both the procedures the load is transferred to the specimen through shear. The ultimate OHC strength $F_x^{OHCu} = P_{max} / A$ is also calculated based on the gross cross sectional area (A= w*t) ignoring the bolt hole dimensions ASTM D 6742/6742 M-02 is used to determine the filled hole tensile and compressive strength of the polymer matrix composite [5]. The results show that the compression design strains are increased by 33% than the open hole test [1]

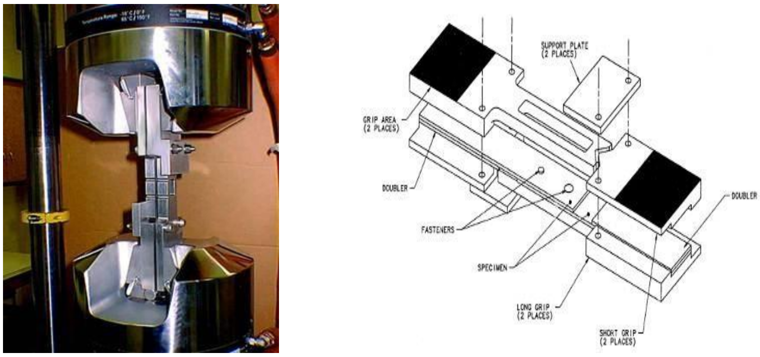

Figure 2. Filled hole compression test fixture ASTM D 6484 [4]

2.2 Bearing test

In a bearing test, the tension bearing strength and the compression loading bearing strength is determined [6]. The bearing test for composites will have double shear for tensile loading and single shear for compression loading. For the bolt hole cases the bearing stress developed when there is 4% deformation of initial bolt diameter is defined as the bearing strength. By monitoring the applied load and bolt-hole deformation the effective bearing strain, ebr, and the effective bearing stress, rbr, are calculated. When the maximum load is reached the test is paused and both the load carried by the specimen at failure, Pf, and the maximum load carried by the test specimen before failure, P_{max}, are recorded [8].

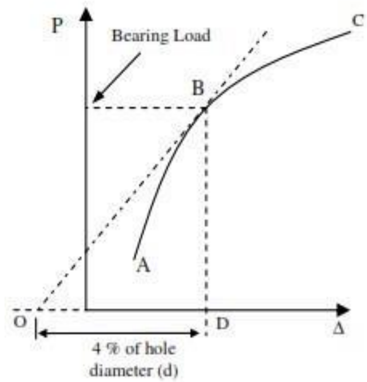

Figure 3. Illustration of how the bearing strength from a typical load– displacement curve is determined [6].

The graph of bearing stress versus bearing strain is plotted and the ultimate bearing strength, $F_{bru}= P_{max}/(k*d*h)$ of the specimen is calculated, where k is the load per bolt-hole factor (1.0 for a single fastener and 2.0 for a double fastener) For a single- shear test two identical specimens similar to the specimen used for double-shear are fastened together through one hole or two holes located centrally near one end for a single- shear, single-fastener test or single-shear, double-fastener, respectively[8].

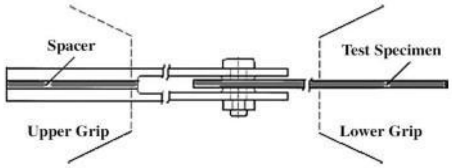

Figure 4. Double-shear test set-up for ASTM D 5961/D 5961M-05 standard test method for bearing response [7].

The single-shear test can be carried out in either stabilized manner by using a support fixture or in an unstabilized manner without any support fixture. The stabilized configuration test fixture is designed for both tension and compression.

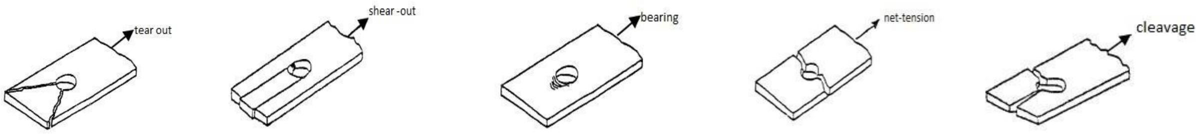

Figure 5. Bearing test failure modes for ASTM D5961/D5961M-05:

2.3 Pull through test

The Pull Through test (PT) is another important test to determine the properties of the fastener used. The PT test is performed as per the standard test methods. Similar to the Open Hole Test (OHT), this test could be done in two strategies. This test method determines the fastener pull-through resistance of multidirectional polymer matrix composites reinforced by high-modulus fibers. Fastener pull-through resistance is characterized by the force-versus-displacement response exhibited when a mechanical fastener is pulled through a composite plate, with the force applied perpendicular to the plane of the plate. The experimental set up for testing the fasteners is shown in the figure6(a).

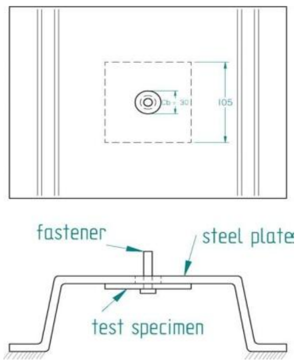

Figure 6 (a). INSTRON test machine which is used for conducting the PT test. (b) PT test with the help of yoke

Two test procedures and configurations are provided. The first, Procedure A, is suitable for screening and fastener development purposes. The second, Procedure B, is configuration dependent and is suitable for establishing design values. In these two procedures, flat test specimens with a circular hole at the center where the fastener is installed is being used. In the procedure A two specimens are connected using a fastener and also four holes for clamping. One specimen is rotated to 45 degrees with respect to the other. In procedure B the load is applied with the help of yoke as shown in figure 6(b). [9]

2.4 Fatigue test

The test procedure includes loading of the polymer and allowing it for desired number of cycles and recording the strain developed in the polymer. The procedure is repeated for different number of cycles and for different loads. Finally the curves between the applied stress (S) and the number of cycles (N) before which the failure occurs is drawn which is usually sigmoidal in shape and flattens out when N becomes larger [10] . The point at which the curve becomes flat indicates the fatigue limit. Unlike metals the fatigue test for polymers are frequency dependent as the temperature of the polymers increases due to the mechanical hysteresis which causes softening of the polymers. Hence the failure may be either brittle or ductile, so there is very little visual warning in polymers prior to failure in case of fatigue failure.

3. Failure modes

The three common modes of failure in polymer fastened joints under in plane loading are net-tension , shear-out and bearing and the out plane loading causes partial or complete pull out of the fastener from the structure. Net-tension failure is due to the stress developed at the bolt hole edge due to the small ration of width to diameter (w/d) or due to high ratio of bypass load to bearing load. The shear and bearing failure occurs due to shear and compression failure of the polymer fibre. The bearing failure is usually slow and progressive, hence it is not regarded as major failure than the other ones [11]. The other failures namely net-tension and shear-out are destructive in nature. The shear out failure is more complex because it is not possible to predict the failure due to the multi axial stress in the failure region adjacent the bolt hole [12]. In addition to these failure modes there are few others namely tear out and cleavage, these failures occur only after the bearing failure occurs, hence they are regarded as secondary modes of failure.

3.1 Failure due to static loading

Prediction of failure in statically loaded polymer fasteners involves several testing procedures. One of the most common testing method is finite element (FE) analysis [13] from which it has been concluded that the stress distribution and failure modes can be found. The failure due to tensile loading was studied by Yan et al [14]. Net tension failure due to ply orientation, clamp up load, washer size, and friction was studied by conducting the open and filled hole test. From the experiment it was concluded that the presence of bolt applies clamp up load and reduces the strength of the laminate containing the hole. Yan et al concluded that higher the clamping pressure the lesser is the net tension strength. Okutan [15] investigated the effect of geometric and material factors and conducted the tensile test on rectangular specimens and found the young's moduli, major poisson's ratio, longitudinal and transverse tensile strength. Shear strength is found by Iosipescu test [16] and the form these values it was found that failure under net-tension and shear out are most destructive.
The Damage Zone Model (DZM) which is based on progressive damage analysis is used to predict the in plane failure due the combined effect of net tension and shear-out failure. Due to the simplicity of this method it is very fast and easy to analyse the strength of the fastened joints. [17]

3.2 Failure due to dynamic loading

Mechanical joints have a significant effect of failure when subjected to dynamical loading. Bolted or riveted joints cause local stiffness and damping changes and are often the primary source of energy dissipation and damping [18].The structural dynamic problems that arise when joined by using bolted joints are predicted by the usage of FE models. Wherein the main parameters are the joint stiffness and damping.In a dynamic loading system , parameter uncertainties contribute to the creation of a random field, and relaxation effects cause time- dependent boundary conditions. These uncertainties creates random eigenvalues of the response, and the probability of failure, which are represented mathematically by the theory of fuzzy sets. Joints with composite bolts had a lower fatigue resistance than the joints having titanium bolts thereby composite bolts are not resistant to shear loading.[19] The composite bolts failed in shear more easily than metallic bolts. It was also shown that fatigue damage initiation is due to the relative displacements between the two composite plates and that fatigue damage initiation can be measured by the variation of strain between the bolt rows.

4. Prevention of failure

Selecting the proper material and proper design increases the life time of the fasteners. The design aspect is governed by ASME pressure vessel code or API standards eg. ASME B16.5 [20] and API 6A [21]. The flange size and the pressure rating usually determines the number, size and strength of the fastener to be used. The strength, toughness and corrosion resistance properties are the primary selection criteria. To avoid brittle fracture improved fatigue strength and resistance to stress corrosion cracking property of the material used is important. The factors that are used in the selection of fasteners are

1. Material strength
2. Material ductility
3. Toughness
4. Resistance to corrosion and stress corrosion cracking
5. Long fatigue life

5. Conclusion

Here the testing methodologies and modes to failure analysis, followed by prevention of failure have been studied. Compression tests usually give higher bearing strength in comparison with the tension bearing test. The Pull Through test (PT) determines the fastener pull-through resistance of multidirectional polymer matrix composites reinforced by high-modulus fibres. The data obtained from the open hole test and filled hole test is significant for choosing the material specifications and the design allowable. Polymers fails at a much lower stress than they would withstand under static loads when they are repeatedly exposed to cyclic loads. Unlike metals the fatigue test for polymers are frequency dependent as the temperature of the polymers increases due to the mechanical hysteresis which causes softening of the polymers. Hence the failure may be either brittle or ductile, so there is very little visual warning in polymers prior to failure incase of fatigue failure.

6. Reference

[1] Srinivasa D. Thoppul,Joana Finegan, Ronald F. Gibson,Mechanics of mechanically fastened joints in polymer- matrix composite structure – a review , October 2008

[2] D5766/D5766M-02a Standard Test Method for Open Hole Tensile Strength of Polymer–matrix Composite Laminates. Vol. 15.03.Composite Materials. ASTM International. West Conshohocken, PA: 2007.

[3] ASTM D3039/D3039M-00 Standard Test Method for Tensile Properties of Polymer–Matrix Composite Materials. Vol. 15.03. Composite Materials. ASTM International. West Conshohocken, PA: 2006.

[4] D6484/D6484M-04 Standard Test Method for Open-Hole Compressive Strength of Polymer–Matrix Composite Laminates, Vol. 15.03. Composite Materials. ASTM International. West Conshohocken, PA: 2004.

[5] D6742/D6742M-02 Standard Practice for Filled-Hole Tension and Compression Testing of Polymer–Matrix Composite Laminates. Vol. 15.03. Composite Materials. ASTM International. West Conshohocken, PA: 2007.

[6] [1] D 953-02 Standard test method for bearing strength of plastic. Vol. 08.01. Plastics, ASTM International. West Conshohocken, PA: 2002.

[7] [2] D5961/D5961M-05e1 Standard Test Method for Bearing Response of Polymer–Matrix Composite Laminates. Vol. 15.03. Composite Materials. ASTM International. West Conshohocken, PA: 2005.

[8] [3] Mechanics of mechanically fastened joints in polymer–matrix composite structures. S.D. Thoppul et al. / Composites Science and Technology 69 (2009) 301–329

[9] ASTM D7332/D7332M – 09. Standard test method for measuring the fastener pull-through resistance of a fiber-reinforced polymer matrix composite; 2009.

[10] I.P. Bond, I.R. Farrow, Fatigue life prediction under complex loading for XAS/914 CFRP incorporating a mechanical fastener, MAY 2000.

[11] Camanho PP, Lambert MA. Design methodology for mechanically fastened joints in laminated composite materials. Compos Sci Tech 2006;66(15):3004–20.

[12] Srinivasa D. Thoppul,Joana Finegan, Ronald F. Gibson,Mechanics of mechanically fastened joints in polymer- matrix composite structure – a review , October 2008

[13] Camanho PP, Matthews FL. Stress analysis and strength prediction of mechanically fastened joints in FRP: a review. Compos A: ApplSciManufact 1997;28(6):529–47.
[14] Yan UM, Sun HT, Wei WD, Chang FK. Response and failure of composite plates Withabolt-filled hole.DOT/FAA/AR-97/85 1998; Office of Aviation Research Washington, DC: 20591.
[15] Okutan B. The effects of geometric parameters on the failure strength for pinloaded multi-directional fiber-glass reinforced epoxy laminate. Compos B:Eng 2002;33(8):567–78.
[16] ASTM D 5379/D 5379M Test method for shear properties of composite materials by the V-notched beam method. Vol. 15.03. Composite Materials ASTM International. West Conshohocken, PA: 1996.
[17] Hollmann K. Failure analysis of bolted composite joints exhibiting in-plane failure modes. J Compos Mater 1996;30(3):358–83.
[18] Song Y, Hartwigsen C J, McFarland DM, Vakakis AF, Bergman LA. Simulation ofDynamics of beam structures with bolted joints using adjusted Iwan beam elements. J Sound Vibration 2004;273(1-2):249–76.
[19] Starikov R, Schon J. Quasi-static behavior of composite joints with protruding-head bolts. Compos Struct 2001;51(4):411–25.
[20] ASME/ANSI B16 – standards of pipes and fittings.
[21] API Spec 6A. Specification for wellhead and christmas tree equipment.Washington DC: American Petroleum Institute; 1996.