ISOCHRONOUS CURVES OF CARBON/EPOXY COMPOSITES BY CREEP TESTS

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Key words: carbon/epoxy composites, filament winding, creep, isochronous curves.

Abstract

The determination of the threshold stress at which the linear behavior occurs can be determined by graphical representation called isochronous curves. In the present study, tensile creep tests in constant load were performed with unidirectional carbon fiber-reinforced epoxy composites specimens at 25ºC and 70ºC and the transition from linear to non-linear behavior through isochronous curves was obtained.
The isochronous curves of the specimens obtained at 60° and 90° in 70°C, show respectively that the linear behavior occurs for stress up to 40% and 35% of rupture strength. For both directions, but at 25°C, the responses were respectively 57.5% and 40% of rupture strength.

1 Introduction

The polymeric materials and the polymeric composites can show a variety of behaviors due to the work conditions, such as load, temperature, humidity and time. For using these materials considered as dependents of the time, besides the knowledge of the mechanical properties and hygrothermal properties, it is necessary a reliable prediction of the evolution of these properties with the time, including the strength properties and damage evolution.
To describe the behavior of composites creep, some mathematical models were developed and they contribute to determine the deformations along the time using tests of short duration. Two of them, commonly pointed in the literature, are the Boltzmann´s model and the Schapery´s model, [1]; that are used to describe, respectively, the linear and non linear behavior .

The Boltzmann superposition principle is accepted as valid only for low levels of stress and strain and most materials exhibit a behavior close to linear under strict conditions of varying stress, strain, time and temperature, and nonlinear under a wide range of some of these variables, [2].

The constitutive equation of simple integral developed by Schapery, develop from the thermodynamic theory and is one of the most widely applied in creep behavior studies of polymeric composites, which can accurately describe the non linear behavior dependent of the time in many types of polymers and polymer composites. The Schapery´s equation uses linear viscoelastic properties (modulus or compliance) and non linear viscoelastic properties (four functions dependent on the strain or stress). For uniaxial load, this equation presents a very similar form to the Boltzmann´s integral superposition, that is used in the linear viscoelastic theory, resulting in a simple application method for materials characterization, [3].

This way, to identify the linear of the non linear behavior and conveniently use the equations that describe the respective phenomena, isochronous curves are built, that are plotted from the values of the deformation in constant time at several levels of stress in creep tests.

2 Materiais and Methods

The specimens were manufactured by a filament winding process, using DGEBA epoxy resin and carbon fiber HT (high strength) with 6000 filaments. The mandrel was a bi-plane with parallel faces, and two plates were obtained by each manufacturing operation, with external dimensions of length 260 mm and of width 344 mm, as illustrated in Figure 1, which shows one of the two faces of the plate.

The curing was performed in an oven at atmospheric pressure and temperatures up to 150°C with slow cooling to air oven itself. After cooling, the plates were cut using a diamond cutting disc, whose cutting directions were, 60° and 90° related to the longitudinal axis of force application. The illustration 2 shows an outline to obtain specimens in both directions. The spacemen geometry and dimensions were based on the ASTM standards D3039/3039M-95th (Standard Test Methods for Tensile Properties of Polymer Matrix Composite Materials), [4].

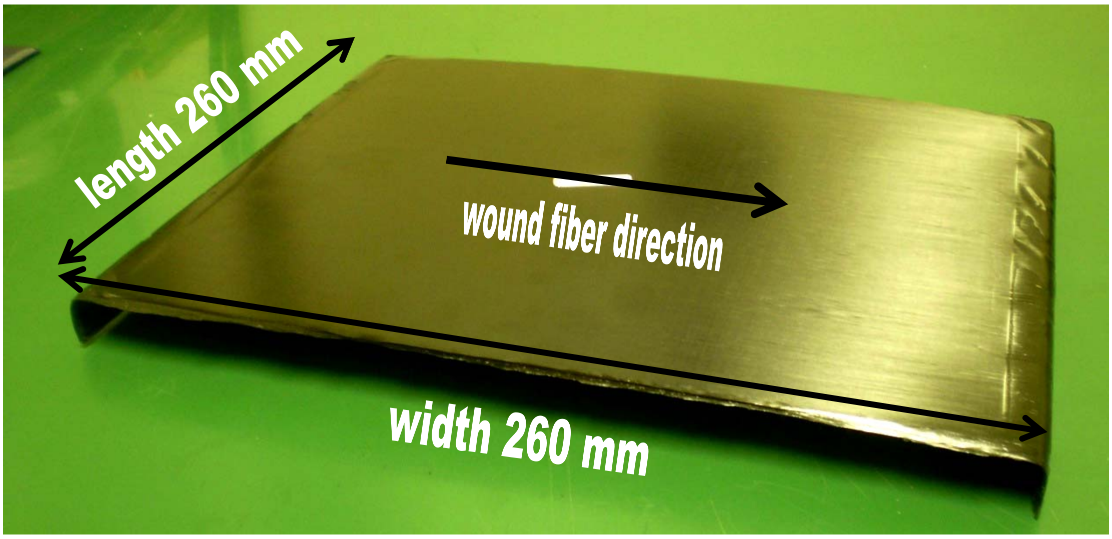
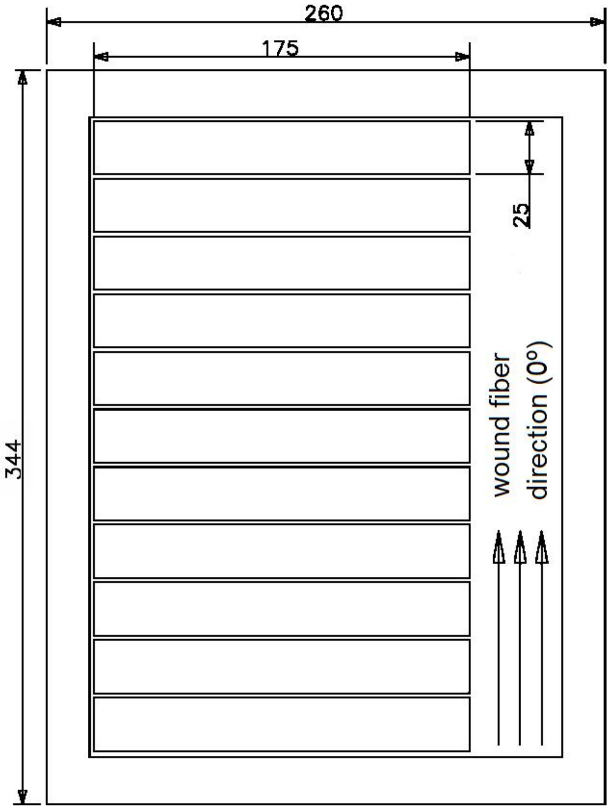


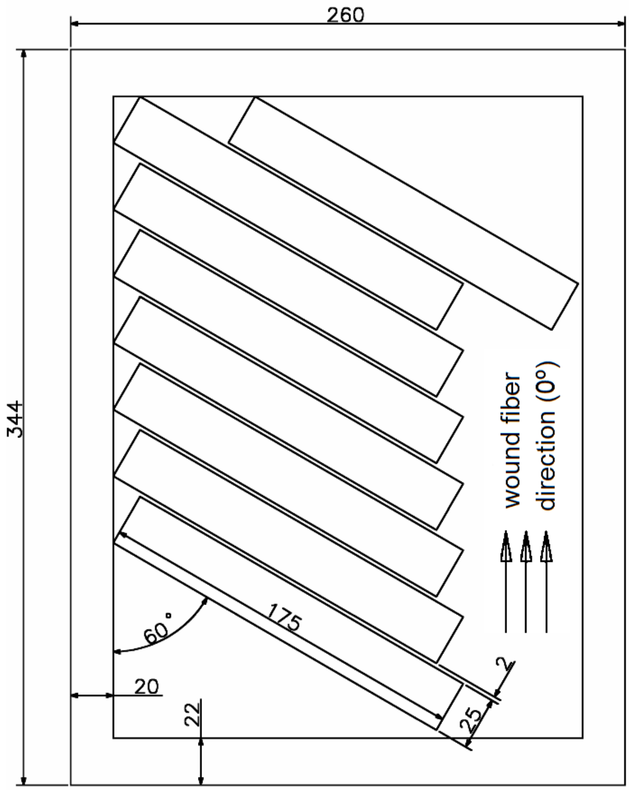
Figure 1. Composite material plate and its final dimensions

3 Results and Discussion

The strength limit of the linear behavior can be determined by isochronous curves. In the present study, these curves were plotted from the deformation values at various stress levels in equal time. Thus, for the interpretation of the graph, the behavior can be made linear in the straight section in which there is proportionality between stress and strain, while for non-linearity this behavior does not occur.



a)



b)

Figure 2. Cut sketch of the composite plate for retreating the specimens: a) 90º, b) 60º

In Figure 3 and 4 are shown isochrones curves at direction of 90° at the temperature of 70°C, respectively, with values of the direct reading of strain gages and those in which the strains were removed by thermal aging. Each curve represents the value of deformation on a fixed time, e.g 1 hour, corresponding to fractions of the creep strength, previously determined from creep graphs, [5].

There is evidence that the stress up to 40% of the stress rupture (σ_{rupt}) the composite shows a linear behavior. Above this value there is the slope of isochronous curves which shows a nonlinear behavior. So the transition from the linear to nonlinear seems to occur for stress between 40 and 50% of stress rupture

In Figures 5 and 6 are shown isochrones curves of the composite at direction of 60° and temperature of 70°C, respectively with values of the direct reading of the strain gages and those in which the strains were removed by thermal aging, included the stress values of 37.3 MPa (54% σ_{rupt}) who presented rupture. Can be verified by linear approximation curve at time of 1h, that there was a linear behavior up to 35% of the stress rupture, reducing to 30% of the stress rupture considering the time-dependent deformation, the curves starting at 100h. Thus, at a temperature of 70°C, the nonlinear behavior of the off-axis composite for angle of 60° begins with the fractional stress slightly lower than those at the direction of 90º.

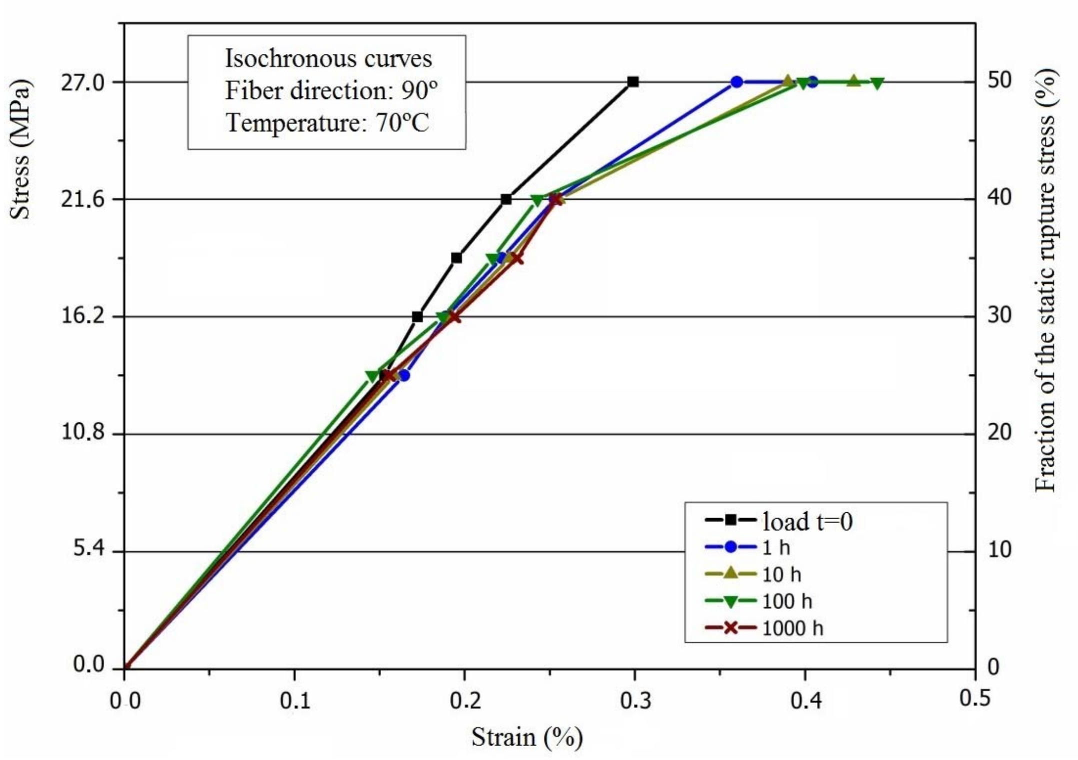


Figure 3. Isochronous curves of the creep tests for specimens at the direction of 90º and temperature of 70ºC

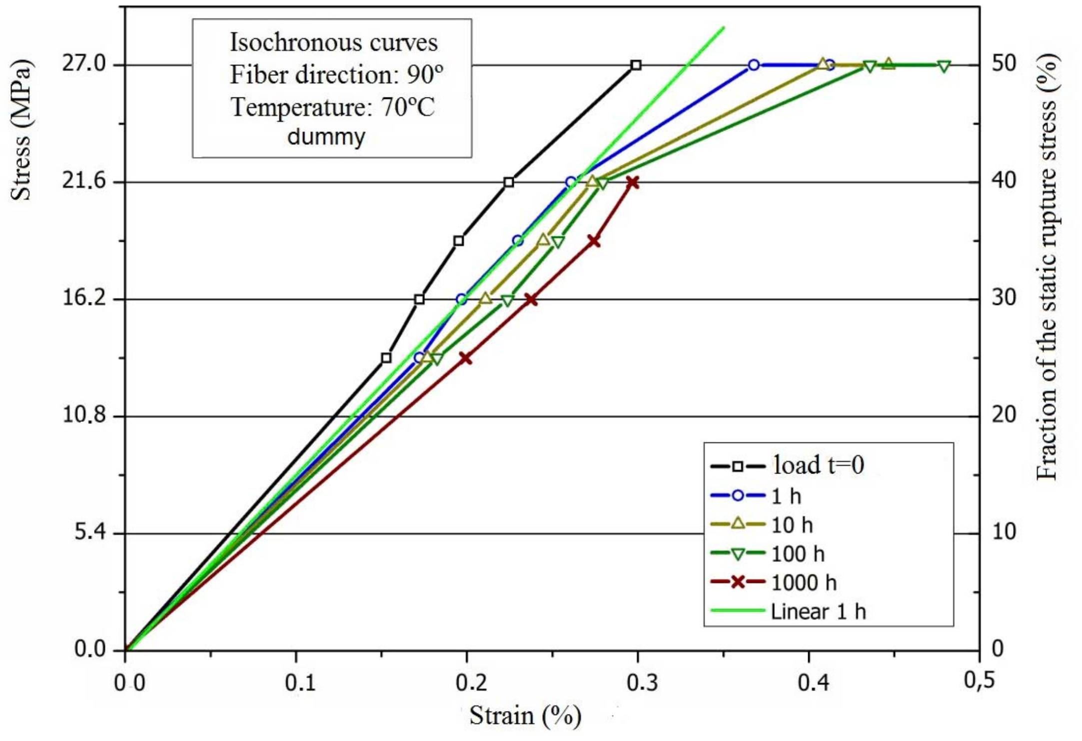


Figure 4. Isochronous curves of the modified creep tests for dummy specimens at the direction of 90º and temperature of 70ºC

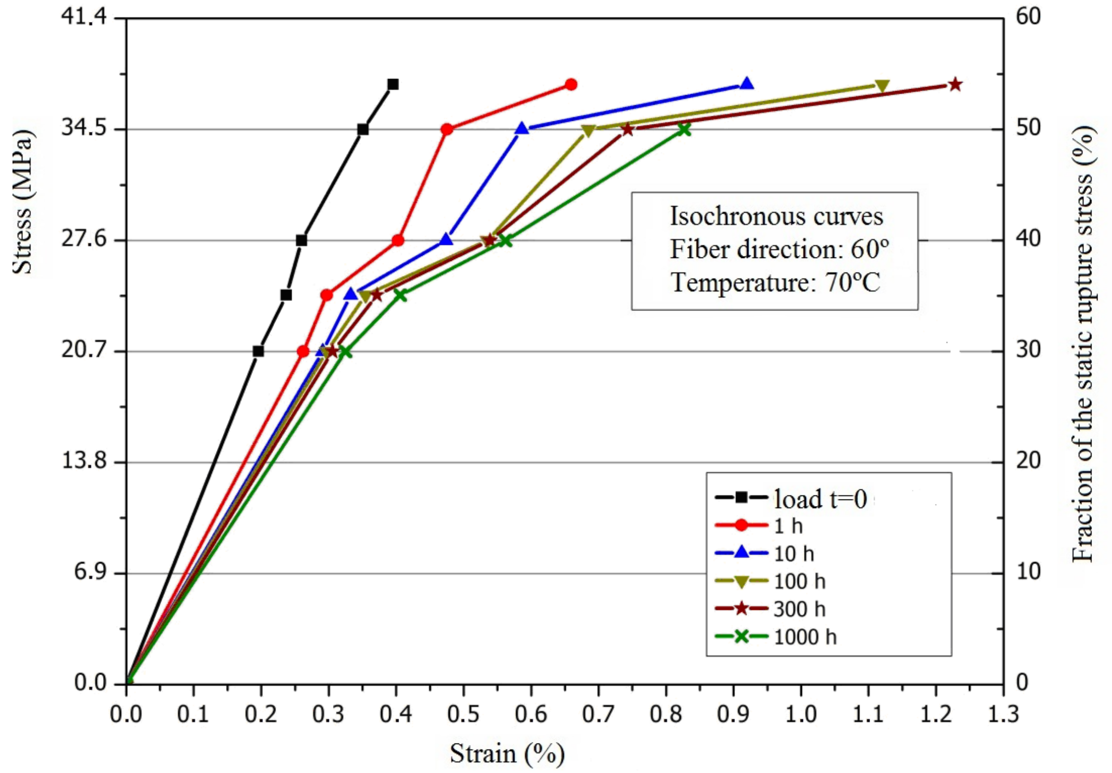


Figure 5. Isochronous curves of the creep tests for specimens at the direction of 60º and temperature of 70ºC

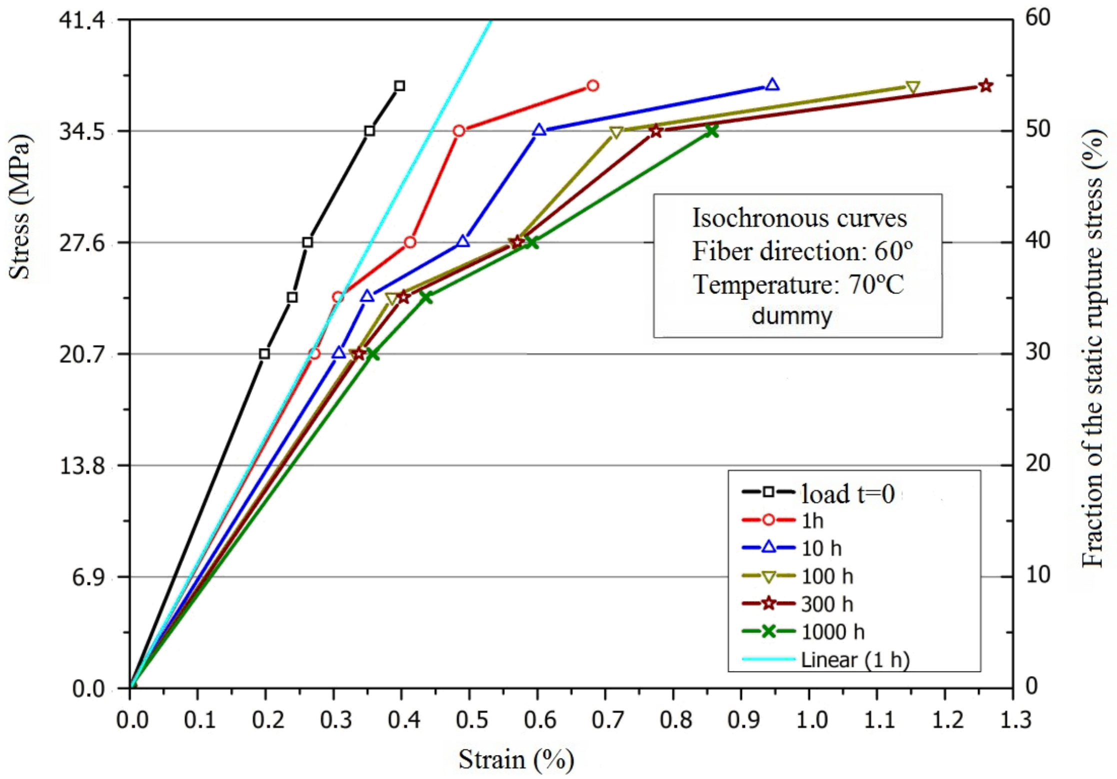


Figure 6. Isochronous curves of the modified creep tests for dummy specimens at the direction of 60º and temperature of 70ºC

The change of the linear behavior to non linear was not modified with the subtraction of the values of the deformations by the thermal aging for the two orientations at the temperature of 70°C. Comparing the isochrones curves at 90° (Figures 3 and 4), occurred a separation and a deviation of the curves, as expected for viscoelastic materials, due to the modification of the shape of some of the creep curves. For a composite at 60º, shown in Figures 5 and 6, there was only an increase in the absolute values of deformation without changing the arrangement of the curves.

In Figure. 7 are shown the isochronous curves of the composite at the direction of 90° at the temperature of 25°C, included the values of 37.5 MPa (60% σ_{rupt}) who presented rupture. It is observed a linear behavior until the stress that corresponds of 57.5% of the rupture stress, verified by the analysis of the linear approximation curve of the deformation at 1h. The nonlinear behavior can be considered as occurred only in a narrow range above 57.5% of stress rupture, because for the tension that corresponds to 60% of the value of the rupture stress, the material presented creep rupture at 202.91h.

In Figure 8 are shown the isochronous curves of the composite at the direction of 60° at the temperature of 25°C, with a nonlinear behavior above 40% of the stress rupture verified by the analysis of the linear approximation curve of the deformation at 1h. In these curves are shown the values of the tests at stress of 60.4 and 63.6 MPa, respectively 75% and 79% of stress rupture, even these presented rupture at 688.88h and 74.05h, respectively.

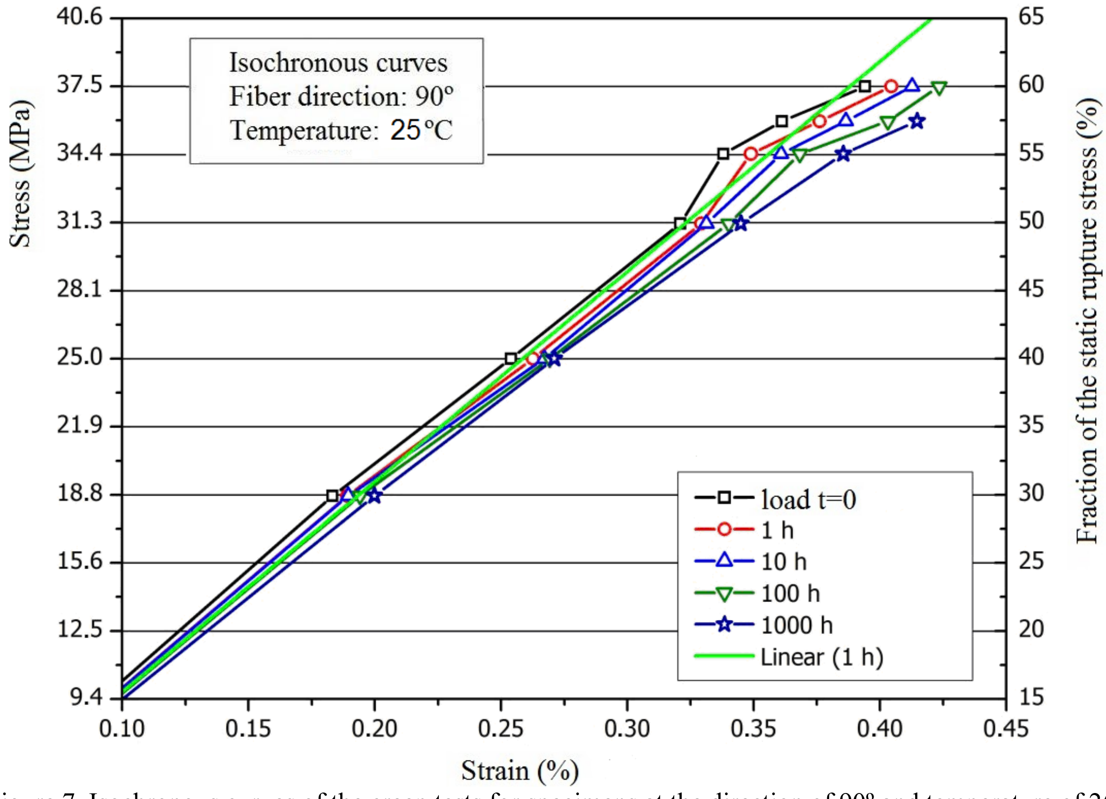


Figure 7. Isochronous curves of the creep tests for specimens at the direction of 90º and temperature of 25ºC

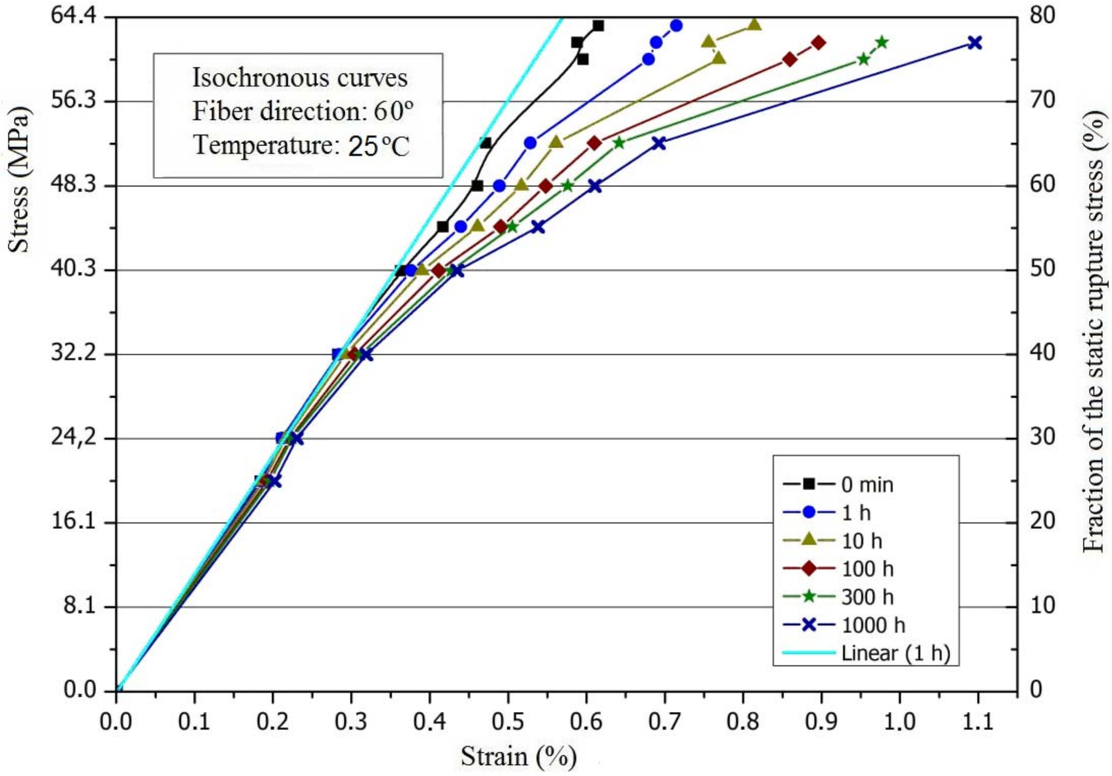


Figure 8. Isochronous curves of the creep tests for specimens at the direction of 60º and temperature of 25ºC

Conclusion

With the isochronic curves, it was found that the increase in temperature influenced on the behavior of the composite of the present study reducing the stress values of the transition from a linear non-linear, when considering composites with the same orientation with respect both to the absolute stress and in relation to the fraction of the static stress rupture (σ_{rupt}).

For composites at the direction of 90° at the temperature of 25°C the transition occurred for stress values above 34.4 MPa, that corresponds of 55% of the rupture stress (σ_{rup}), while at the temperature of 70°C the transition occurred above 21.6 MPa, that corresponds of the 40% of the σ_{rupt}. For composites at the direction of 60º, to the same temperatures, the transitions occurred respectively to stress greater than 32.2 MPa (40 % of σ_{rupt}), and about 24.15 MPa (35% of σ_{rupt}).

Acknowledgement

The authors thank to Fundação de Amparo à Pesquisa do Estado de São Paulo– FAPESP for the financial support, according to the process 07/50969-7, and to Brazilian Navy Technological Center in São Paulo.

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