Aspects Concerning the Transversal Contraction in the Case of Some Composite Materials Reinforced with Glass Fabric

CAMELIA CERBU[1]*, IOAN CURTU[1], DAN MIHAI CONSTANTINESCU[2], MATEI CONSTANTIN MIRON[2]

[1] „Transilvania" University of Braşov, Faculty of Mechanical Engineering, Department of Automotives and Mechanical Engineering, 29 Eroilor Av., 500036, Braşov, Romania,

[2] Politechnic University of Bucharest, Faculty of Engineering and Technological Systems Management, Strength of Materials Department, 313 Splaiul Independentei, 060042, Bucharest, Romania

The work presents the experimental determination of the transverse contraction coefficient í (Poissson's ratio) for three kinds of composite materials. For this purpose, it was used the digital image correlation method that is an optical method for the measuring of the deformations. The composite materials were made of the same epoxy resin but the reinforcement was different: reinforcement with glass fabric; reinforcement with oak wood flour; reinforcement both with oak wood flour and with glass fabric (hybrid composite material). The specimens were subject to tensile test and during the test, it was used the system Aramis 2M for image acquisition and their post-processing to determine both the longitudinal strain ε_x (axial strain) on the direction of tensile loading and transversal strain ε_y on the direction of the specimen width. The variations of the transverse strains ε_y as a function of the axial ones for each specimen were graphycal lyrepresented. Then, the experimental data were approximated by linear regression that is by linear functions. The slopes of the straight lines represent Poisson's ratio ν. It was found that the adding of the oak wood flour as filling material in case of the composite materials reinforced with glass fabric, leads to the increasing of the Poisson's ratio ν.

Keywords: composite material, wood flour, tensile test, Poisson's ratio

During the recent years, numerous papers have been published on various types of mechanical characterization of composite materials reinforced with glass fibres. Many of them were related to the influence of the material structure (type of glass fabric, the number of layers, fibres orientation) [1-3] and to the effects of the environmental factors (humidity, thermal cycles, radiation, UV rays) [4] on the mechanical behaviour. On the other hand, it was proved that some local problems occur in laminated composite structures concerning the strain-field [5, 6]. But only a few papers show experimental results concerning the determination of Poisson's ratio ν, which is a very important elastic characteristic needed for correctly modelling of the material in the finite element analysis software.

Some works focused on the mechanical characterization of the fabrics. Therefore, a paper [7] studied the mechanical behaviour in tensile test in case of the novel double-helix yarn and the composite made from this yarn.Graphs concerning to the variation of longitudinal strain against lateral strain, obtained by using linear strain gauges affixed on the specimen were provided.

Another work [8] studies the evolution of the Poisson's ratio as a function of the longitudinal strain in case of a carbon fibre-reinforced polyphenylene sulphide, in multiple experiments by using strain gauges, optical fibres and an extensometer for transverse strain measurement. It was shown that the hyperbolic-like shape of this function is entirely caused by the nonlinear behaviour of such a composite material.

The tensile testing coupled with the strain-field analysis via the method of digital image correlation (DIC) was used [9] to study the plastic micro-strains in an epoxy resin reinforced with short borosilicate glass fibres (35% in weight) during mechanical loading. It was demonstrated the anisotropic behaviour of such a composite material that depends on the orientation angle of the fibres relative to the load direction. DIC method which is also known as photogrammetry, was also used to propose as a failure parameter the local strain at the crack tip, for interface damage characterization of sandwich specimens with two initial inter-laminar defects [10].

In the last year, the using of wood flour as filling material to develop new hybrid composite materials reinforced with glass fabric lead to the necessity of their mechanical characterization. Some properties obtained in tensile or flexural tests, are discussed in certain previous published papers [1-3].

The main objectives of this work is to determine the Poisson's ratio for such a hybrid composite and finally, comparing the results with the ones obtained in case of composite reinforced either only with glass fabric or only with wood flour. For this purpose, the strain-field analysis via digital image correlation (DIC) which is also known as photogrammetry, was used to measure both the axial (longitudinal) strain ε_x and transversal strain ε_y. Then, the experimental ε_y-ε_x curves were approximated by linear regression and the slopes of the linear functions gave us the values of the Poisson's ratio ν.

Experimental part

Materials and methods

First of all, three laminated composite plates whose reinforcements and thickness are described in the table 1were manufactured. In this table, the letter G is abbreviation for glass fibres while the letter K is used when oak wood flour was used as filler material. The Composite 1 was reinforced only with E-glass woven fabric while only oak wood flour was used to reinforce Composite 2. The last, Composite 3, is a hybrid composite material reinforced both with E-glass woven fabric and oak wood flour.

* *email: cerbu@unitbv.ro*

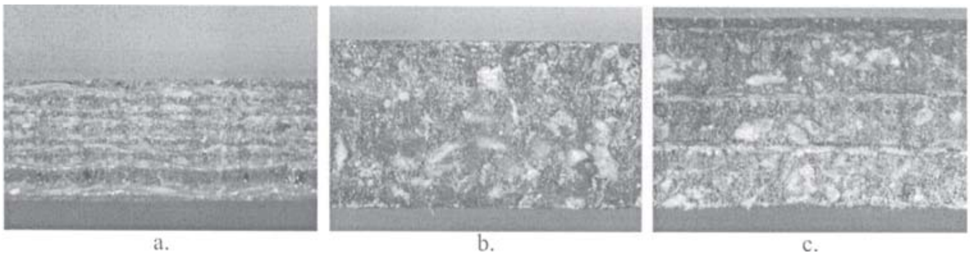


Fig. 1. Photos of the cross-sections of the composite materials by using the digital microscope: a – Composite 1; b – Composite 2; c – Composite 3

Moreover, the figure 1.a shows a photo of a cross-section of the laminated composite material by using a digital microscope.

The glass woven fabric used was the same for both Composite 1 and Composite 3. This fabric is made of the same type of glass yarn both on the warp direction and on weft direction.

The oak wood flour in form of particles, whose dimensions are smaller than 500 mm, was obtained by recycling of the selected oak wood wastes. A laboratory mill was used to obtain wood flour. The weight ratio of the reinforcement materials (glass woven fabric, oak wood flour or both) was approximately equal to 34% in case of all composites tested. To initiate and to accelerate the polymerisation process, a hardener agent was mixed with the epoxy resin.

The epoxy resin [11] used was the same for the three kinds of composites. A lower forming pressure was used to manufacture the plate by using hand lay-up technology. The epoxy resin is widely used for manufacturing the laminated composite materials by handing lay-up technology, injection with low pressure and filament wrapping. This kind of resin has a good behaviour for impregnation of timber. The physical and chemical characteristics of the epoxy resin in liquid state are shown in the table 2 while the mechanical characteristics of the same resin without reinforcing are shown in the table 3. Analysing its properties, one may remark that this resin has lower viscosity good mechanical properties as well as a good behaviour in wet environment [11].

The tensile specimens were cut from the composite plates so that their shape and dimensions were in accordance with the european standard [12]. LR5K Plus machine (fig. 2,a), was used to tensile load of each specimen tested. The maximum force capacity is ±5 *kN*. The figure 3 shows a photo of the specimen during the tensile test. The speed of loading was 1 mm/min [12]. Before each tensile test of a specimen, the dimensions of the cross-section and accuracy precision of 0.1 mm were measured then, they were considered as input data in the software program of the machine. The testing equipment allowed us to record pairs of values (force F and elongation Δl of the tensile specimen) in form of files having 200-300 lines. Therefore, the average values of the following quantities could be accurately computed: Young's modulus E in tensile test; maximum tensile stress σ_{max} at maximum load etc.

The LR5K Plus tensile test machine was coupled with the DIC (Digital Image Correlation) measurement system as in figure 2. In order to record the deformation during the tensile tests, images were taken by using the two cameras

Table 1
CODING AND MATERIAL STRUCTURE CORRESPONDING TO THE SPECIMENS TESTED

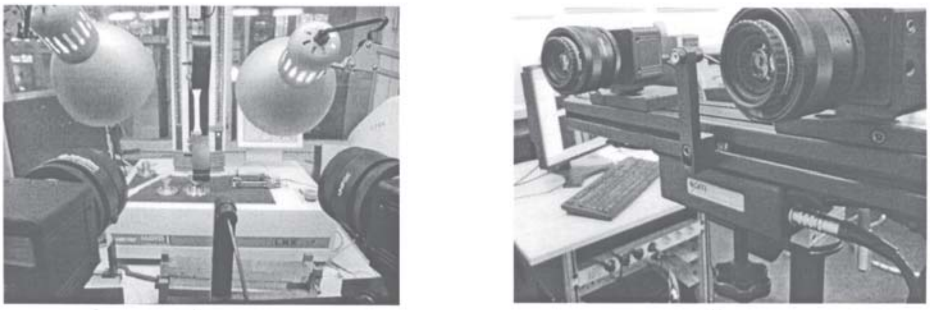
Composite material	Code of the specimens	Resin	Reinforcement	Thickness of specimen (mm)
Composite 1	G01...G10	epoxy resin	E-glass woven fabric (7 layers)	2.5
Composite 2	K01... K10		oak wood flour	3.0
Composite 3	4GK01... 4GK10		E-glass woven fabric (4 layers) + oak wood flour	3.5

Table 2
PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE EPOXY RESIN USED, IN LIQUID STATE [11]

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

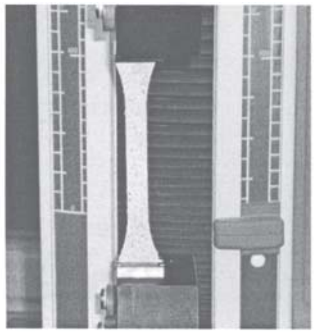
Table 3
MECHANICAL CHARACTERISTICS OF THE EPOXY RESIN (WITH HARDENER) WITHOUT REINFORCING [11]

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



a. b.

Fig. 2. Testing equipment: a – LR5K Plus tensile test machine; b – Aramis system



c.

Fig. 3. The specimen during tensile loading

controlled by the Aramis system in case of 3D measurement [13]. These data served as input to calculate the displacement field using the DIC method.

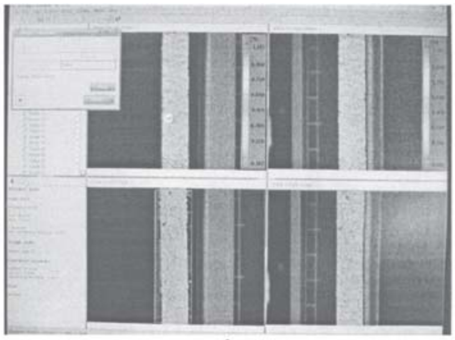
DIC method offers an optical solution for deformation measurement. It also provides a strain distribution map all over the tested surface. Aramis is a non-contact optical 3D deformation measuring system [13]. Aramis analyzes, calculates and documents material deformations being particularly suitable for three-dimensional deformation measurements under static and dynamic load in order to analyze deformations and strain of the real components. After creating the measuring project in the software, images are recorded in various load stages of the specimen. After computation, the measuring result is available as 3D view.

Main hardware and software components of the system are: sensor with two cameras; trigger box for power supply of the cameras and to control image recording; PC system; Aramis application software and Linux system software.

Herein, to determinate the Poisson's ratio ν, Aramis system was used to measure the strains ε_x and ε_y along the both longitudinal direction and transversal direction of the tensile specimen, respectively. Aramis 2M system (fig. 2, b) uses DIC method to evaluate the strain state occurred on the analysed surface. This is composed by two photo cameras with CCD sensor having 2 Megapixels. Photo acquisition is controlled by a device called „frame grabber" that assures synchronized tripping of the exposure for each camera. On the other hand, it controls the exposure time for each frame. Also, the role of the device „frame grabber" is to unload the acquired images in the hard-disk of the Aramis system.

The specimens that will be tested by using the Aramis system, must be preliminarily coated with a layer of white dye. Then, a layer of black dye points are randomly sprayed on the white layer. To evaluate the strain state occurred on the analysed surface, the analysis soft divides the calculus area in some rectangular facets. These facets include many black dots (fig. 4) that are recognized by analyzing of the gray gradients on the surface analyzed. In the first acquired frame called frame of reference, all facets generated have a rectangular shape. By identifying the black points and reconstruction of the facets in the frames acquired during the test, the system determines the deformations and the strains occurred within the facets.

The link among the virtual distance between two different pixels having black dots, located on the digital computing area and the real distance between the two black dots located on the surface analysed, is made by calibrating of the system [13]. Calibration process supposes the acquisition of a set of images containing a standard gage that is located in certain positions made by manufacturer. Thus, the analysis program may make the link among the digital distance and real distance.



d.

Fig. 4. Data aquired by ARAMIS application software

The size of the surface that may be monitored by using the Aramis system and this may be between 1x1 mm^2 and 2000x2000 mm^2. It depends on the dimension of the gauge used for the calibration. The strains that may be measured by using the Aramis system are between 0.01 % and 100 %. The calibration was made by using the gauge having the size 35x26 . The dimensions of the facets used were 25x25 pixels and step size of 17 x 17pixeli. The acquisition speed of the system was equal to one frame per 3 s. The length of the virtual strain gauges emulated in analysis was on the average of 8 mm.

Approximation of the experimental data

The experimental data graphically shown are points having 2D coordinates (x_i, y_i), in this case, the coordinates being (ε_{xi} ,ε_{xyi}) where ε_{xi} represents longitudinal (axial) strain and ε_{yi} represents the transverse strain. Approximation of the experimental data was made by linear regression which means approximation by a linear function. So that the approximation to be considered "the best", sum of squares of the distances from each point to the curve that approximates the data, must be minimal. This is known as squares regression method [14]. A measure of the quality of the curve fitting is called R-squared value that may be computed by using the formula [14]:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - f_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \qquad (1)$$

where n represents the number of the data points; y_i represents the real value (ordinate of the point i); f_i is the value of the function of linear regression and are sometimes called the predicted values.

In the above equation (1), $\overline{y}$ is the mean of the observed data [14]:

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i. \quad (2)$$

In regression, the R-squared value (R^2) is a measure of how well the regression line approximates the real data points. A trend-line (or curve fitting) is more accurate when R-squared value is equal to or near 1(R<1). When one approximates the experimental data by using a linear function, its R-squared value should be computed.

Results and discussions

Figure 5 shows stress-strain (σ–ε) curves recorded by LR5K Plus tensile testing machine in case of some specimens tested. Because some of curves almost overlap, there are presented only the curves recorded for two specimens made of each material. Analyzing these curves, it may be noticed that the slopes corresponding to the curves recorded in case of Composite 1 are higher than in case of the other two composites tested. It follows that the Young's modulus is higher in case of Composite 1 reinforced only with glass fibres. At the same time, maximum tensile stress σ_{max} is higher in case of this composite material, the average value being 189.05 *MPa*. This quantity was equal to 61.94 MPa in case of Composite 2and 25.61 *MPa* in case of Composite 3.

On the other hand, the photos captured with the two cameras of the Aramis system, were processed with software Aramis. To determine Poisson's ratio ν the data were firstly analysed by DIC (Digital Image Correlation) method to determine the variation of the transverse strain ε_y as a function of the axial strain ε_x on the surface of each specimen tested. The results corresponding to two specimens tested for each composite material, are graphically shown in the figures 6-8. These data were approximated by linear regression so the linear functions pass through the origin. The R-squared value was also calculated and displayed on the charts to determine the reliability of the linear function and accuracy of the approximation. It may be noted that the value of R-squared is very close to 1 like the theory recommends (section 2.3).

Analysing the charts shown in the figure 6, it may be noticed that Composite 1 is characterized by a nonlinear behaviour concerning to the variation of the transverse ε_y strain versus the axial strain ε_x. From this reason and taking into account the shape of stress σ–ε strain curves (fig. 5), only the data corresponding to $\varepsilon_x \leq 1.1$were approximated by linear regression in this case. This phenomenon also occurred in case of one specimen made of Composite 3 (fig. 8, b). In contrast, all data points were approximated by linear functions in case of the specimens made of Composite 2 (fig. 7). This composite material reinforced

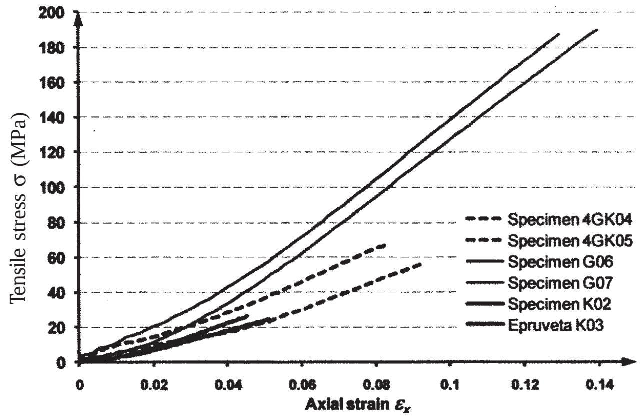
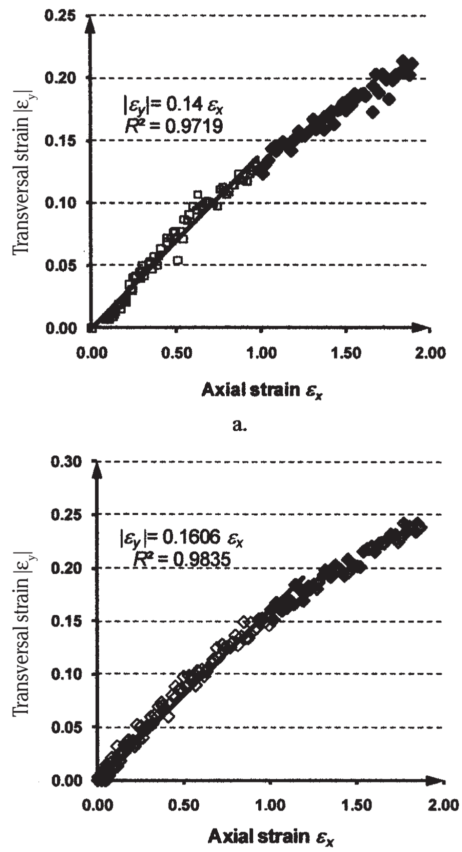


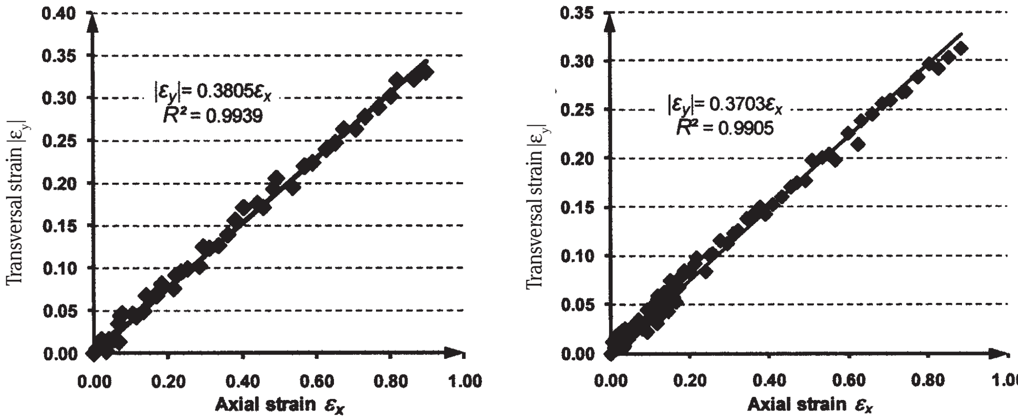
Fig. 5. Stress – strain curves (σ-ε) recorded in case of some specimens tested



a.

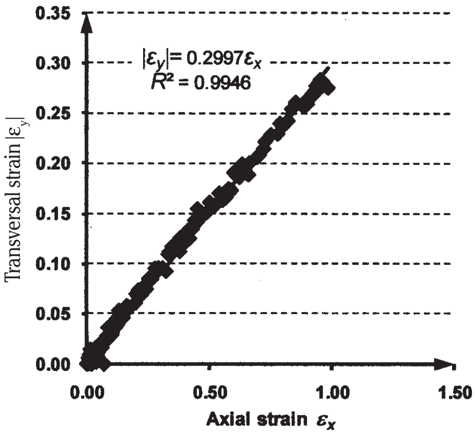
b.

Fig. 6. Change of transversal strain ε_y versus longitudinal strain ε_x in case of Composite 1



a. b.

Fig. 7. Change of transversal strain ε_y versus longitudinal strain ε_x in case of Composite 2



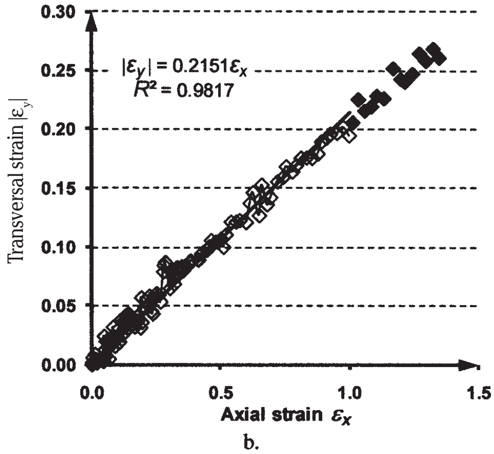


Fig.8. Change of transversal strain ε_y versus longitudinal strain ε_x in case of Composite 3

only with oak wood flour, shown a linear behaviour up to the rupture during the tensile test (fig. 5).

The average values obtained for Poisson's ratio were: 0.1503 in case of Composite 1; 0.3754 in case of Composite 2 and 0.2574 in case of Composite 3. It may be noticed that the use of oak wood flour as filler in the case of the composite materials reinforced with glass fabric, leads to increasing of Poisson's ratio ν. The highest value of Poisson's ratio ν, corresponds to the Composite 2 material reinforced only with oak wood flour. In contrast, the smallest values of the Poisson's ratio ν were recorded in case of Composite 1 material reinforced only with wood flour.

In case of the tested materials, it must be taken into account that the glass woven fabric used is made of the same type of glass yarns both on warp direction and weft direction. This means that the composite material reinforced with this kind of glass fabric is orthotropic one characterized by the same value of Young's modulus $E_1 = E_2 = E$ on the both directions. It follows that Poisson's ratio ν should have the same value $\nu_{12}=\nu_{21}=\nu$ in reinforcement plane taking into account the symmetry of the rigidity matrix.

Conclusions

It is known that in case of the finite element analysis (FEA) of the stress state is very important to know the value of Poisson's ratio ν for an accurate modelling of the material. Its value must be experimentally determined, especially for fiber reinforced polymeric composite materials whose properties are highly dependent both on fiber-resin ratio and the nature of components.

The results presented within this work may be used in simulations of the mechanical behaviour of the structures or component parts made of one of the composite material tested. Moreover, it was demonstrated that the adding of the oak wood flour as filler in the epoxy resin, leads to the increasing of the Poisson's ratio ν.

This conclusion experimentally demonstrated in this paper, may justify the development of the matrix cracks in parts made of such wood flour composite materials when they are mechanically loaded or are subject to temperature variations. In other words, the increasing of the Poisson's ratio ν could speed up the development of such cracks in matrix.

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