

# The Assessing of the Failure Behavior of Glass/Polyester Composites Subject to Quasi Static Stresses

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**Abstract.** Using glass fabric reinforced composites for structure of wind turbine blades requires high mechanical strengths especially to cyclic stresses. Studies have shown that approximately 50% of composite material failure occurs because of fatigue. Composites behavior to cyclic stresses involves three stages regarding to stiffness variation: the first stage is characterized by the accelerated decline of stiffness with micro-cracks, the second stage - a slight decrease of stiffness characterized by the occurrence of delamination and third stage characterized by higher decreases of resistance and occurrence of fracture thereof. The aim of the paper is to analyzed the behavior of composites reinforced with glass fibers fabric type RT500 and polyester resin subjected to tensile cyclic loading with pulsating quasi-static regime with asymmetry coefficient  $R = 0$ . The samples were tested with the universal tensile machine LS100 Lloyd Instruments Plus, with a load capacity of 100 kN. The load was applied with different speeds of 1 mm/min, 10 mm/min and 20 mm/min. After tests, it was observed that the greatest permanent strains were recorded in the first load cycles when the total energy storage by material was lost due to internal friction. With increasing number of cycles, the glass/polyester composites ability to store energy of deformation decreases, the flow phenomenon characterized by large displacements to smaller loading forces appearing.

## 1. Introduction

Numerous studies on the fatigue behavior of glass-reinforced composites (GFRC) have mainly addressed the effect of environmental conditions (temperature variation, glass transition temperature, humidity variation, artificial aging).

The results of these studies have shown that there is a close link between the dimensions and shape of the fibers, their orientation and distribution, and the viscous-elastic behavior of the matrix [1-3]. The behavior of materials in fatigue is very important in all engineering applications [4,5]. Since the composites have a polymer as matrix, their behavior is viscous-elastic or viscous-plastic, being grounded in the theory of cooperative [6,7].

Mechanical and/or temperature loading cause changes in matrix-fibers linkages or in chemical-physical rearrangements or in van der Waals forces distribution. If these changes exceed the internal cohesion forces or in some areas the chains are weak, the material has viscous-plastic behavior [2,8]. Even though the fibers determine the mechanical properties like elastic modulus or strength, the matrix provides the physical and chemical durability by protecting the fibers from environmental influences [2]. Although the viscous-elastic behavior of glass fibers composites is well-known [1-3],



however, there is a knowledge gap about the dependence of mechanical properties evolution on cyclic loading and speed of loading. The high tensile strength of the composite is due to reinforcement and type of fibers used, while flexural strength is due to the elastic characteristics close of the two components - matrix and reinforcement, which makes both components to work together [9-11]. Experimental tests have shown that the failure in a laminated composite is very often progressive in nature, occurring by a process of damage accumulation [12,13].

Fatigue life predictions for service load histories are generally based on fatigue data performed with constant amplitude loading, which can be substantially influenced by cyclic frequency in thermoplastics [14]. The paper aims to determine the speed of deterioration of the mechanical properties under the influence of the velocity of the stress and the pulsating cycles.

## 2. The experimental set-up

### 2.1. Materials

The specimens were realized from four layers of unidirectional RT500 fabric and polyester matrix with specific geometry of tensile test according to SR-EN ISO 527-2, having the geometrical characteristics in table 1.

**Table 1.** Dimensions of the specimens before testing.

Input Data /	Samples Code	RT1	RT2	RT3	RT4	RT5
Sample Length [mm]		150	150	150	150	150
The length of the calibrated part [mm]		70	70	70	70	70
Width [mm]		10	10.3	10	10.2	10
Thickness [mm]		2.5	2.5	2,2	2.5	2.5
Area [mm <sup>2</sup> ]		25	25.75	22	25.5	25
Load [kN]		2.5	2.5	2.5	3.0	3.0
Loading speed [mm/min]		1	10	20	10	20
Number of loading cycles		1-10-15				

### 2.2. Experimental method

The samples were subjected to tensile loading in an algorithm test consisting of three series of pulsating cycles (1, 10 and 15 cycles) at 1, 10 and 20 mm/min and maximum load of 2.5 kN and 3.0 kN respectively. An important consideration in axial fatigue testing is the uniformity of stress and strains in the specimen gage section.

The tests were made with the LR5K Plus Lloyd's Instruments Universal Machine and the results were processed using the NEXYGEN Plus software. Several tests were performed to analyze the influence of the loading cycles on the integrity of the composite material in terms of modulus of elasticity, stiffness and storage capacity of the deformation energy. The elastic-viscous-plastic behavior of the composites was also evaluated.

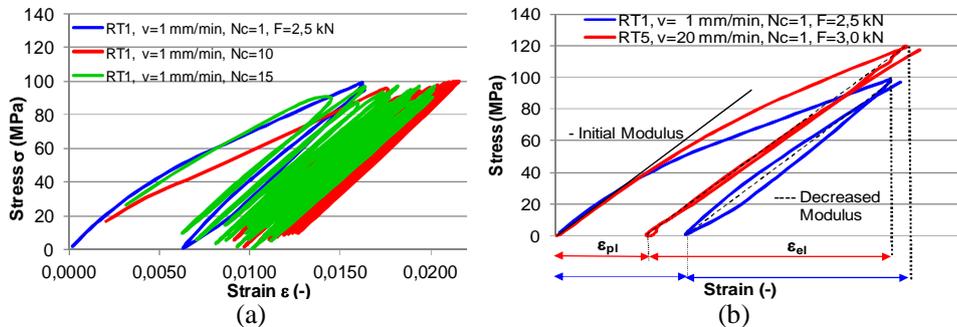
## 3. Results and discussion

The changes in cyclic deformation behavior are more pronounced at the beginning of cyclic loading (transient behavior) when the plastic deformation reached almost 50% from the total plastic strain at the final of cyclic loading (figure 1).

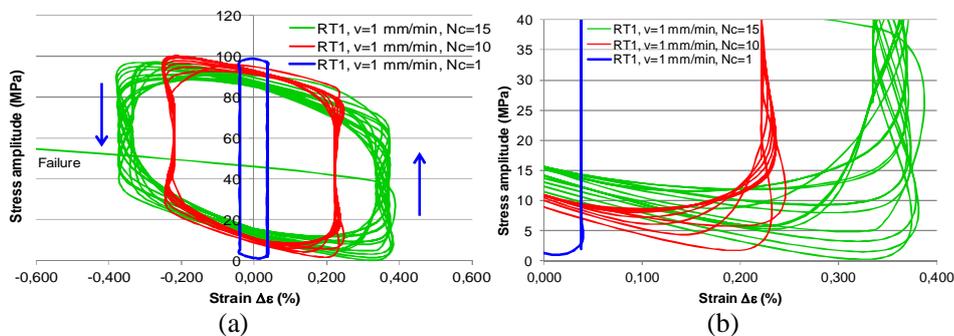
The area within a hysteresis loop is energy dissipated during a cycle; with increasing the number of cycles, the material usually gradually stabilizes (steady-state).

The yield strength in tension or compression was reduced after applying a load of the opposite sign that caused inelastic deformation (figure 2, a).

An appreciable progressive change is observed in stress-strain behavior during inelastic cycling (figure 2, b).

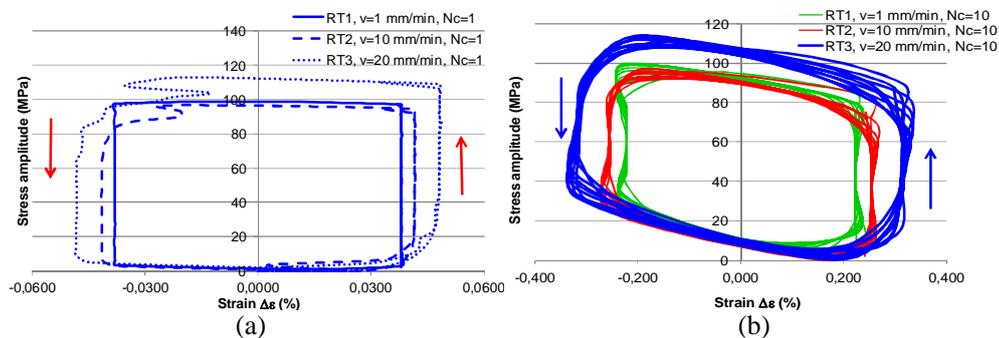


**Figure 1.** The hysteresis loops: a) comparison of hysteresis loops obtained at 1, 10 and 15 cycles; b) elastic and plastic strains with increasing the loading for monotonic stress.



**Figure 2.** Comparison between stress-strains curve obtained for different cycles: (a) the cyclic stress-strain response for load speed of 1 mm/min; (b) detail of inelastic deformation during softening cycles.

In figure 3b, the values of the percentage specific deformation of GFRC for different loading rates are observed. Thus, the highest deformation values (0.30%) are recorded at 20 mm/min during the 10 cycles. For monotonic loading (figure 3a), the most stable behavior is recorded for load speed of 1 mm/min.

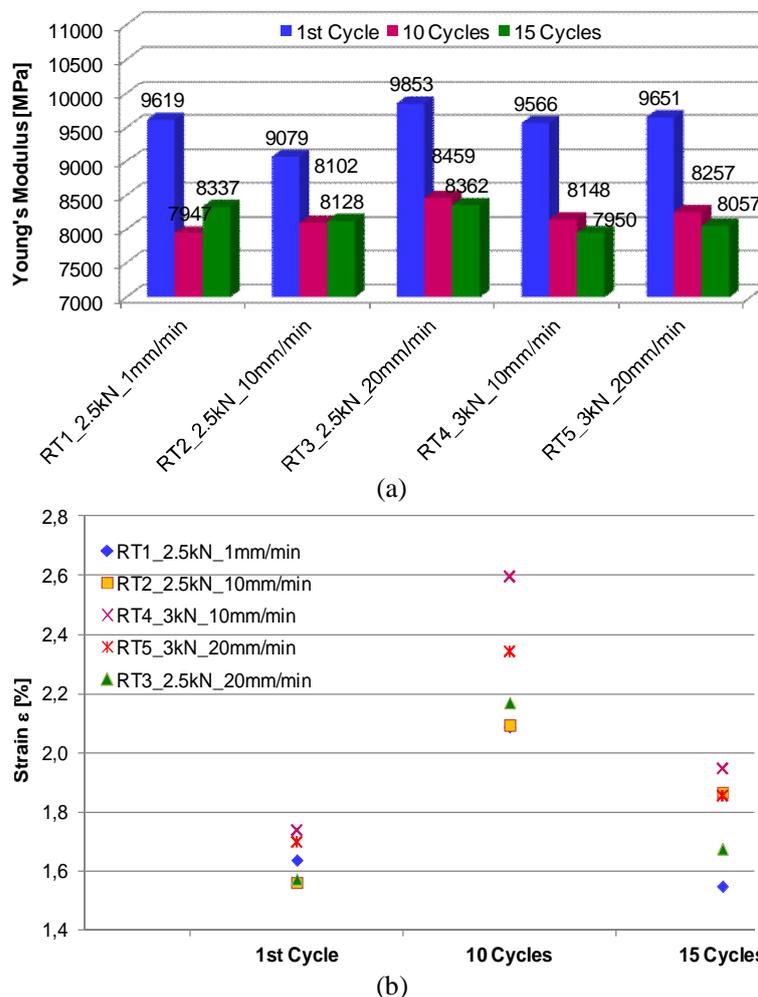


**Figure 3.** Strain/stress for different loading rates: (a) The monotonic stress-strain response at different loading speed; (b) the increasing of strain with increasing of loading rate.

Because of crosslink degradation in the matrix structure or plastic deformation of interfaces between matrix and glass fibers with continued cycling, the mechanical properties in terms of Young's modulus, stiffness and strength decreased (figure 4).

In the same time, a decreased resistance at deformation, irrespective a softening of materials is recorded. With increasing the loading rate with 100%, the Young’s modulus value increased with 2% for monotonic stress-strain, which lead to appearance of a hardening zone which is a precedent of fatigue cracks and failure.

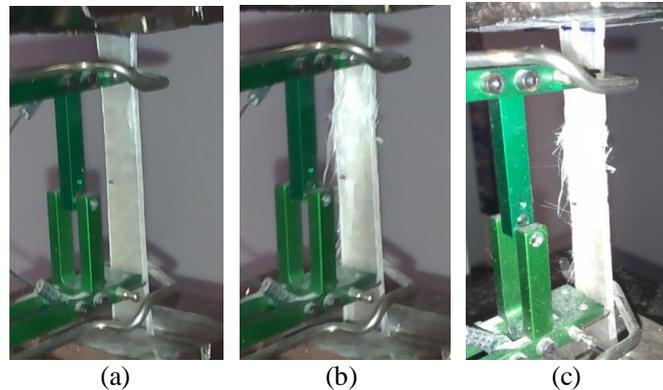
The intensity of load play influences the elastic modulus value: with increasing of applied force with 20%, the rigidity of materials decreased with almost 5%. The rate is useful for determining the life time of composites under fatigue test.



**Figure 4.** Variation of mechanical properties: (a) variation of elasticity modulus; (b) strain variation with respect the number of cycles.

In the case of the GFRC, it has been observed that the matrix had broken first, the inner efforts being distributed to longitudinal fibers of the glass fabric which continuous the deformation until reaching the breakage at the maximum stress (figure 5).

At the monotonic stress-strain (figure 5, a) there is no surface damage; with increasing the number of loading cycles with asymmetry coefficient  $R = 0$ , it can be seen the matrix failure and buckling of fibers (figure 5, b). Finally, at 15<sup>th</sup> cycles, the GFRC samples failure, both matrix and fabric, the fracture region being characterized by cracking, debonding, crushing. In that stage, the material has reached the plasticity limit and damage.



**Figure 5.** Failure area for the tested specimens: (a) after first cycle; (b) after 10 cycles; (c) after 15 cycles.

During cyclic stresses, beside the axial stresses which are developed in matrix and fibers, at the interfaces between both components appear tangential stresses due to different stiffness of each component. So, these stresses lead to sliding between layers because the elastic limits of matrix and fibers are not overlap. Than appears the first fractures from composite. The majority of the criteria proposed in literature identify the following failure modes: fiber fracture; transverse matrix cracking; shear matrix cracking [12-14].

#### 4. Conclusions

The analyses the elastic-plastic behavior of glass fabric reinforced composite under cyclic loading compared to behavior under static loading have been carried on. The parameters which were varied were: the number of cycle, the speed of loading, the intensity of the applied force.

The stress-strain response of the GFRC samples subjected to cyclic loading is quite different from that under monotonic loading:

- the material have an linear and homogeneous response when is subjected to one loading cycle;
- with increasing the number of cycles, the material responded with viscous and plastic deformation with losing the capacity to recover the strain;
- cyclic deformation behavior indicated progressive modulus reduction and unsymmetrical straining in tension and compression;
- the plastic strain clearly depends on the applied load level.

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