Engineering Solid Mechanics 7 (2019) 93-108

Contents lists available at GrowingScience

Engineering Solid Mechanics

homepage: www.GrowingScience.com/esm

Orthotropic mode II shear test fixture: Iosipesque modification

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A R T I C L E I N F O

Article history:
Received 26 December, 2018
Accepted 18 April 2019
Available online
18 April 2019

Keywords:
Orthotropic Mode II
Shear test fixture
Composite materials
Isotropic materials
In-Plane
EFM

A B S T R A C T

In-plane strength and constitutive properties of composite materials is known as crucial problems. Although, several studies have been made for obtaining the in-plane mode II properties, the common test fixtures are blind in confrontation of shear zone. Furthermore, toughening mechanisms and consequently mode II fracture toughness cannot be evaluated, precisely. Also, proposing the convenient configuration of shear test fixture increase the accuracy of evaluation for the shear-zone energy dissipation, especially in orthotropic materials. Hence in the present research, a novel shear fixture configuration is proposed based on Iosipesque structural modification. Hereof, some arbitrary composite materials (e.g. graphite/epoxy and wood) were studies on the basis of DOE and E-691 ASTM. Furthermore, as the numerical method for indicating the comparison of the uniform and non-uniform shear stress distribution in the modified and common shear test fixture, a statistical procedure is used based on ASTM standard in addition to FEM analysis. The obtained results reveal that applying major amendments through the new scheme of the shear test fixture, would provide a remarkable precision and a reasonable estimation of the shear strength in comparison with the previous Iosipesque experiments.

1. Introduction

Today, a number of reliable test methods are available for analyzing and investigating mode I and mode II fracture toughness of composite materials. In this context, double cantilever beam (DCB) specimen (Davidson et al., 1995, De Moura et al., 2008), three-point bending and wedge splitting techniques (Reiterer et al., 2001, Vasic & Smith, 2002) are applied for investigating the mode I fracture toughness, while, the End Notched Flexure (ENF), the End Loaded Split (ELS) specimens are governed for pure mode II (Carlsson et al., 1986). In addition, the mode II end-loaded split cantilever beam (Vanderkley, 1981), and the other beam specimens e.g. Double-Edge Notched Beam (DENB) (Murphy, 1979), Center Slit Beam (CSB) (Murphy, 1988), Single Edge Notched Beam (SENB) (Hunt & Croager, 1982; Russell, 1982; Mall & Mol, 1991) are performed to analyze the mode II fracture toughness for composite materials and as well as wood and a number of metals. These configurations are somehow differ from the conventional test configurations often used for mode I and mode II fracture testing of brittle and quasi-brittle materials like glass, rock, concretes, some polymers, ceramics, graphite and etc (Bocca et al., 1991; Chang et al., 2006; Aliha & Saghafi, 2013; Berto et al., 2012; Gómez et al., 2009;

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doi: 10.5267/j.esm.2019.4.003

Suresh et al., 1990; Akbardoost & Rastin, 2015; Afendi et al., 2013; Maccagno & Knott, 1989; Aliha & Ayatollahi, 2008; Rao et al., 2003; Lim et al., 1993; Negro et al., 2003; Awaji & Sato 1978; Aliha et al., 2017a-e; Mirsayar et al., 2014, 2018; Fakhri et al., 2017; Razavi et al., 2018; Heidari-Rarani et al., 2014; Ameri et al., 2012,2016; Ayatollahi et al., 2011; Ahmad 1993). However, one of the undeniable mandatory information is estimation of material properties like shear strength. For a more general representation, not only in-plane properties are required but also through thickness properties has to be considered. From proper shear tests, both the constitutive behavior and strengths may be evaluated (Iosipescu, 1967). There are several methods to obtaining mode II properties like the Iosipescu test (Walrath & Adams, 1983, 1984; Lee & Munro, 1986; Barnes et al., 1987), the 10º off-axis test (Lee & Munro, 1986; Barnes et al., 1987; Broughton et al., 1990; Ho 1991), the $(+45^{o}/-45^{o})_{ns}$ tensile test (Ho, 1991; Ho et al., 1993a,b; Pierron & Vautrin, 1998; Chiang & He, 2002), the two-rail shear test (Xavier et al., 2004; Melin & Neumeister, 2006; Bradley et al., 2007), the three-rail shear test (Melin, 2008), torsion of a rod (Manalo et al., 2010), torsion of thin-walled tubes (Hufenbach et al., 2011; Osei-Antwi et al., 2013; Sun et al., 2013; Catalanotti & Xavier, 2015) and Arcan shear test method (Standard, 1997). These methods are generally based on ASTM standard, like the Iosipescu and the V-Notched Rail test that are based on ASTM D 5379 (Liu, 2000) and D 7078 (Daiyan et al., 2012), respectively. The Arcan shear test was presented by Arcan and coworkers in (Standard, 1997) as a method to produce in-plane mixed mode loading states (Iosipescu 1967). The two/three-rail shear tests (Xavier et al., 2004; Melin & Neumeister, 2006; Bradley et al., 2007, Melin, 2008), were proposed for strengthen reinforced composites. In spite of several advantages, there will be singularity in strain-stress field from clamping to the specimen that causes inaccuracy in strength and constitutive properties (Boothroyd, 2005; Ciornei et al., 2012). Moreover, the Iosipesque shear test fixture was attended and applied by the association of polymer matrix composites within the last 30 years.

The preliminary applying of the Iosipescu specimens was done by Bland and Altman (1996) for obtaining the shear strength of metals. Moreover, Walrath and Adams (1983) introduced the Iosipescu shear test fixture by incorporate several improvements. In 1986, Lee and Munro(1986) evaluated the in-plane characteristics of a number of novel composite materials through the shear test. Barnes et al. (1987) showed that the measured shear modulus does not depend on the reinforcement orientation. They also issued that various failure modes occur in various reinforcement orientations. Broughton et al. (1990) measured the shear moduli and the apparent strength of unidirectional carbon-fiber reinforced composites using specimens with two different fiber orientations. Also, finite element analysis was used to determine the stress distribution within the Iosipescu specimen. A detailed evaluation of the modified Wyoming fixture has been made by Ho and his colleagues(Ho et al., 1993a) for various fiber orientations (0°, 90° and 0º/90°) of Kevlar composites. Also, finite element analysis and moiré interferometry are used to assess the uniformity of the shear stress field. Another numerical consideration based on the correction factors has been made by (Ho et al., 1993b)for evaluation of the unidirectional and cross-ply graphite/epoxy composites. In other study, Pierron and Vautrin (1998) addressed an experimental and numerical in-plane shear strength's measurement for unidirectional carbon/epoxy composites by Iosipescu shear test. It was proved that the quadratic failure leads to the strength of the in-plane shear.
Chiang and He (2002) proposed the v-notch shear test which is an efficient evaluation method for the shear test of Iosipescu. Furthermore, Xavier et al. (2004) studied the off-axis and Iosipescu test methods in wood. Melin and Neumeister (2006), modified Iosipescu test according to the material orientation and anisotropy. They presented a modified Iosipescu test through the novel idea of variable notch opening angle (Iosipescu 1967). Manalo et al. (2010) investigated the in-plane shear characteristics of advanced composites for structural beams. Considering the sandwich structures, they also recommended the asymmetrical shear test for studying the shear characteristics of high-strength. Osei-Antwi et al. (2013) evaluated the role of shear stiffness and strength parameters of balsa wood using Iosipescu specimens. Catalanotti and coworkers (Catalanotti et al. 2010, Catalanotti and Xavier 2015) evaluated the mode II fracture toughness by proposing a modified Iosipescu specimen on fiber-reinforced composites. Several numerical modeling techniques have been proposed for simulation of composite specimens in shear loading which can be categorized into mesh free methods such as Smoothed Particle (SPH) (Nguyen et al., 2008, 2016; Vu-Bac et al., 2011; Ren et al., 2016; Dai et al. 2017), Element-Free Galerkin Method

(EFGM) (Belytschko et al., 1994; Rabczuk et al., 2008; Nguyen et al., 2016), Finite Difference Method (FDM)(Gourlay & Griffiths, 1980) and Meshless Methods (Rabczuk & Belytschko, 2005; Nguyen-Xuan et al., 2008; Yang et al., 2015) as well as mesh-based methods such as Finite Element Method (Huang & Usmani, 2012; Bathe, 2007; Dhatt et al., 2012) and Boundary Element Method (BEM)(Brebbia, 1980; Hall, 1994; Simpson et al., 2012a,b; Nguyen et al. 2016). In the present research, XEFM method is considered.

In a similar case, a geometrical approach named “Representative Circular Elements (RCEs)” was proposed for simulation of variety in directions and dimensions of damage zone at crack tip vicinity of orthotropic media (Fakoor & Khansari 2016). A general mixed mode I/II fracture failure criterion is proposed in which it is assumed that the fracture occurs in the isotropic matrix and it is the effect of the fibers modeled as tensile or shear reinforcements (Fakoor & Khansari, 2018a). Moreover, Probabilistic micromechanical damage model based on uncertainty has been employed for representing the mixed mode I/II fracture investigation of composite materials (Khansari et al., 2019). Due to the fact that, the evaluation of K_{IIC} has significant role in mixed mode fracture criteria and mode II fracture properties, it used to be a serious concern encountering to fracture mechanics of orthotropic materials. Therefore, additional research has been made to investigating the damage parameters by obtaining the experimental-base mode II fracture toughness (KIIc) (Fakoor & Khansari, 2018b). It is worth noting that experimental procedures and test method are actually in the basis of statistical computation that was not full- detailed in (Khansari et al. 2019), and only it has been limited to the analytical estimation of the mode II fracture toughness. Therefore, in the present research, there is some statistical attempting to prove the performance and functionality of modified shear test fixture in comparison to Isopescue shear test fixture, experimentally. In this context, repeatability and reproducibility standard deviation have been employed for two different materials namely: Wood (naturally composite) and Graphit/Epoxy (artificial composite). As it is well-known, there are wide spread utilizing of the Iosipescu shear test fixtures while it can be proved that due to some structural bugs, pure mode II cannot be applied, accurately. On the other hand, by performing some principal modification, precise shear mode properties can be obtained. Accordingly, in the present research, a new fixture based on some fundamental amendment has been produced and tested. Some of the new fixture’s characteristics can be described as reducing the number of fixture components, the specimen thickness changeability, collision avoiding by altering the angle of the upper and lower grip opening from10º to 40º degrees, grip motion and delamination preventing by executing parallel shaft, increase the height of the fixed grip to increase the stroke of movement and clash preventing. Furthermore, XEFM method and standard statistical method of E-691 ASTM (ASTM 2003) were utilized for the standard and modified forms of fixture. Eventually, the results provide confirmatory evidence that by employing amendments more concentrated shear load applied in shear zone in comparison with preceding one.

2. Fracture mechanics of orthotropic materials

In Linear elastic materials, the stress–strain based on the constitutive equation in an arbitrary linear elastic material is stated as:

$$\varepsilon_i = C_{ij}\sigma_j \tag{1}$$

where σ and ε are stress and strain vectors, respectively, and C presents the compliance matrix:

$$C_{ij} = \begin{pmatrix} 1/E_1 & -\nu_{21}/E_2 & -\nu_{31}/E_3 & 0 & 0 & 0 \\ -\nu_{12}/E_1 & 1/E_2 & -\nu_{32}/E_3 & 0 & 0 & 0 \\ -\nu_{13}/E_1 & -\nu_{23}/E_2 & 1/E_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/G_{23} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/G_{31} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/G_{12} \end{pmatrix} \tag{2}$$

where, E, G and v represented as modulus of elasticity, shear modulus and Poisson's ratio, respectively. Moreover, for plane stress state in (x_1, x_2) plane, only the $C_{11}, C_{22}, C_{12}, C_{21}$, and C_{66} will be remained. For plane strain issues, the equations remain similar except four components of compliance matrix with plane stress conditions which are stated as $\overline{C}_{ij}$ and defined as follows:

$$\overline{C}_{ij} = C_{ij} - C_{i3}C_{j3} / C_{33} \quad (i, j = 1,2,6) \tag{3}$$

When the crack is assumed along the fibers, stress-displacement filed around the crack tip is as follows:

$$\sigma_{11} = \frac{K_I}{\sqrt{2\pi r}} A + \frac{K_{II}}{\sqrt{2\pi r}} B \tag{4}$$

$$\sigma_{22} = \frac{K_I}{\sqrt{2\pi r}} C + \frac{K_{II}}{\sqrt{2\pi r}} D \tag{5}$$

$$\sigma_{12} = \frac{K_I}{\sqrt{2\pi r}} E + \frac{K_{II}}{\sqrt{2\pi r}} F \tag{6}$$

$$\begin{aligned} u = {} & \sqrt{\frac{2r}{\pi}} K_I \operatorname{Re}\left[\frac{\mu_1 p_2 \sqrt{(\cos\theta + \mu_2 \sin\theta)}}{\mu_1 - \mu_2} - \frac{\mu_2 p_1 \sqrt{(\cos\theta + \mu_1 \sin\theta)}}{\mu_1 - \mu_2}\right] + \\ & \sqrt{\frac{2r}{\pi}} K_{II} \operatorname{Re}\left[\frac{p_2 \sqrt{(\cos\theta + \mu_2 \sin\theta)}}{\mu_1 - \mu_2} - \frac{p_1 \sqrt{(\cos\theta + \mu_1 \sin\theta)}}{\mu_1 - \mu_2}\right] \end{aligned} \tag{7}$$

$$\begin{aligned} v = {} & \sqrt{\frac{2r}{\pi}} K_I \operatorname{Re}\left[\frac{\mu_1 q_2 \sqrt{(\cos\theta + \mu_2 \sin\theta)}}{\mu_1 - \mu_2} - \frac{\mu_2 q_1 \sqrt{(\cos\theta + \mu_1 \sin\theta)}}{\mu_1 - \mu_2}\right] + \\ & \sqrt{\frac{2r}{\pi}} K_{II} \operatorname{Re}\left[\frac{q_2 \sqrt{(\cos\theta + \mu_2 \sin\theta)}}{\mu_1 - \mu_2} - \frac{q_1 \sqrt{(\cos\theta + \mu_1 \sin\theta)}}{\mu_1 - \mu_2}\right] \end{aligned} \tag{8}$$

where, **Re** states the major part of the statement and K_I and K_{II} are the factors for stress intensity of mode I and mode II, respectively. Moreover, coefficient A, B, C, D, E and F defined as:

$$\begin{aligned} & A = \operatorname{Re}\left[\frac{\mu_1\mu_2}{\mu_1 - \mu_2}\left(\frac{\mu_2}{b_2} - \frac{\mu_1}{b_1}\right)\right], B = \operatorname{Re}\left[\frac{1}{\mu_1 - \mu_2}\left(\frac{\mu_2^2}{b_2} - \frac{\mu_1^2}{b_1}\right)\right], \\ & C = \operatorname{Re}\left[\frac{1}{\mu_1 - \mu_2}\left(\frac{\mu_1}{b_2} - \frac{\mu_2}{b_1}\right)\right], D = \operatorname{Re}\left[\frac{1}{\mu_1 - \mu_2}\left(\frac{1}{b_2} - \frac{1}{b_1}\right)\right] \\ & E = \operatorname{Re}\left[\frac{\mu_1\mu_2}{\mu_1 - \mu_2}\left(\frac{1}{b_1} - \frac{1}{b_2}\right)\right], F = \operatorname{Re}\left[\frac{1}{\mu_1 - \mu_2}\left(\frac{\mu_1}{b_1} - \frac{\mu_2}{b_2}\right)\right] \end{aligned} \tag{9}$$

Also, $b_i (i=1,2)$ defines as follows:

$$\begin{aligned} b_1 &= (\cos\theta + \mu_1 \sin\theta)^{1/2} \\ b_2 &= (\cos\theta + \mu_2 \sin\theta)^{1/2} \end{aligned} \tag{10}$$

Furthermore, $\mu_i (i = 1, 2)$ are the roots of following characteristic equation that extracted from a fourth-order partial differential equation introduced by Lekhnitskii (1963).

$$C_{11}\mu^4 - 2C_{16}\mu^3 + (2C_{12} + C_{66})\mu^2 - 2C_{26}\mu + C_{22} = 0 \tag{11}$$

Also, p_i and $q_i\,(i=1,2)$ defined as:

$$
\begin{aligned}
p_i &= C_{11}\mu_i^2 + C_{12} - C_{16}\mu_i \qquad i=1,2 \\
p_i &= C_{12}\mu_i + \frac{C_{22}}{\mu_i} - C_{26} \qquad i=1,2
\end{aligned}
\tag{12}
$$

2.1. Strain energy density

Take into account of the singularity at the crack tip vicinity, the strain energy density function introduced as(Sih, 1974):

$$
SED = \frac{1}{2}\sigma_{ij}\varepsilon_{ij} \approx \frac{E_S}{r} \tag{13}
$$

in which, E_s is the strain energy density factor define as:

$$
E_S = Z_{11}k_1^2 + 2Z_{12}k_1k_2 + Z_{22}k_2^2 \tag{14}
$$

in which, $k_1 = \frac{K_I}{\sqrt{\pi}}, k_2 = \frac{K_{II}}{\sqrt{\pi}}$. Also, the quantities (i, j = 1, 2) are compliance-base functions of the orthotropic and defined as:

$$
\begin{aligned}
Z_{11} &= \frac{1}{4}\left[\bar{C}_{11}A^2 + \bar{C}_{22}C^2 + \bar{C}_{66}E^2 + 2\bar{C}_{12}AC + 2\bar{C}_{16}AE + 2\bar{C}_{26}CE\right] \\
Z_{12} &= \frac{1}{4}\left[\bar{C}_{11}AB + \bar{C}_{22}CD + \bar{C}_{66}EF + \bar{C}_{12}(AD+BC) + \bar{C}_{16}(AF+BE) + \bar{C}_{26}(CE+DE)\right] \\
Z_{22} &= \frac{1}{4}\left[\bar{C}_{11}B^2 + \bar{C}_{22}D^2 + \bar{C}_{66}F^2 + 2\bar{C}_{12}BD + 2\bar{C}_{16}BF + 2\bar{C}_{26}DF\right]
\end{aligned}
\tag{15}
$$

For pure mode II, the strain energy density factor reduced as $E_S = Z_{22}k_2^2$ that can be plotted for various materials.

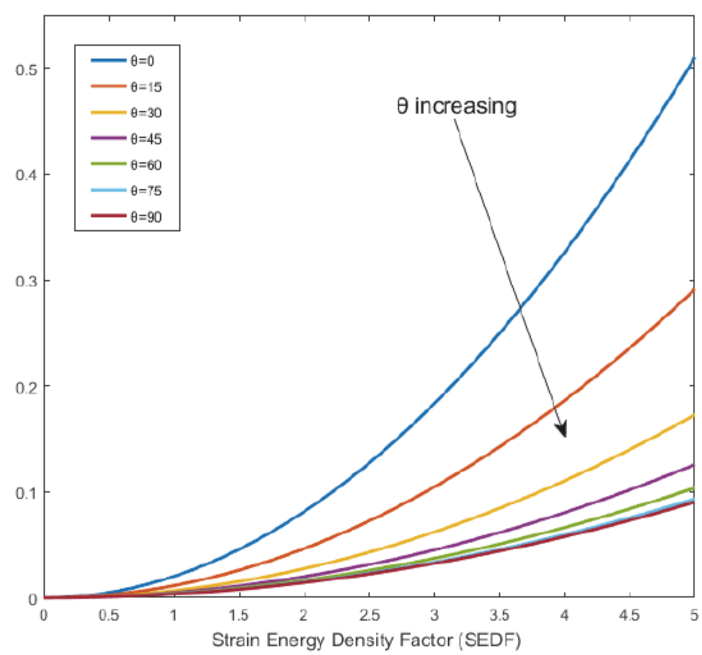


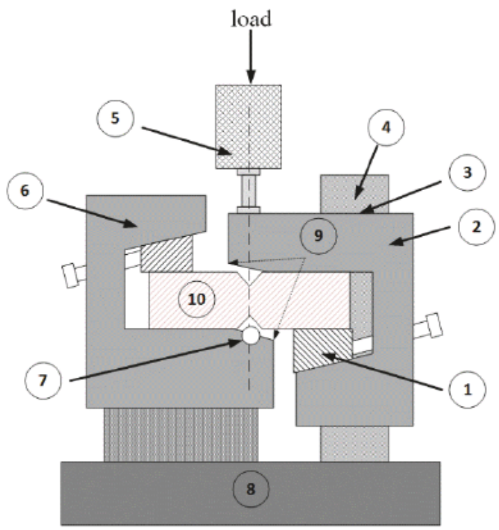
Fig. 1. Strain energy density factor versus crack tip position

As it is shown in Fig. 1, by increasing the amount of K_{II} and fiber orientation, the strain energy density factor is decreased by moving from mode I (i.e. θ=0) to mode II (i.e. θ=90). It means that the strain energy density factor has opposite behavior with respect to the direction of fiber. Therefore, for pure mode II, obtaining the strain energy density can be summarized to investigation of on-axis and off-axis stresses.

3. Materials and Methods

3.1. Structural Modification

Since the mid-1980s, the preliminary configuration of the shear test fixture had been extensively utilized and been highly respected by the composites research the materials testing community. To recall, the pure shear stress in the region is known as “shear zone”. It is a target of the fixture which can be applied by a couple of counteracting force. Therefore, for having the precision in in-plane shear properties, the complete transmission of applied load to the shear zone must come to consideration. Recently configuration of Iosipescu shear test fixture including its main components illustrates as follows (shown in Fig. 2):



No.	Component
1	Adjustable Jaws
2	Upper Grip
3	Bearing Post
4	Guide Shaft & Bush
5	Test Machine Adaptor
6	Lower Grip
7	Alignment
8	Base Plate
9	Trailing Edge
10	Specimen

Fig. 2. ordinary configuration of Iosipescu shear test fixture

Based on several experimental tests, some structural shortcomings (like trailing edge collisions, the grip rotating, and upper grip collisions) were found in the Iosipescu shear fixture that can greatly affect the final results. A few of these modifications in the new fixture are as follows (that are shown in **Error! Reference source not found.** to 6):

- lower grip altitude was changed from 96 mm to 110 mm
- Due to the grip rotation, two guide shafts were designed and replaced.
- For the prevention of clash, the trailing edge angle was altered from 10º to 40º

Components were reduced to 27 parts based on design for manufacture and assembly (DFMA) principal

- And also two special clamps were utilized for fixing the specimen.

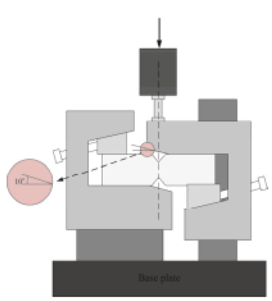


Fig. 3. Collisions of the specimen (Iosipescu) and trailing edge

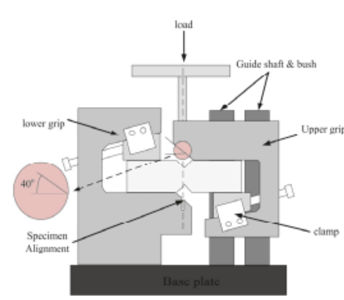


Fig. 4. No collisions of the specimen (modified) and trailing edge

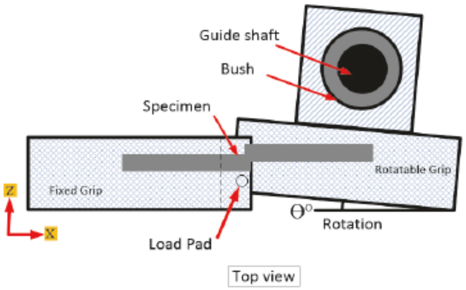


Fig. 3. Upper grip rotation (Iosipescu)

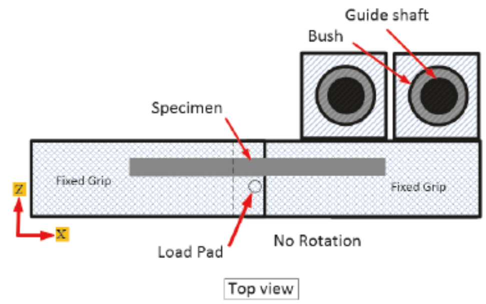
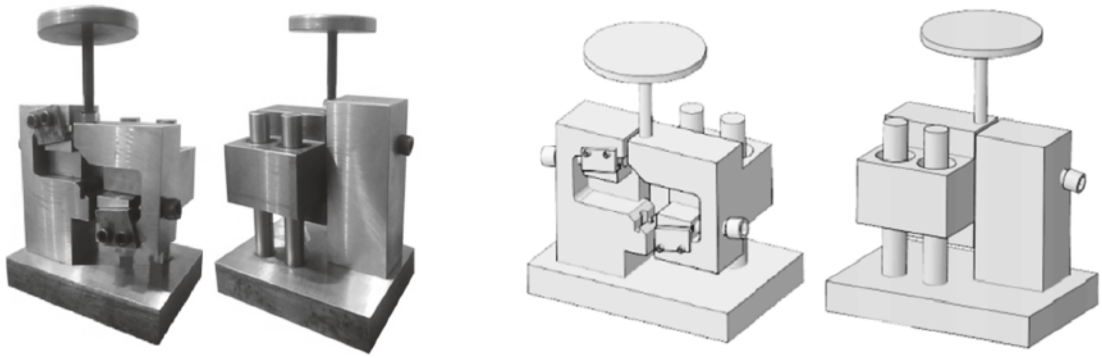


Fig. 4. No upper grip rotation (modified)

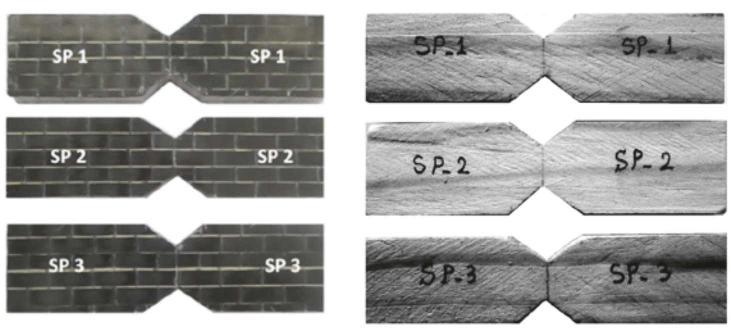
Take into account of the experimental bugs, the final version of the modifications shear test fixture was designed and produced as shown in Fig. 7:



(a) (b)

Fig. 5. (a) and (b) depict as manufactured and model of the modified shear test fixture

Experimental tests of graphite/epoxy and Western White Pine wood (shown in Fig. 6) sized in the desired orientation, milled and ground to the final dimensions specified by ASTM D 5379 (Properties 1996).



(a) (b)

Fig. 6. (a) and (b) represent as graphite/epoxy and Western White Pine wood

In this section, mechanical properties of graphite/epoxy composite along and perpendicular to fiber direction have been measured with universal tensile tests machine. The geometries and the number of samples have been prepared according to the ASTM D3039 standard. 6-layered graphite/epoxy composite specimens have been made according to the ASTM D3039 standard and by considering VRTM method. similar experimental approach for evaluation of mechanical properties addressed in (Fakoor and Khansari 2018). Therefore, mechanical properties of composite, wood and PMMA have been evaluated for parallel fiber and crack (i.e $\theta=0^{o}$) as presented in Tables 1 and 2

Table 1. The Elastic properties of Graphite/Epoxy and PMMA

Material		E_1(GPa)	E_2(GPa)	ν_{12}	ν_{23}	ν_{31}	G_{12}(GPa)
B	**Graphite/Epoxy**	131	17	0.27	0.39	0.32	4.76
C	**PMMA**	2.74	2.74	0.26	0.26	0.26	0.3

Table 2. The Elastic properties of Scots pine and western white pine wood

Material		E_L(GPa)	E_T(GPa)	ν_{LT}	ν_{TR}	ν_{LR}	G_{LT}(GPa)
A_1	**WOOD (western white Pine)**	4.717	0.163	0.344	0.410	0.329	0.226
A_2	**WOOD (scot Pine)**	16.30	0.57	0.45	0.31	0.47	1.74

3.2. Stress-Strain Results

The stress-strain diagrams for both graphite/epoxy and Western white pine materials have been examined and reported as below Figs. 9 to 12.

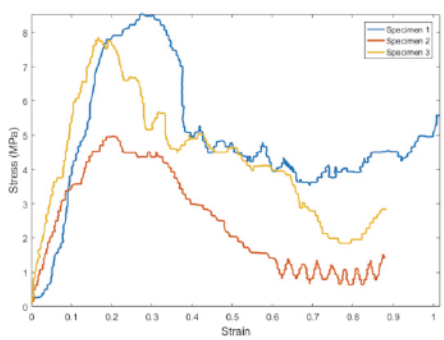


Fig. 7. graphite/epoxy plotted by the Iosipescu fixture.

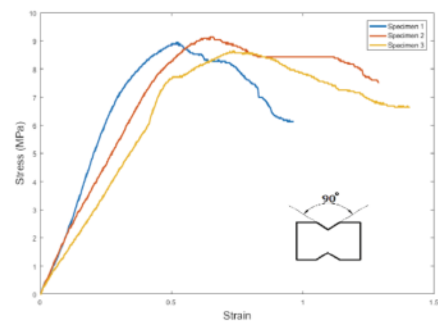


Fig. 8. graphite/epoxy plotted by the modified fixture

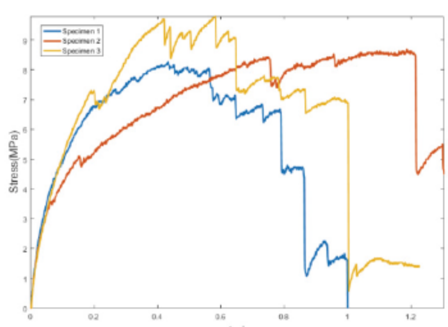


Fig. 9. Western white pine wood examined by the Iosipescu

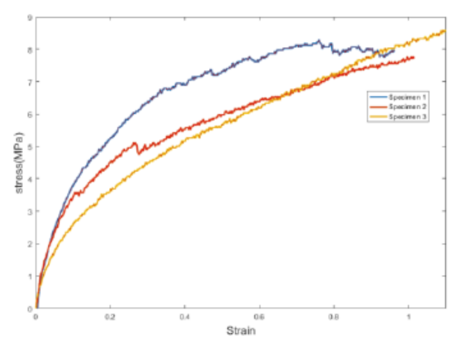


Fig. 10. Western White Pine wood examined by the modified fixture

As it can be seen, the curvature of the stress-strain diagrams related to the modified shear test fixture, has significantly improvement in comparison to the Iosipescu one. Also, data scattering and fluctuation of every diagram has been reduced in the modified shear test results.

4. Numeric Analysis

4.1. Test Method Precision

The standard deviation (or SD) is a measure that is used to quantify the amount of variation or dispersion of a set of data values (Bland and Altman 1996). ASTM E-691 (ASTM 2003) applied SD and reproducibility and repeatability concepts in the Iosipescu shear test fixture based on the amount of deviation in which low and high standard deviation stand as close and spread out to the mean value. Equations (16) and (17) indicate the formulation of mean and standard deviation, respectively (ASTM 2003).

$$\bar{x} = \sum_{1}^{n} \frac{x}{n} \tag{16}$$

$$S = \sqrt{\sum_{1}^{n} (x-\bar{x})^2 / (n-1)} \tag{17}$$

In which, $\bar{x}$, x , n and s denote as average of the test results, the individual test results, the number of test results and cell standard deviation in one cell, respectively. Take into account of the reproducibility and repeatability concepts (Trochim and Donnelly 2001), three distinctive materials were considered into six distinctive labs. In this regard, three times repetition of each laboratory was performed according to the E-691 ASTM principles. In this context, cell deviation, the number of laboratories, repeatability and reproducibility standard deviation were investigated as follows (ASTM 2003):

$$d = \bar{x} - \bar{\bar{x}} \quad \& \quad \bar{\bar{x}} = \sum_{1}^{p} \frac{\bar{x}}{p} \tag{18}$$

$$s_{\bar{x}} = \sqrt{\sum_{1}^{p} \frac{d^2}{(p-1)}} \tag{19}$$

$$s_r = \sqrt{\sum_{1}^{p} \frac{s^2}{p}} \tag{20}$$

$$(s_R)^* = \sqrt{(s_{\bar{x}})^2 + \frac{(s_r)^2 (n-1)}{n}} \tag{21}$$

$$h = \frac{d}{s_{\bar{x}}} \tag{22}$$

$$K = \frac{s}{s_r} \tag{23}$$

in which, d, P, $S_{\bar{x}}$, S_r and S_R denote as cell deviation, the number of laboratories, repeatability and reproducibility standard deviation, respectively. Also, $(s_R)^*$, h and K indicate the provisional of reproducibility standard deviation, the between-laboratory consistency statistic and the within-laboratory consistency statistic, respectively (ASTM 2003). Repeatability and reproducibility standard deviation in Iosipescu and modified shear test fixture examined for test specimens (Table 3 and Table 4).

Table 3. Repeatability and reproducibility standard deviation for specimens by Iosipescu shear test fixture

Lab. No.	Test Result 1	Test Result 2	Test Result 3	$\bar{x}$	S	d	h	k
Material (A)- Wood								
1	415.1	365.3	405.1	395.2	26.32	25.03	1.34	0.47
2	390.1	310.5	400.6	367.1	49.26	-3.069	-0.165	0.879
3	290.4	400.5	328.1	339.7	55.93	-30.45	-1.64	0.999
4	412.4	300.1	380.4	364.3	57.85	-5.83	-0.314	1.033
5	428.1	408.6	304.7	380.5	66.32	10.34	0.557	1.184
6	450.2	357.9	314.3	374.1	69.36	3.98	0.214	1.238
Material (B)-COMPOSIT (Graphite/Epoxy)								
1	250.1	120.2	190.1	186.8	65	-10.3	-0.978	1.45
2	190.2	250.3	180.1	206.8	37.9	9.75	0.925	0.846
3	240.3	132.1	220.5	197.6	57.61	0.497	0.0471	1.285
4	140.1	230.2	200.6	190.3	45.9	-6.8	-0.645	1.025
5	180.1	175.5	210.3	188.6	18.9	-8.48	-0.805	0.421
6	238.1	210.1	189.2	212.4	24.5	15.34	1.456	0.547

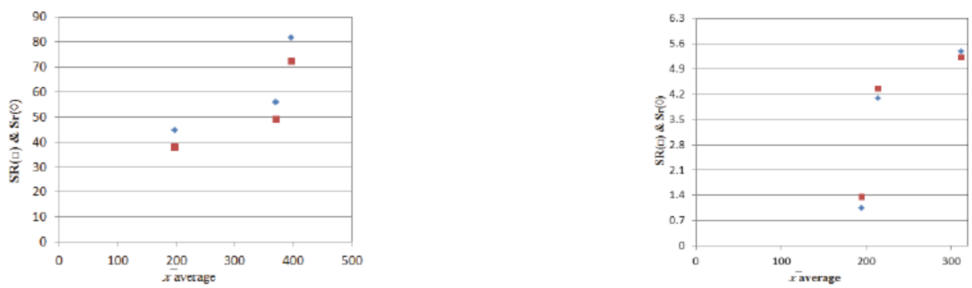
Mat.	$\bar{\bar{x}}$ Average	$S_{\bar{x}}$	Sr	SR	r	R
Mat (A)	396.3	27.62	81.82	72.29	229.1	202.4
Mat. (B)	197.1	10.53	44.82	38.08	125.5	106.6

Table 4. Repeatability and reproducibility standard deviation for specimens by modified shear test fixture

Lab. No.	Test Result 1	2	3	$\bar{x}$	S	d	h	k
Material (A)- WOOD								
1	192.1	191.3	210.1	197.8	10.63	2.873	1.03	1.96
2	189.1	195.2	190.3	191.5	3.22	-3.443	-1.23	0.597
3	193.1	191.3	194.1	192.8	1.417	-2.12	-0.760	0.262
4	195.3	192.4	192.5	193.4	1.648	-1.563	-0.560	0.305
5	195.2	192.9	199.6	195.9	3.371	0.95	0.340	0.624
6	205.1	195.3	194.4	198.2	5.946	3.303	1.18	1.1
Material (B) – COMPOSIT (Graphite/Epoxy)								
1	312.2	310.1	311.1	311.1	1.075	-0.56	-0.53	1.011
2	311.3	312.4	310.7	311.4	0.827	-0.25	-0.24	0.778
3	310.4	310.6	309.1	310	0.821	-1.66	-1.58	0.773
4	312.9	310.5	313.4	312.3	1.564	0.578	0.550	1.472
5	312.1	313.6	313.2	313	0.775	1.265	1.205	0.729
6	311.2	312.5	313.4	312.3	1.1	0.641	0.611	1.035

Mat.	$\bar{x}$ Average	$S_{\bar{x}}$	Sr	SR	r	R
Mat.(A)	194.99	2.788	5.401	5.217	15.12	14.61
Mat.(B)	213.7	2.787	4.101	4.356	11.48	12.19

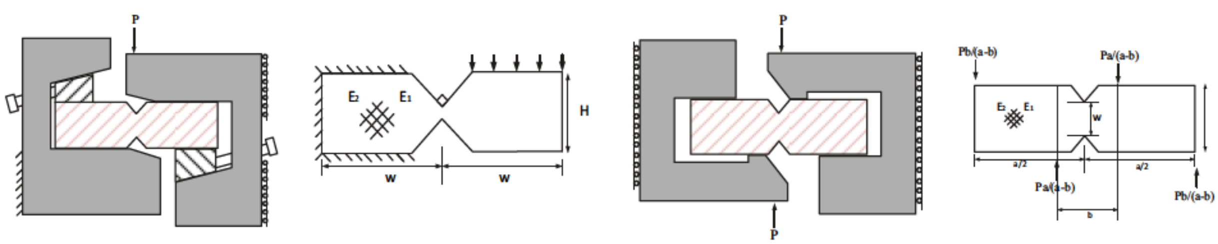
Therefore, S_r and S_R versus average amount of $\bar{x}$ for Iosipescu and modified shear test fixture was plotted in Fig. 11.



(a) (b)

Fig. 11. (a) and (b) denote as Sr and SR versus average amount of for Iosipescu and modified shear test fixture

Sr and SR have more precision in comparison with Iosipescu. Here, in order to prove the accuracy of modified shear test fixture, the numerical method was applied. In this context, energy dissipation comparison for both fixtures at shear zone can be used based on the loading conditions (Fig. 12).



(a) (b)

Fig. 12. (a) and (b) schematic representation of the modified and Iosipescu shear test fixture

For investigating the accuracy of modified shear test fixture, the stress-based or energy based method can be utilized. In this context, comparison of stress (e.g. shear stress) for both fixtures at shear zone can be used.

4.2. Finite Element Method (FEM)

The finite element analyses (FEM) is a well-stablished approach for analyzing the shear fixture specimens. The purpose of this section is to compare numerically the performances of Iosipesque and new shear fixture. In this regard, three dimensional analyses of Iosipesque and modified shear fixture were prepared and analyzed in the ABAQUS FEM software. element type for the whole cracked body was 8-node linear brick solid elements (C3D8R) in addition of applying the mesh-refining method at crack tip vicinity (Fig. 13).

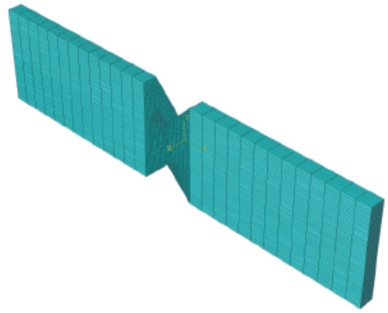


Fig. 13. Typical 3D mesh pattern generated for the standard shear specimens

Moreover, the geometrical dimensions and material properties are presented in Table 5.

Table 5. Geometrical dimensions and material properties

Quantity	Value
Length	76 mm
Wide	20 mm
Thickness	3 mm
Young's modulus	70 GPa
Poisson's ratio	0.3

By defining a path crossing the shear zone, the shear stress (S_{12}) and normal stress (S_{11}) distribution for both the Iosipesque and modified shear test has been investigated as presented in Fig. 16.

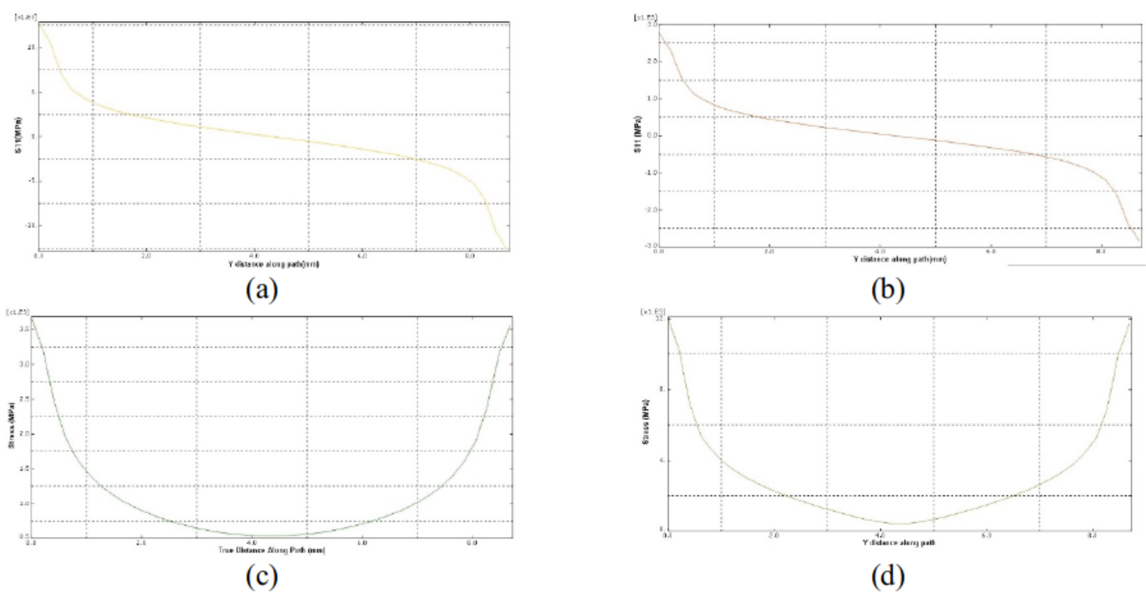


Fig. 14. (a), (c) and (b), (d) denote the variations of normal stress and shear stress thorough the path defined between two v-notched regions for Iosipesque and modified shear test, respectively

Due to the structural modification in new shear test fixture, distribution of shear stress between two v-notched regions in the new shear test fixture is more accurate than Iosipesque one whereas, normal stress in Iosipesque have more capacity during the loading that show the structural delamination. Moreover, the amount of shear stress is more in the modified fixture in comparison to the Iosipesque one. Therefore, not only shear loads concentration would be better in modified fixture, but also, standard deviation could be enhanced, precisely.

5. Conclusion

This research has presented a novel experimental approach in modification of shear test fixture for investigating in-plane mode II orthotropic properties. Through the modified shear test fixture a common Iosipescu shear test fixture was conducted. Furthermore, the arbitrary composite materials of wood, graphite/epoxy and glass/epoxy were studied considering DOE, DFMA and E-691 ASTM approaches. It was found that through using amendments in the modified shear test fixture, the repeatability, reproducibility standard deviation and concentration of shear loads were enhanced. Also, FEM method proved the fact that the modified fixture has more accuracy. Accordingly, the standard deviation of the new fixtures for polymer based composite and wood were diminished to 48% and 82.7%, respectively. Moreover, variations of the stress-strain diagrams were significantly removed; which demonstrates the remarkable precision of the modified shear test fixture.

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