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ON THE RESIDUAL INTERNAL STRESSES IN GFRP TUBES

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Abstract: *This paper presents a cutting method to put into evidence the residual internal stresses that have been introduced in the manufacturing process of two glass fiber-reinforced composite tubular structures based on unsaturated polyester resin. The deformations and angular changes of these tubular structures resulting from this destructive method have been used to compute the residual internal stresses. The experiments show the presence in these structures of the compression residual internal stresses on their inner surface respective tensile residual internal stresses on their outer surface.*

Keywords: *destructive method, composite tube, internal stress, tensile stress, compression stress*

1. INTRODUCTION

In the last ten years, the Mechanical Engineering department of Transilvania University in Brasov has channeled its efforts in research, development and testing of structures made of new composite materials, with potential in various applications. The results of these researches have been published in specialized journals with international impact and visibility [1-15]. An important part of this research focused on the development of new experimental methods in the field of composite materials. A safe and comprehensive calculation for the determination of residual internal stresses introduced in the manufacturing process of a composite tubular structure is very difficult to perform, because the mathematical description must take into account a lot of influence factors and material values dependent on temperature and time. Therefore, experimental methods for determining residual internal stresses are still used. The methods for determining the internal stresses are divided into destructive and non-destructive methods of the structure. All destructive methods for determining residual internal stresses are based on determining variations in the shape of the composite structure, caused by the disturbance of the equilibrium state. The equilibrium state is disturbed because the flow of forces included inside the composite structure is interrupted by the destructive process. The shape variations of the structure (deformations and angular changes) resulting from the destructive process will be interpreted as a measure of the residual internal stresses. By determining the variations of the shape of the composite structure, it will be possible to compute the values of these internal stresses. The most well-known destructive methods for measuring residual internal stresses introduced in the manufacturing process of a composite tubular structure are the cutting method, the combined method of drilling and detachment by unscrewing, the ring core method and the sounding hole method [16].

2. MATERIAL AND METHOD

Regarding the experimental determination of the residual internal stresses introduced in the manufacturing process of the tubular specimens produced by COMPOZITE Ltd., Brasov, we used a method partially similar to the method described by Aleong *et al.* [17]. The experiments were performed on specimens based on polyester resin reinforced with fiberglass fabric with a specific weight of 500 g/m^2, with the fabric strip taken both on the warp (specimen type 1, see Table 1) and at 45 ° to the warp direction (specimen type 2, presented in Table 2). Before the actual measurement took place, from the specimens subjected to the experiments we took rings with a length of 25 mm, from the left end (L), from the middle (M) and from the right end (R) of the specimen. In principle, the method for determining the residual internal stresses consists in disturbing the equilibrium state of the rings, by cutting them on generators in the radial direction and determining the deformations of the external surface resulting from the cutting process. In the case of specimens manufactured by the winding method (pure circumferential winding), the highest residual internal stresses are formed in the circumferential direction. Axial residual internal stresses can be neglected because they are insignificant compared to the circumferential ones and do not act in the direction of the main stress. In this way, what is determined is a uniaxial distribution of internal stresses.

The maximum value of this distribution of the residual internal stresses is found in the layer of the outer surface of the ring, a value that decreases in the direction of the neutral fiber [18]. In the case of radial cutting of the ring, the equilibrium state of the residual internal stresses is disturbed, the stresses become free and deform the ring. An enlargement of the ring means the existence in the cut ring, of the residual internal stresses of compression or tensile on the inner and outer surface of the ring. A decrease in the ring diameter after the cutting operation means the initial existence of residual internal tensile stresses or compression on the inner and outer surface of the ring. Due to the small differences in diameter, the residual internal stresses inside the tube specimen have values close to those existing on its outer surface, because a symmetrical distribution of stresses is formed.

2.1. The chord measurement method

The method of measuring the chord consists in computing the residual internal stresses existing on the outer surface of the ring, after previously measuring the length of the chord between the cutting edges of the neutral fiber, formed after its radial cutting (Fig. 1). The calculation of these residual internal stresses is accomplished according to the circumference of the neutral fiber, the angle of the chord neutral fiber between the two ends of the ring, Young's modulus, the radius of the outer surface of the ring, the radius of the neutral fiber of the ring, the wall thickness of the tubular specimen as well as the width of the cut.

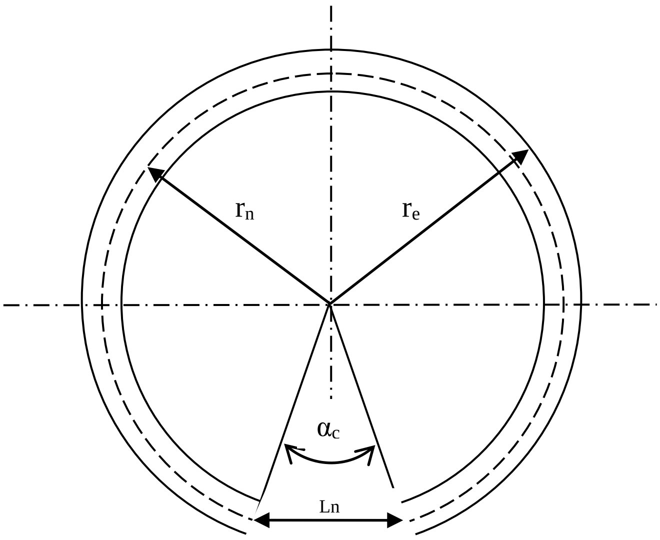

Figure 1: Schematic representation of the chord measurement method

The chord neutral fiber length (L_n) between the ends of the ring is a function given in relation (1) and the residual internal stress on the ring's outer surface (σ_e) can be computed from the parameters presented in relation (2) [19]:

$$L_n = C_n \frac{360}{\pi(360-\alpha_C)} \sin\frac{\alpha_C}{2} \qquad (1)$$

$$\sigma_e = E\,\frac{(2\pi r_n) + \dfrac{(360-\alpha_C)\,t\pi}{360\left[1-\frac{1}{180}\arcsin\left(\frac{l_t}{2r_n}\right)\right]} - 2\pi r_e}{2\pi r_e} \qquad (2)$$

where:
C_n (mm) represents the circumference of the neutral fiber;
L_n (mm) is the chord length between the two ends of ring's the neutral fiber;
α_C (°) designates the chord angle of the neutral fiber between the ring's ends;
σ_e (MPa) represents the residual internal stress on the ring's outer surface;
E (MPa) is the Young's modulus;
r_e (mm) represents the radius of the ring's outer surface;
r_n (mm) designates the radius of the ring's neutral fiber;
t (mm) is the wall thickness of the tube's specimen;
l_t (mm) represents the cut width.

Table 1: Characteristics of specimen type 1

Specimen type 1	Feature/value
Matrix	UP resin
Type of reinforcement	Fiberglass fabric 500 g/m^2 specific weight
Nominal tube's diameter	80 + 0.4 mm
Tube's length	100 mm
Wall thickness	3.1 – 4 mm
Number of layers	8
The thickness of the individual layers	0.38 - 0.5 mm
Fabric winding angle on the mandrel	0°
Average fibers volume fraction	35 %

Table 2: Characteristics of specimen type 2

Specimen type 2	Feature/value
Matrix	UP resin
Type of reinforcement	Fiberglass fabric 500 g/m^2 specific weight
Nominal tube's diameter	80 + 0.4 mm
Tube's length	100 mm
Wall thickness	3.6 – 5 mm
Number of layers	8
The thickness of the individual layers	0.45 – 0.62 mm
Fabric winding angle on the mandrel	0°
Average fibers volume fraction	35 %

3. EXPERIMENTAL RESULTS

The experimental features of the chord measurement method including the rings radial cutting from specimens type 1 and 2 are presented in Tables 3 and 4. The results of the experimental determinations of the residual internal stresses introduced in the manufacturing process of the tubular specimens type 1 and 2 according to the described method are shown in Figs. 2 and 3 as well as a comparison is presented in Fig. 4.

Table 3: Experimental characteristics of the chord measurement method for type 1 specimen

	Left ring (L)	Middle ring (M)	Right ring (R)
Tubular specimen's wall thickness (mm)	3.6	3.6	3.6
Radius of the outer surface of the ring (mm)	44	44	44
Neutral fiber radius of the ring (mm)	42.2	42.2	42.2
Cut width (mm)	2	2	2
Neutral fiber chord angle between the two ends of the ring (°)	2.98	3.39	2.98
Neutral fiber circumference (mm)	265	265	265
Chord length between neutral fiber cutting edges (mm)	2.2	2.5	2.2
Young's modulus (MPa)	25000	25000	25000

Table 4: Experimental characteristics of the chord measurement method for type 2 specimen

	Left ring (L)	Middle ring (M)	Right ring (R)
Tubular specimen's wall thickness (mm)	4	4	4
Radius of the outer surface of the ring (mm)	44.5	44.5	44.5
Neutral fiber radius of the ring (mm)	42.5	42.5	42.5
Cut width (mm)	2	2	2
Neutral fiber chord angle between the two ends of the ring (°)	2.98	3.5	2.98
Neutral fiber circumference (mm)	267	267	267
Chord length between neutral fiber cutting edges (mm)	2.2	2.6	2.2
Young's modulus (MPa)	14000	14000	14000

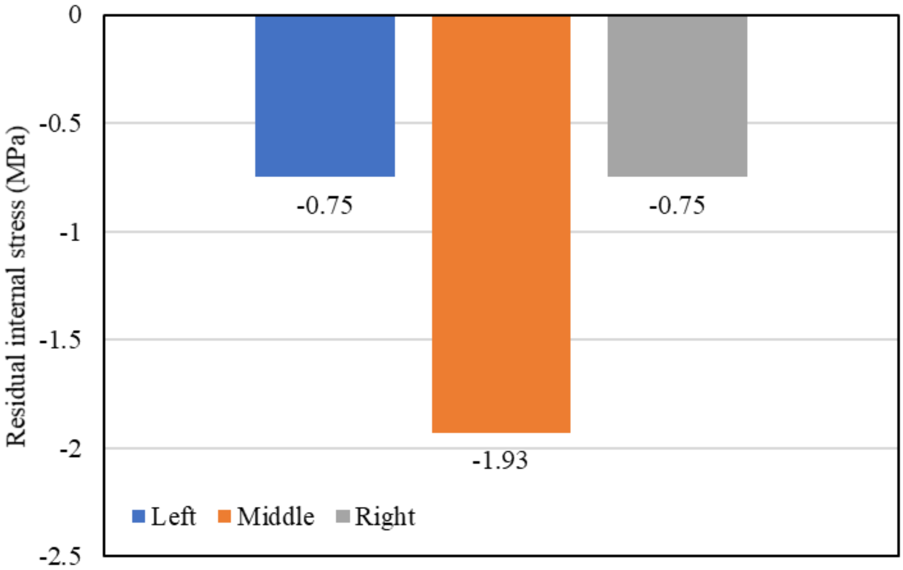

Figure 2: Residual internal stresses introduced in the manufacturing process of type 1 specimen

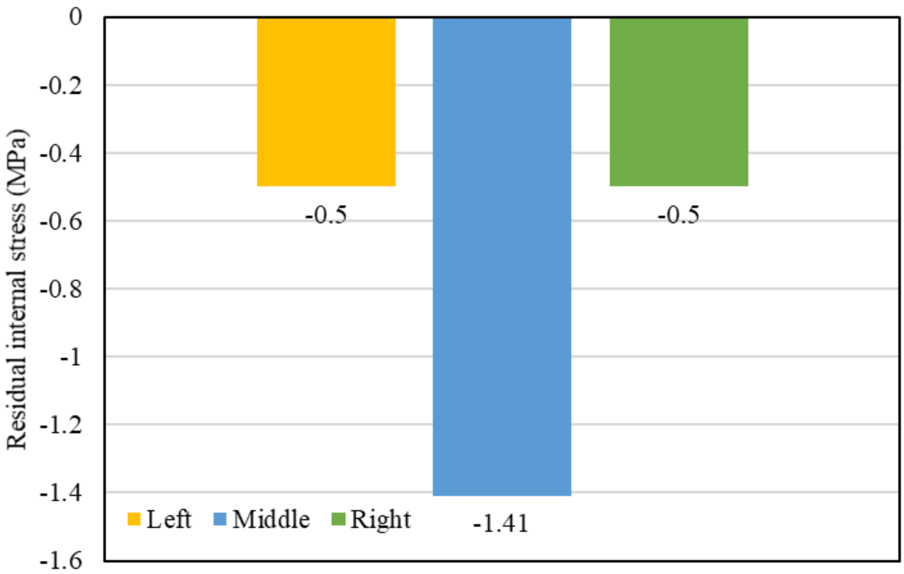

Figure 3: Residual internal stresses introduced in the manufacturing process of type 2 specimen

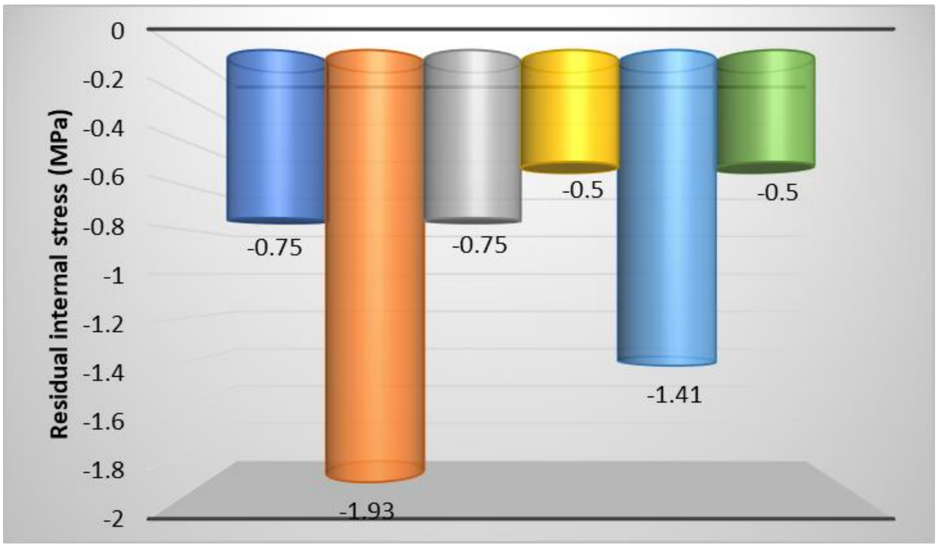

Figure 4: Comparison between residual internal stresses in two types of composite tubes

4. CONCLUSION

Following the experimental determination of the residual internal stresses introduced in the manufacturing process of the specimens, it can be concluded that there are maximum values of residual internal stresses found in the extreme layers of the tubular specimens. The value of these residual internal internal stresses decreases in the direction of the neutral fiber of the specimen's wall thickness.

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