



A modified V-notched beam test method for interlaminar shear behavior of 3D woven composites



Gang Liu, Li Zhang, Licheng Guo^{*}, Qimei Wang, Feng Liao

Department of Astronautic Science and Mechanics, Harbin Institute of Technology, Harbin 150001, China

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ABSTRACT

The V-notched beam test (VNB) is recognized as a standard test method to determine the shear properties of composite materials. But it is not easy to make sure that the specimen placed in a predetermined position; the force conditions of the specimen become very complex when the large deformation of the specimen is generated, the friction between the internal components of fixture cannot be ignored when bending moment is generated as well when using traditional V-notched beam test fixtures. A modified V-notched beam test fixture has been proposed and designed based on standardized apparatus. After improvement, specimen with different thicknesses can be positioned easily. Meanwhile, effects of friction and bending moment are greatly reduced, and it has been validated by finite element simulation. Furthermore, some typical of experiments have been carried out by using the proposed fixture to determine the interlaminar shear modulus and shear strength of a type of 3D woven composites. Some new experimental data are presented in this paper, which can provide guidance and help for future study and industrial design of the 3D woven composites.

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1. Introduction

As a new type of composite material, three-Dimensional (3D) woven composite is widely used in the advanced engineering structure of the plane, launcher helicopter, civil architecture and medical devices, owing to their multifarious advantages such as excellent mechanical properties in the thickness direction, good impact damage resistance and good integrity.

It is well known that composite material has complicated damage evolution and failure modes since its inhomogeneity, anisotropy, and internal cracks, holes and interfacial defects caused by the production process. Therefore, many scholars have studied the stiffness, strength, residual strength and stability of the composite materials in recent years. It is essential to obtain real, vital and reliable material properties, but sometimes it is not that easy. Up to now, there is no specific test standards for the performance testing of 3D woven composites.

The advanced design of multidirectional fiber-reinforced polymers shows an increased need for reliable intra- and interlaminar shear parameters [1,2]. However, the reliability and accuracy of data measurement of material properties depend on the quality

of test equipment and experimental procedures. Considerable shear test methods have been put forward to obtain shear moduli and shear strengths of composites by former researchers. For example, Iosipescu V-notched beam test method was developed from Iosipescu [3] by Walrath D. E. et al. [4] and Adams D. F. et al. [5], who applied the Iosipescu shear test method to the field of composites [6–8] and suggested that the Iosipescu shear test techniques employing a double edge-notched flat specimen with two counteracting moments would satisfy the conditions of providing a region of pure, uniform shear stress [9]. This method was then developed eventually by Swanson et al. [10], Gipple et al. [11], Morton et al. [12], Melin et al. [13], and some other researchers [14–15]. Shear test methods like V-notched rail shear test developed by Whitney et al. [16] and Adams et al. [17], standardized by [18], and modified by Gude et al. [2] and Totry et al. [19]. Methods of three rail shear test [20,21], $\pm 45^\circ$ tensile test [22] and Arcan test [23,24] were also widely used. Extensive research on the Iosipescu shear test method has been conducted and developed by a large number of investigators [2,25,26].

Appropriate shear test method should be chosen and developed according to the type of materials and the purposes of measurement by users [27–29].

Problems still exist and tend to be solved in future though the Iosipescu shear test method are developed and applied by many researchers [30–32].

^{*} Corresponding author.

E-mail address: guolc@hit.edu.cn (L. Guo).

For some textile reinforced composites, the effect of the large deformation of the specimens and the bending moment generated on the guide column must be taken into consideration. When using traditional V-notched beam test fixtures, first of all, it is difficult to make sure that the specimen placed in a predetermined position. Secondly, the force conditions of the specimen become very complex when the specimen in the condition of large deformation. Thirdly, the friction between the internal components of fixture cannot be ignored when bending moment is generated.

In order to solve the above problems effectively and sufficiently, this paper proposed a modified V-notched beam test fixture on the basis of standardized apparatus suitable for various thicknesses. The newly modified fixture can better ensure the pure shear state of the specimen even under the condition of relatively larger deformation. Meanwhile, the specimen can be easily positioned, the effects of friction and bending moment are greatly reduced, which means the area contacted by the fixture components in the specimen will not be easily crushed caused by stress concentration.

The second part of this paper will give a brief introduction and analysis of the test fixture in ASTM D5379. Then some improvements, validations will be made on the fixture, which are well designed and manufactured as presented in the third part. Finally, some typical experiments will be carried out by using the proposed modified fixture to determine the interlaminar shear modulus and shear strength of a type of 3D woven composites.

2. The analysis of test device according to ASTM D5379-05

The standard V-notched beam (VNB) method was demonstrated in ASTM D5379/D 5379M-05 [14] at length, which was adopted to obtain the shear properties of composites by some researchers [33–37]. The standard test V-notched device (Fig. 1) in this method is composed of two halves (an upper grip and a lower grip). The lower grip is fixed on a holder and the upper grip can slide through by a linear bearing post. The grip holder and the bearing post are fixed on the baseplate resting on the testing machine. A specimen can be inserted into the test device, adjusted

and fastened by using two adjustable jaws tightened by thumbscrews and a specimen alignment pin. The two halves of the clamping apparatus are compressed by a testing machine while monitoring load. Then an approximately uniform shear stress distribution on the specimen between the two notches.

For fiber reinforced composites, especially for three-dimensional woven/braided composites, good in-plane and inter layer shear behavior and complex shear damage process make it difficult to obtain accurate and reliable shear properties of these materials unless robust test devices and procedures are used.

If the standardized VNB test fixture is adopted to obtain the shear properties of 3D woven/braided composites, the following issues should be taken into consideration. Firstly, improvements ought to be made to position the specimen in the predetermined place since the specimen is easy to generate skewing in the vertical direction (See in Fig. 2). Secondly, high requirement is needed on the strength of the adjustable jaws (wedges) when thicker specimens are tested, because the adjustable jaws (wedges) might be crushed and deformed under the condition of large load. Simultaneously, stress concentration will occur inevitable in the area the specimen pressed by the wedges, resulting in the crush at edge of the specimen. Thirdly, unwanted bending will appear ineluctable due to the friction between the upper grip and the bearing post when the load becomes large (Fig. 3). Furthermore, the approximately uniform shear stress distribution between the two notches will not exist when large deformation occurs on the specimen. The specimen will subject to both shear and tensile loading simultaneously. With the increasing of the load, the specimen will slide, the assumed approximately uniform shear stress state between the notches turns into the state of a combination of shear and tension, which may lead to the increase of the friction between the upper grip and the bearing post. Eventually the experimental results may deviate from what we expected. If the fixture is kept on loading, premature failure in the specimen becomes imminent due to excessive bending of the bearing post and the sliding of the specimen.

An modified V-notched beam test fixture based on ASTM D5379/D 5379M-05 are designed and manufactured to take the

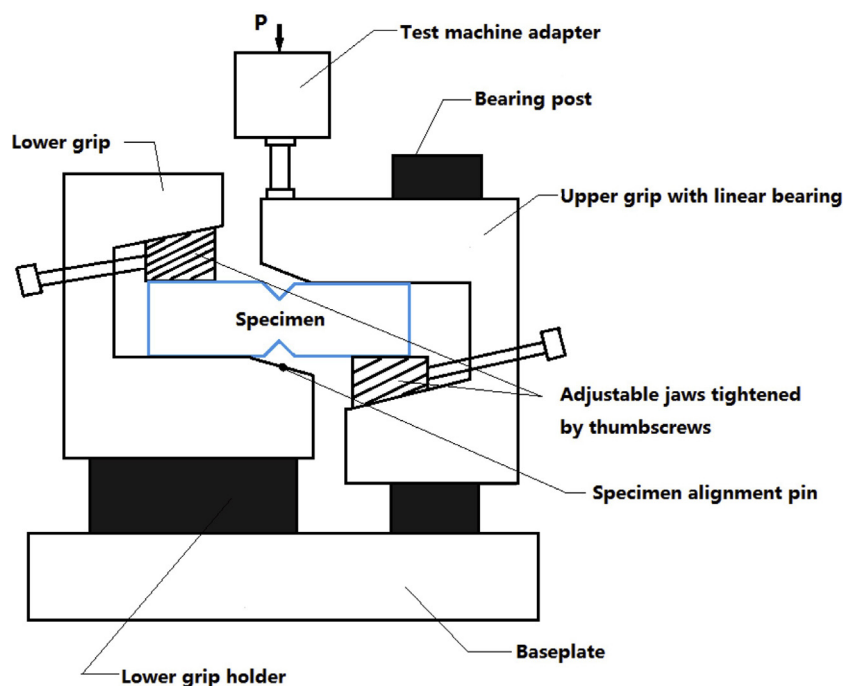


Fig. 1. V-Notched Beam Test Fixture Schematic [14].

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