Vol.10, Issue No 3, Sep 2020

DELAMINATION OF COMPOSITE PRETWISTED ROTATING CONICAL SHELLS AND ITS IMPACT ON FREE VIBRATION PROPERTIES AS A FUNCTION OF HUMIDITY AND TEMPERATURE

Chandrakumar.C, Hafeezgayasudin, K,Sharanappa Koni

Asst. Prof, Asst. Prof, Asst. Prof

chakrapdit@gmail.com, hafeezbellary@gmail.com, sharanukoni@gmail.com

Department of Mechanical, Proudhadevaraya Institute of Technology, Abheraj Baldota Rd, Indiranagar, Hosapete, Karnataka-583225

Abstract. Aiming primarily at composite and aluminium alloy materials subjected to tensile testing, this work investigates the feasibility of using digital image correlation to ascertain the Poisson's ratio. The positive outcomes shown with aluminium alloy specimens demonstrate that Digital Image Correlation meets the criteria for calculating Poisson's ratio. Composite materials made of jute and epoxy, as well as jute and glass and epoxy, were the subjects of the testing method. Photographs of the tensile specimen were taken using a digital camera during the testing process. The Digital Image Correlation approach is used to all recorded pictures for each specimen after processing in order to estimate the transverse strain and the longitudinal strain in the direction of the tensile force. There was a visual representation of the transverse strain data in relation to the longitudinal strain. Every specimen that was evaluated had its stress-strain curve's beginning part estimated using a linear regression function. A measure of Poisson's ratio is the slope of the line that fits the data. When comparing Jute/epoxy composites with Jute/glass/epoxy composites, the Poisson's ratio for the fabric-reinforcing plane is 35.5% higher.

1. Introduction

Due to several distinct advantages such as low weight, high ratio between strength and weight, and high stiffness-weight ratio, composite materials have been widely used in industry in recent years, even in the aerospace field [1-3]. Thus it is essential to propose a reliable and efficient method to characterize the mechanical properties of the composite materials. The Poisson’s ratio of composite materials is an indispensable parameter in the finite element analysis, but the studies concerning the determination of the Poisson’s ratio are rarely reported [4].

During tests, extensometers and strain gauges are generally used in order to measure the displacements or strains of specimens and then, in order to determine the mechanical properties [5]. However, what they can provide is just an average value of the displacement or strain over the gauge length at every moment in the experiment [6, 7]. The experimental information regarding the deformation field of composite materials is too limited because the mechanical behaviour of composite materials is more complicated in comparison with that of isotropic materials [7].

The Digital Image Correlation (DIC), a powerful optical testing technique which emerged in recent years, has been widely used to observe the stress-strain behaviour [8, 9], residual stress [10] and crack propagation [11] . Compared with traditional methods, its prominent advantage lies in the non-contact and full-field measurement [12, 13]. By means of the DIC, some researchers have successfully investigated the strain fields of composite materials both in macro- and micro-scales [14]. Among these studies, the reinforcements involve carbon fibre [15], glass fibre [16], woven synthetic [17] and natural fibers [18]. It is worth noting that most of the existing studies focus on the description of strain distribution or failure evolution.

On the other hand, over the past years, there has been a great interest in the use of natural fibres (jute, flax, hemp fibres) to reinforce the composite materials used as building materials for ecological buildings.

Taking into account the above-mentioned aspects, this paper aims to determine and compare Poisson's ratio of two kinds of composite materials reinforced with vegetable fibers by means of the DIC technique. The composite materials tested are the following: Jute / epoxy composite material; Jute / glass / epoxy composite material whose core layers are reinforced with jute fabric, while the outer layers are reinforced with glass fabric. For this purpose, the strain fields of specimens involving longitudinal strain s_l and transverse strain s_t were calculated by Vic-2D software. The values of Poisson's ratio can be finally achieved by fitting the data of the transverse strain s_t related to the longitudinal strain s_l corresponding to the elastic portion of the stress-strain $(\sigma - \varepsilon)$ curve.

2. Materials. Testing method

2.1. Materials

The materials tested were: the EN AW-6060-T6 aluminium alloy; jute / epoxy composite material; jute / glass / epoxy composite material. The aluminium alloy was tested to determine the Poisson's ratio in order to validate the experimental technique that consists in combining of the tensile test with the Digital Image Correlation method.

In accordance with the European Standard EN 573 – 3 / 2010 [19], the EN AW 6060 aluminium alloy belongs to the series of 6000 of the aluminium alloys AlMgSi (aluminium – magnesium – silicon). The chemical composition of the aluminium alloy EN AW 6060 is: 0.3÷0.6% Si; 0.1÷0.3% Fe; 0.10% Cu; 0.35÷0.60 % Mg; 0.05 % Cr; 0.15% Zn; 0.10 % Ti; 0.05 % other metallic components so as the sum does not exceed 0.15 %; the difference is covered by the aluminium [19]. According to [20], the EN AW 6060 aluminium alloy being in T6 heat treatment condition is encoded EN AW-6060-T6.

Aluminium tensile specimens are manufactured according to EN ISO 6892-1: 2002 [21]. Some dimensions of the tensile specimen are: total length – $l = 150\,mm$; active length $l_0 = 60\,mm$; width $b = 10\,mm$ of the active length; width $B = 10\,mm$ of end part that is clamped in the tensile machine.

The composite materials involved in this paper are made of Epolam epoxy resin. One kind of composite material contains four layers reinforced only with jute woven fabric. The other composite material contains also four layers: two core layers reinforced with flax woven fabric; one bottom outer layer (shell) reinforced with E-glass woven fabric; one top outer layer (shell) reinforced also with E-glass fabric. E-glass and jute woven fabrics have the same kind of yarn on both warp and weft directions. The densities corresponding to jute and glass woven fabrics are $400\,g/m^2$ and $200\,g/m^2$, respectively.

The Epolam epoxy resin whose physical and chemical characteristics are shown in table 1, is used to manufacture the composite materials [22]. To initiate and to accelerate the polymerisation process, the hardener agent was mixed with the epoxy resin before the impregnation of the fabrics. The mechanical characteristics of the epoxy resin with hardener are shown in table 2 [22].

One panel was manufactured for each kind of composite material, whose dimensions were 500x500 mm^2. The jute and glass fabrics used to reinforce the layers have the same orientation in all layers. A lower forming pressure was used to manufacture each panel by using hand lay-up technology. The composite panels were kept for one week at room temperature $\left(\approx 20^{\circ} C\right)$ before cutting of the tensile specimens.

For both composite materials, the tensile specimens were cut so as their length should be parallel with the same direction of the reinforcing fabrics. It was not necessary to cut two specimen sets (one set corresponding to warp direction of jute fabric and another set corresponding to weft direction) because both jute and glass fabrics used as reinforcement are made of the same yarn in warp direction like in weft direction. The shape and dimensions of the tensile specimens made of composite materials were in accordance with standard [23].

Five tensile specimens were tested in case of each material involved in this paper.

Table 1. Physical and chemical characteristics of the Epolam epoxy resin, in liquid state [22].

Characteristic	Value	Unit of measure	Method
Density, 25 ºC	1.15	g/cm^3	ISO 1675: 1985
Viscosity, 25 ºC	1550	mPa·s	Brookfield LVT
Mixture ratio with hardener agent	32 (weight ratio) 38 (volume ratio)	%	-
Gel-time, at 23 ºC (100 g resin + 32 g hardener)	2.5	Hours	-
Manipulation time (100 g resin + 32 g hardener)	60	Minutes	-
Glass transition temperature	80	ºC	ISO 11359: 2002°C9188

Table 2. Mechanical characteristics of the Epolam epoxy resin (with hardener) without reinforcing [22].

Characteristic	Value	Unit of measure	Method
Tensile stress in tension	70	MPa	ISO 527: 1993
Flexural stress	120	MPa	ISO 178: 2001
Modulus of elasticity E	3100	MPa	ISO 178 :2001
Impact strength - Charpy (unnotch specimen)	40	kJ/m^2	ISO 179
Elongation in tensile test	5	%	ISO 527: 1993
Toughness	83	Shore D15	ISO 868: 2003

2.2. Testing method

Herein, the testing method consists in combining the tensile test with the digital image correlation method in order to determine the Poisson's ratio (transverse contraction coefficient), in addition to the other tensile properties corresponding to the composite materials described above. Firstly, the technique is used in the case of the aluminium alloy, just to validate the experimental procedure.

The Poisson ratio ν is another elastic characteristic of a material and it is computed by using the following relationship (1):

$$\nu = \left|\frac{\varepsilon_t}{\varepsilon_l}\right|, \qquad (1)$$

where: ε_l represents the strain in the longitudinal direction of the tensile specimen that coincides with the direction of the tensile force; ε_t is the strain of the tensile specimen in the transverse direction that is the direction perpendicular to the tensile force.

The composite material reinforced with bidirectional woven fabrics is an orthotropic material with respect to the material coordinate system denoted with 123, whose 1 and 2 axes coincide with the directions of the fabrics. In this context, in the case of the composite materials which are the focus of this paper, one determines the Poisson's ratio ν_{12} corresponding to the reinforcing plane with fibers because the plane of the tensile specimens is parallel to the reinforcing fabrics and all tensile specimens were cut so as their length be parallel to the same direction of the reinforcement fabrics.

A photo of the set-up of the experimental test is shown in the figure 1.

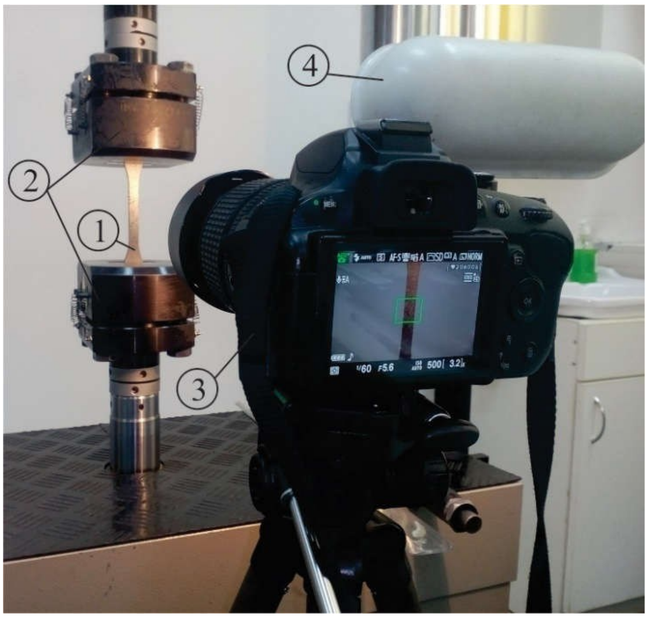


Figure 1. Set-up of the tensile test combined with DIC method: 1 – Tensile specimen; 2 - Fixing device of the tensile machine; 3 – Photo camera; 4 – Light source

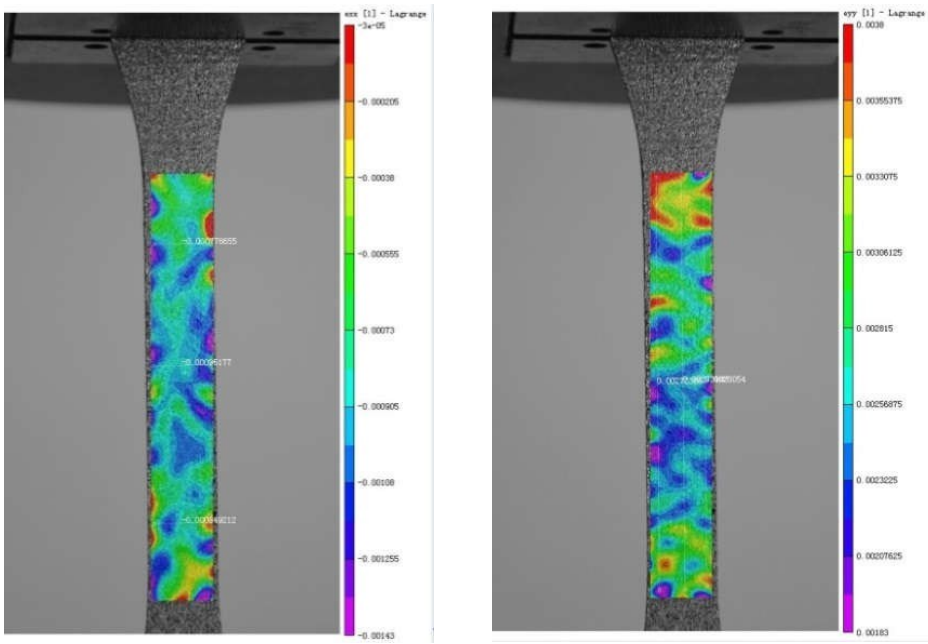
Figure 2. Tensile specimen clamped in tensile machine

Tensile tests were conducted on the universal digitally-controlled testing machine type LFV 50-HM, 980 (Walter & Bai, Switzerland). The universal machine whose maximum force is 200 kN is equipped with devices for tensile, compressive and bending tests. The software of the machine permits the recording, with a high acquisition frequency, of the following data: tensile force F, elongation Δl and the time t. The speed of loading was 1 mm/min. in tensile tests. The data of the elastic portion of the tensile stress-strain $(\sigma - \varepsilon)$ curve were approximated by using a linear function whose slope represents the modulus of elasticity E (Young's modulus). The curve of the longitudinal strain ε_l related to the time t is also plotted in case of each specimen in order to correlate it with the data obtained by using the digital image correlation method.

In order to measure both the longitudinal strain ε_l and the transverse strain ε_t, the VIC-2D system is used in the digital image correlation technique. This system consists of the computer software VIC-2D and the digital camera denoted by 3 in figure 1. In fact, the VIC-2D system may be used to provide two dimensional maps of any planar specimen mechanically loaded in the plane of the specimen.

The digital image correlation technique consists in capturing a set of photos of the specimen during the deformation by using the digital camera. Then, the digital photos recorded are analysed in order to create a contour plot of the strains. Before the test, it is necessary to prepare the specimen by spraying a random dot pattern (speckled pattern) on the surface of the specimen that is photographed. Figure 2 shows the speckled pattern on the tensile specimen clamped in the tensile machine. Before the test begins, a reference photo is taken. During the mechanical test, the camera takes other photos. The VIC-2D software analyses the displacements expressed in pixels by comparing the photos captured during deformation with the reference photo and, finally, correlate them to show the plot contour of the strains. The displacement plots may also be obtained after calibration by using a calibration plate.

A DSLR Nikon D5100 camera was used whose maximum resolution is 4928x3264 pixels and whose lens 18-55 mm f/3.5-5.6 permits the sequential shooting. The photo camera was set to capture one photo per second for 200 photos in case of each tensile test. Then, all photos were post-processed by using the VIC-2D software in order to obtain the graph of the transverse strain ε_t related to the longitudinal strain ε_l in the case of each tested specimen (figure 3).



a. b.

Figure 3. Contour plot of the strains by using VIC 2009 software:
a. Transverse strain $\varepsilon_t\left(\varepsilon_{xx}\right)$; b. Longitudinal strain $\varepsilon_l\left(\varepsilon_{yy}\right)$.

For each tensile specimen tested, the $\varepsilon_t - \varepsilon_l$ curve was correlated with the stress-strain $(\sigma - \varepsilon)$ curve and longitudinal strain – time $(\varepsilon_l - t)$ curve in order to determine the Poisson's ratio. In other words, the data of the $\varepsilon_t - \varepsilon_l$ curve corresponding to the elastic portion of the $\sigma - \varepsilon$ curve, were approximated with a linear function whose slope represents the Poisson's ratio ν in accordance with the relationship (1).

3. Results

Firstly, the medium stress-strain curve recorded in the case of the EN AW-6060-T6 aluminium alloy is shown in the figure 4, and the average values of the tensile properties are shown in the table 3.

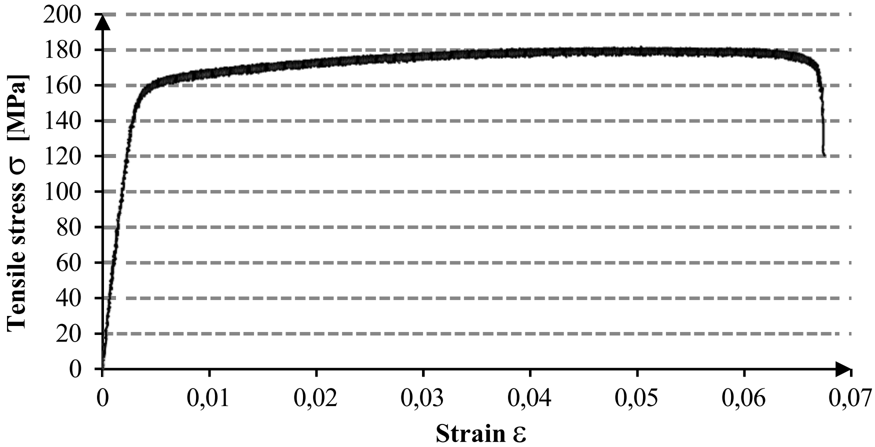
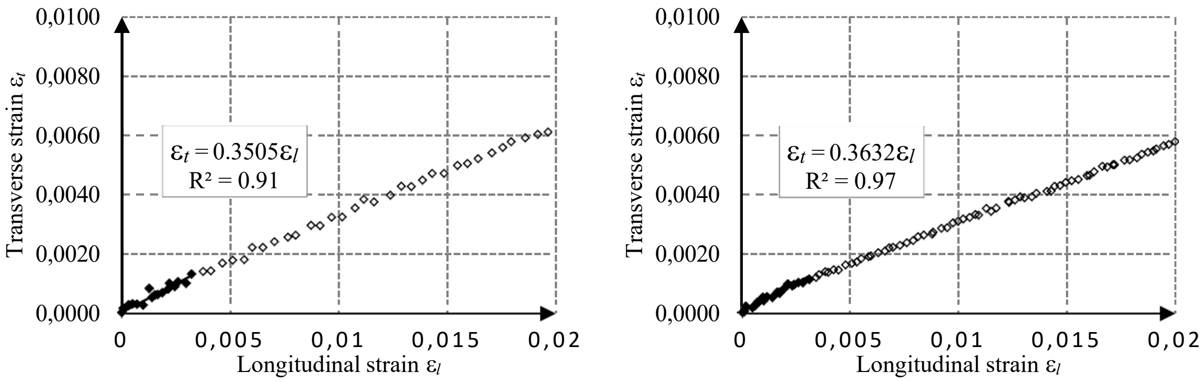


Figure 4. Stress-strain $(\sigma - \varepsilon)$ curve recorded in tensile test for EN AW-6060-T6 aluminium alloy.

Table 3. Tensile properties and Poisson's ratio ν determined for EN AW-6060-T6 aluminium.

	Young's modulus E (MPa)	Stress σ_e at the elastic limit	Max. stress σ_{max} (MPa)	Strain s_e at the elastic limit	Strain s la F_{max}	Poisson's ratio ν
Average value	52780	144	182	0.002784	0.047019	0.353
Stdev	2393	28	12	0.0004	0.0052	0.010

The Poisson's ratio $\nu = 0.353$ of the aluminium alloy is the average value and it is approximately equal to the value given in specialty literature [24]. Two $\varepsilon_t - \varepsilon_l$ recorded in the case of two tensile aluminium specimens are plotted in figure 5. In table 3, one may also remarks a good result concerning the standard deviation value (Stdev) corresponding to Poisson's ratio ν in the case of the EN AW-6060-T6 aluminium alloy.



a. b.

Figure 5. Transverse strain related ε_t to longitudinal strain ε_l in case of EN AW-6060-T6 aluminium alloy: a. Specimen 1; b. Specimen 3.

Figure 6 shows the tensile stress-strain $(\sigma - \varepsilon)$ curves recorded for the two kinds of composite materials tested. The tensile properties corresponding to each tested specimen made of composite material are shown in table 4, including the average values and Stdev values of these properties.

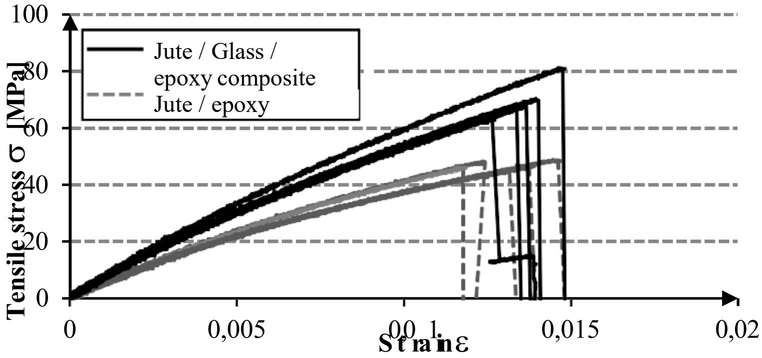


Figure 6. Stress-strain $(\sigma - \varepsilon)$curves recorded in tensile test in case of the composite materials tested.

Table 4. Tensile properties of the composite materials tested.

Specimen	Jute / epoxy			Jute / glass / epoxy		
	Young's modulus E (MPa)	Max. stress σ_{max} (MPa)	Strain s la F_{max}	Young's modulus E (MPa)	Max. stress σ_{max} (MPa)	Strain s la F_{max}
1	5250.3	48.36	0.0123	6913.2	67.86	0.0137
2	5122.4	46.25	0.0117	6634.0	63.19	0.0126
3	4583.0	45.23	0.0131	6831.0	70.30	0.0139
4	4707.5	48.96	0.0145	6555.6	68.68	0.0135
5	5086.3	46.48	0.0137	7146.6	81.17	0.0146
Average value	4950	47	0.0131	6816	70	0.0137
Stdev	288	1.6	0.0011	234	6.7	0.0007

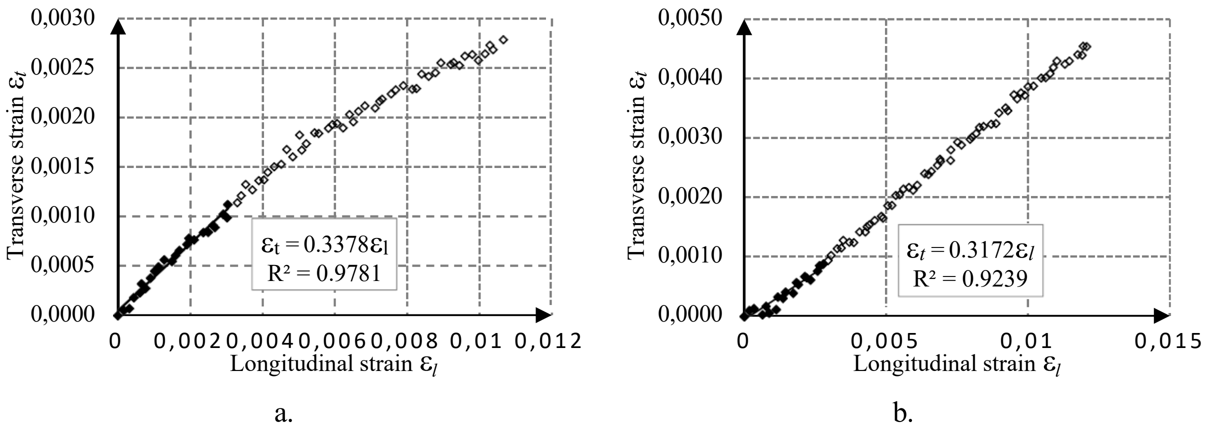


Figure 7. Transverse strain related ε_t to longitudinal strain ε_l in case of the Jute / epoxy composite: a. Specimen 2; b. Specimen 3.

Regarding the curves of the transverse strain ε_t related to the longitudinal strain ε_l, this paper shows only two curves corresponding to two kinds of composite material tested: figure 7 for Jute / epoxy composite material; figure 8 for Jute / glass / epoxy composite material. The Poisson's ratio ν_{12} (figure 7 and 8) was computed by taking into account the data of $\varepsilon_t - \varepsilon_l$ curve corresponding to $\varepsilon_l = 0 \div 0.03$ in accordance to the linear portion of the stress-strain $(\sigma - \varepsilon)$ curve (figure 6).

The values of the Poisson's ratio ν_{12} computed for all specimens made of composite materials including the average values and Stdev are shown in table 5.

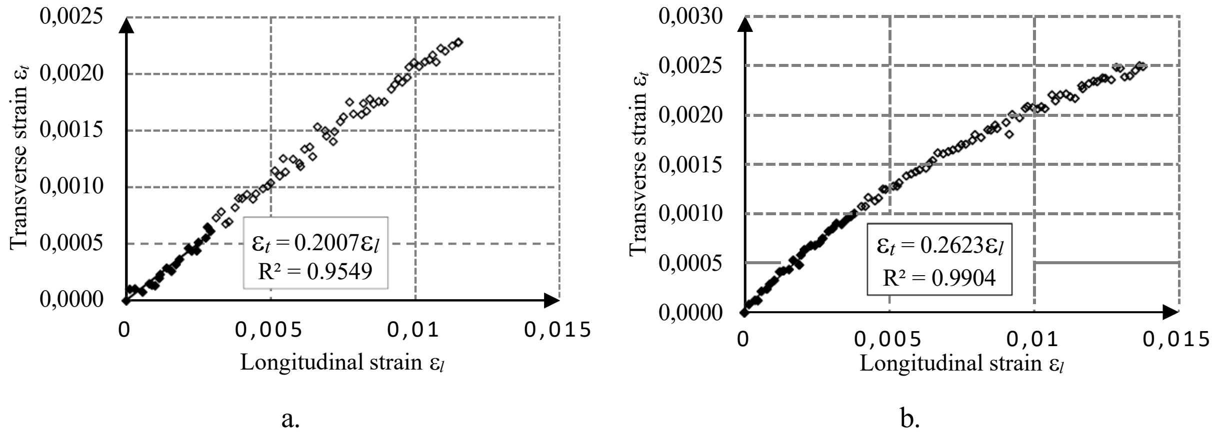


Figure 8. Transverse strain related ε_t to longitudinal strain ε_l in case of the Jute / glass / epoxy composite material: a. Specimen 1; b. Specimen 5.

Table 5. Poisson's ratio ν_{12} computed for the composite materials tested.

No. of tensile specimen	Jute / epoxy	Jute / glass / epoxy
Specimen 1	0.3149	0.2007
Specimen 2	0.3378	0.2639
Specimen 3	0.3172	0.2011
Specimen 4	0.3816	0.2593
Specimen 5	0.2579	0.2623
Average value	0.3219	0.2375
Stdev	0.0447	0.0334

One is to note the higher degree of scattering of the results for the Poisson's ratio ν_{12} in the case of the Jute/glass composite material in comparison with the Poisson's ratio ν_{12} corresponding to Jute / glass / epoxy composite material. The reason is the poorer homogeneity corresponding to the Jute / epoxy composite material at microscopic level in comparison with the homogeneity corresponding to the Jute / glass / epoxy composite material. The outer layers of the Jute / glass / epoxy hybrid composite material are reinforced with glass fabric whose density is 200 g/m^2 that is equal to half of the density of 400 g/m^2 corresponding to the jute fabrics. In other words, the yarns of the glass fabric are thinner than the yarns of the jute fabric, which ensures a better homogeneity at the surface of the tensile specimens made of Jute / glass / epoxy hybrid composite material.

The Poisson's ratio ν_{12} corresponding to the reinforcing plane of the composite is in fact an equivalent Poisson's ratio of the laminated composite material because it corresponds to a fictitious orthotropic material whose mechanical behaviour is similar to the behaviour of the laminated composite material.

4. Conclusions

The experimental technique presented in this paper is very useful to determine the Poisson's ratio of the materials taking into account that this elastic property is required to characterize the material of any mechanical structure analysed by using the finite element analysis. This work also extends the application of the DIC method especially in testing composite materials, and can provide valuable data for finite element simulation.

The Poisson's ratio ν_{12} corresponding to Jute / epoxy composite material is 35.5% greater in comparison with Poisson's ratio ν_{12} corresponding to Jute / glass / epoxy composite material. Moreover, Poisson's ratio of the Jute / glass / epoxy composite material is greater than Poisson's ratio corresponding to the composite material reinforced only with glass fabric that is $\nu_{12} = 0.15$ in accordance with the results reported in previous work by the authors [4].

The above remarks lead to the conclusion that the reinforcing with jute fabric of all layers of the polymeric composite materials involves the increase of the *Poisson*'s ratio comparatively to the *Poisson*'s ratio of the hybrid composite material whose outer layers are reinforced with glass fibers.

As the yarns of the glass fabric are thinner than the yarns of the jute fabric, the above findings could be caused by this aspect. The density of the fabrics used to reinforce the outer layers of the polymeric composite materials could have an effect on the Poisson's ratio ν_{12} corresponding to the reinforcing plane.

The article reports elastic properties of composite materials reinforced with natural fibers (jute fabric) which has been a large area of interest in recent years, taking into account their ecological advantages. These kinds of composite materials are used in the field of the automotive industry (the interior of the doors) and in the construction of the ecological buildings (thermal or sound insulation panels, interior design panels etc.).

Acknowledgments

The authors hereby acknowledge the structural founds project PRO-DD (POS-CCE, O.2.2.1., ID 123, SMIS 2637, ctr. No 11/2009) and Transilvania University of Brasov for providing the infrastructure used in this work.

References

[1] Boufaida Z, Boisse J, André S and Farge L 2017 Mesoscopic strain field analysis in a woven composite using a spectral solver and 3D-DIC measurements *Composite Structures* **160** 604-612

[2] Perrier A, Touchard F, Chocinski-Arnault L and Mellier D 2016 Mechanical behaviour analysis of the interface in single hemp yarn composites: DIC measurements and FEM calculations *Polymer Testing* **52** 1-8

[3] Cerbu C and Curtu I 2011 Mechanical characterization of the glass fibres / rubber / resin composite material *Materiale Plastice* **48** (1) 93-97

[4] Cerbu C, Curtu I, Constantinescu D M and Miron M C 2011 Aspects concerning the transversal contraction in the case of some composite materials reinforced with glass fabric *Materiale Plastice* **48** (4) 341-345

[5] Nguyen V-T, Kwon S-J and Kwon O-H 2017 Mechanical properties identification of sheet metals by 2D-digital image correlation method *Procedia Engineering* **184** 381-389

[6] Wang Y H, Jiang J H, Wanintrudal C, Du C, Zhou D, Smith L M and Yang L X 2010 Whole field sheet-metal tensile test using digital image correlation *Experimental Techniques* **34** (2) 54–59

[7] Bruno L 2018 Mechanical characterization of composite materials by optical techniques: A review *Optics & Lasers in Engineering* **104** 192-203

[8] Wang H 2013 Marker Identification Technique for Deformation Measurement *Advances in Mechanical Engineering* **2013** Article ID 246318, 8 pages.

[9] Wang H and Kang Y 2002 Improved digital speckle correlation method and its application in fracture analysis of metallic foil *Optical Engineering* **41**(11) 436-45

[10] Lord J D, Penn D and Whitehead P 2008 The Application of Digital Image Correlation for Measuring Residual Stress by Incremental Hole Drilling *Applied Mechanics and Materials* **13-14** 65-73

[11] Abanto-Bueno J and Lambros J 2002 Investigation of crack growth in functionally graded materials using digital image correlation *Engineering Fracture Mechanics* **69**(14–16) 1695-1711

[12] Pan B, Qian K, Xie H and Asundi A 2009 Two-dimensional digital image correlation for in-plane displacement and strain measurement: A review *Measurement Science & Technology* **20**(6) 152-154

[13] Wang H and Hou Z 2010 Application of Genetic Algorithms in a surface deformation measurement technique *2010 Sixth International Conference on Natural Computation* 2291-2295 doi: 10.1109/ICNC.2010.5584215

[14] Mehdikhani M, Aravand M, Sabuncuoglu B, Callens M G, Lomov S V and Gorbatikh L 2016 Full-field strain measurements at the micro-scale in fiber-reinforced composites using digital image correlation *Composite Structures* **140** 192-201

[15] Brynk T, Molak R M, Janiszewska M and Pakiela Z 2012 Digital Image Correlation measurements as a tool of composites deformation description *Computational Materials Science* **64** 157-161

[16] Cascelli C 2014 Application of digital image correlation to glass fibre-reinforced composites under transverse tensile loading *Master of Science Thesis Delft University of Technology*

[17] Nicoletto G, Anzelotti G and Enrica R 2009 Mesoscopic strain fields in woven composites: Experiments vs. finite element modeling *Optics & Lasers in Engineering* **47**(3-4) 352-359

[18] Perrier A, de Vasconcellos D S, Touchard F, Chocinski-Arnault L and Mellier D 2015 Full-field Measurement at the Weave Scale in Hemp/Epoxy Composite Using Digital Image Correlation Polymers & Polymer Composites Shropshire 23(9) 589-599

[19] EN 573-3: 2010. Aluminium and aluminium alloys. Chemical composition and form of wrought products. Part 3: Chemical composition and form of products. Romanian Standard version, ASRO, 2010

[20] EN 573-5: 2008. Aluminium and aluminium alloys. Chemical composition and form of wrought products. Part 5: Codification of standardized wrought products. Romanian Standard version, ASRO, 2008

[21] EN ISO 6892-1: 2010 (or EN ISO 6892-1: 2002). Metallic materials. Tensile testing. Part 1: Method of test at room temperature

[22] Data sheet of the Epolam 2015 epoxy resin. Axson Technologies (U.S.A.), 2006

[23] EN ISO 527-4:1997. Plastics – Determination of tensile properties. Part 4: Test conditions for isotropic and orthotropic fiber-reinforced plastic composites

[24] https://www.makeitfrom.com/material-properties/6060-T6-Aluminum (accessed in April 2018)