Creep analysis of a GRP cylinder under hydrostatic test

Análise de fluência de um cilindro GRP sob teste hidrostático

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ABSTRACT
The GRP (Glass Reinforced Polymer) has been widely used in several industrial applications mainly due to its low cost, high availability, and easy manufacturing process. The matrix made by a combination of glass fibers and epoxy offers good engineering properties for the composite material. This study aims to investigate the creep behavior of a glass fiber/epoxy composite cylinder when it was subjected to hydrostatic pressure at room temperature, and when heated at 50ºC. The geometrical viscoelastic deformation was identified by processing signal data positioned on the cylinder surface. Then, electronic data processing was performed to obtain the characteristic of the creep phase phenomenon attributed to this polymeric composite. The cylindrical specimen has been manufactured using a 4-axis CNC (Computer Numeric Control) filament winding machine, which is equipment designed to produce cylindrical components in the composite industry. A creep test was performed by submitting the cylinder to a hydrostatic load for 500 hours, with a controlled injection of fluid up to a 50 bar pressure. Moreover, fiber volume fraction and composite density were determined to control de manufacturing parameters. The results showed that the glass transition temperature of the composite was 120°C. This also indicated a high level of reliability in the manufacturing parameters of the composite specimen. In the experiment carried out at 50ºC, the polymer matrix showed a loss of stiffness, which contributed to increased strain levels in the composite material. The structure did not show a significant creep effect after 500 hours, ensuring good dimensional and structural stability from the cylinder. Once the creep test finished, the cylinder was submitted to increase the pressure level to rupture. The microstructure was also evaluated using scanning electron microscopy (SEM). The SEM analyses presented a good agreement with the filament winding manufacturing parameters and showed the excellent quality of impregnation between glass fiber and epoxy resin

applied on the cylinder specimen. The images presented evidence of an excellent adhesion of the fiber into the matrix, contributing to a good performance of the composite.

Keywords: Creep, glass fiber, filament winding, polymeric composite.

RESUMO
O GRP (Glass Reinforced Polymer) tem sido amplamente utilizado em várias aplicações industriais, principalmente devido ao seu baixo custo, alta disponibilidade e fácil processo de fabrico. A matriz feita por uma combinação de fibras de vidro e epóxi oferece boas propriedades de engenharia para o material composto. Este estudo visa investigar o comportamento de fluência de um cilindro de fibra de vidro/composto epoxídico quando submetido a pressão hidrostática à temperatura ambiente, e quando aquecido a 50ºC. A deformação viscoelástica geométrica foi identificada pelo processamento de dados de sinal posicionados na superfície do cilindro. Depois, o processamento electrónico de dados foi realizado para obter a característica do fenómeno da fase de fluência atribuída a este compósito polimérico. A amostra cilíndrica foi fabricada utilizando uma máquina enroladora de filamentos CNC (Controlo Numérico Computadorizado) de 4 eixos, que é um equipamento concebido para produzir componentes cilíndricos na indústria do compósito. Foi realizado um teste de fluência submetendo o cilindro a uma carga hidrostática durante 500 horas, com uma injecção controlada de fluido até uma pressão de 50 bar. Além disso, a fracção de volume da fibra e a densidade do compósito foram determinadas para controlar os parâmetros de fabrico. Os resultados mostraram que a temperatura de transição vítrea do compósito era de 120°C. Isto também indicou um elevado nível de fiabilidade nos parâmetros de fabrico da amostra composta. Na experiência realizada a 50ºC, a matriz polimérica mostrou uma perda de rigidez, o que contribuiu para o aumento dos níveis de tensão no material compósito. A estrutura não mostrou um efeito de fluência significativo após 500 horas, garantindo uma boa estabilidade dimensional e estrutural a partir do cilindro. Uma vez terminado o ensaio de fluência, o cilindro foi submetido a aumentar o nível de pressão até à sua ruptura. A microestrutura foi também avaliada utilizando microscopia electrónica de varrimento (SEM). As análises SEM apresentaram uma boa concordância com os parâmetros de fabrico do enrolamento do filamento e mostraram a excelente qualidade da impregnação entre fibra de vidro e resina epoxi aplicada sobre a amostra do cilindro. As imagens apresentaram provas de uma excelente adesão da fibra à matriz, contribuindo para um bom desempenho do compósito.

Palavras-chave: Creep, fibra de vidro, enrolamento do filamento, compósito polimérico.

1 INTRODUCTION

The current engineering composites have shown great potential for use in a variety of materials such as carb, glass, basalt, and many other combinations and varieties of fibers. Those applications cover almost all industry segments including the nuclear field. In several industrial applications, carbon fiber and glass fiber have been very widespread. Furthermore, glass fiber presents itself as a less expensive and better alternative due to its increased availability and easy manufacturing process, especially in emerging countries. The matrix made by a combination of glass fibers and epoxy usually offers excellent engineering properties for the composite material.

Moreover, it may increase the application possibilities of fiberglass as reinforcement inside of the structural engineering components of polymeric composites.

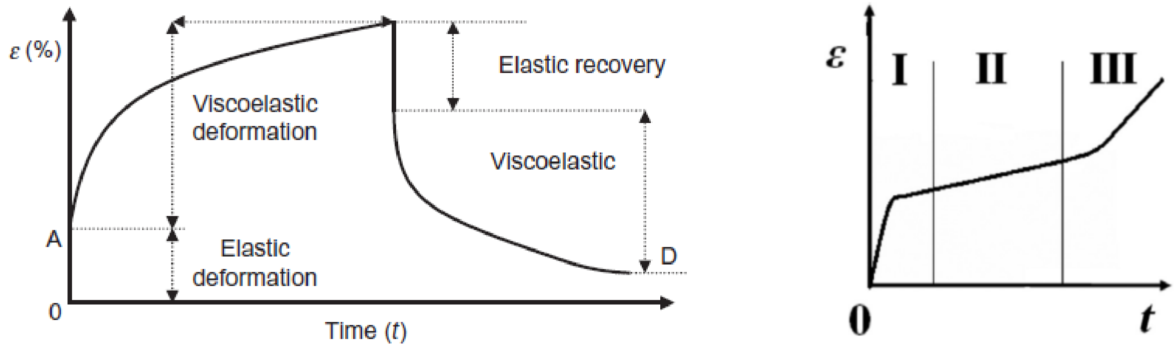
This study investigates the creep behavior of a GRP (Glass Reinforced Polymer) composite cylinder when subjected to hydrostatic pressure at room temperature and when heated at 50ºC. The geometrical viscoelastic deformation was identified by processing signal data positioned at the cylinder surface. Then, electronic data processing was performed to obtain the characteristic of the creep phase phenomenon attributed to this polymeric composite.

2 METHODOLOGY

According to Guedes, (2019) [1] creep is defined as “the phenomenon in which materials under the influence of a constant mechanical load at constant temperature and humidity showed an increase in deformation over time”. Conversely, the phenomenon called recovery is observed with the instant removal of the constant mechanical load and a time-dependent reduction in deformation occurs. A graphical representation of both phenomena is shown in Figure 1a [1].

Figure 1 - a) Strain vs. time curve showing the creep and creep-recovery phenomena [1], b) Creep stages curve [2]

a) b)



As described by Papanicolaou and Zaoutsos, (2019) [2] in many experienced tests, creep can be observed in three stages: primary, secondary, and tertiary. In the first stage, the material undergoes deformation at a decreasing rate, in the second it proceeds at a nearly constant rate. In the last stage (third or tertiary stage), the creep phenomena occur at an increasing rate finishing with fracture of material as shown in Figure 1b.

The cylindrical specimen was manufactured using a 4-axis CNC (Computer Numeric Control) filament winding machine which controls rotation and translation movements of the machine axes. The winding angles were 90º and 30º. This type of equipment is widely used for the large production of components with cylindrical and spherical geometric profiles by the composite industry.

The creep test was carried out at room temperature in a reinforced fiberglass cylinder, with a duration of 500 hours. The cylindrical specimen was subjected to a hydrostatic load, with a controlled injection of a fluid inside it, until the constant pressure defined at 50 bar was reached. Data was collected through the installation of strain sensors (strain gauges) fixed by adhesive at pre-defined points on the cylinder surface so that it was possible to obtain circumferential strain measurements and longitudinal on the surface of the cylindrical specimen.

Moreover, the fraction volume test and density determination test of this composite material were performed. Those tests aimed to identify the constituent content and to follow physical changes in the density of this composite. They also help evaluate the quality of fabricated material and assess the processes used during the manufacturing model. The void volume of a composite material may significantly affect some of its composite properties (mechanical, physical, thermal, or electrical).

The analytical evaluation must be done to provide some critical characteristics affected by the reinforcement or matrix. The density determination test is conveniently measured to identify a material, indicate the degree of uniformity among different specimens, or present the average density of a large item. Both tests were carried out according to standard methods [3,4]. Additionally, the differential scanning calorimetry (DSC) test was performed to determine the transition temperature of the GRP composite and was carried out following the standard method [5].

Additionally, the scanning electron microscopy (SEM) method that produces images of a sample observed in a high vacuum by scanning the selected surface with a focused beam Of Electrons [6] Was performed. The SEM allowed measurement and analysis at the nanometer scale in the GRP filament sample cut from the radial peripherical region of the composite cylinder.

3 RESULTS AND DISCUSSION

The performed DSC test results show the transition temperature of the GRP composite analyzed was 120 ºC as the results were carried out according to the standard method [5]. This result can also indicate a high level of reliability in the manufacturing parameters of these composites.

Instead of the fact that the comparison of the results in different studies does not use the same supplier or sample, the results were presented generally in agreement. The Table 1 shows a comparison of results of the volume fraction with the results from studies of Abdalla, (2008) [7].

The cylindrical composite fiber volume fraction found was 55% and the density was 1.96 g.cm^{-3} [4]. That result indicates that the volume fraction was 7.4% above of reference, as shown in Table 1. Thus, it may indicate better mechanical properties can be performed in this composite. This fact can be attributed to the enhanced manufacturing process used during the production of the cylindrical specimen tested in this work.

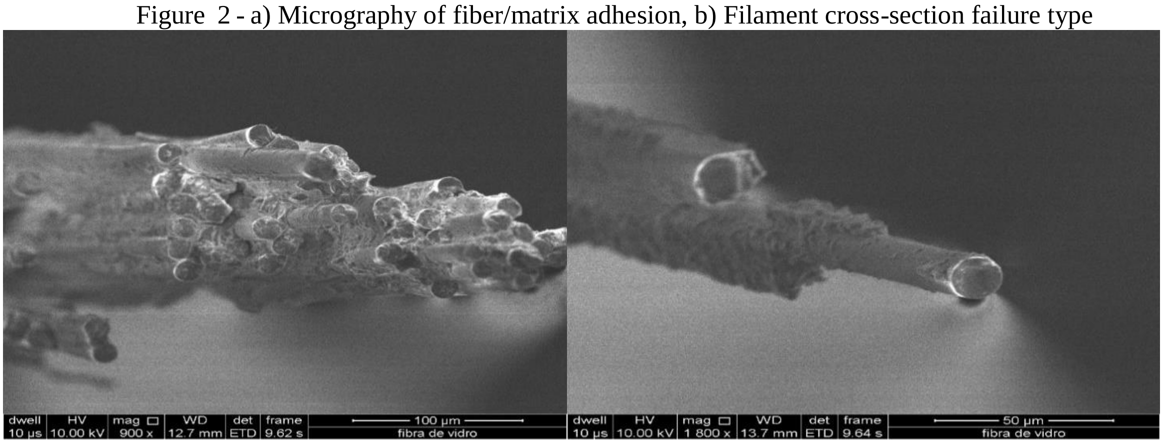
Table 1 - Volume ratio comparison between the present study and literature [7]

Fiber Composite	Specific mass (g.cm^{-3})	Fiber ratio in volume v_f (%)	Matrix ratio in volume v_m (%)	Voids volume v_v (%)	m_f (%)	m_m (%)
Present study	**1.96**	**55.0**	**44.0**	**1.0**	**73.0**	**27.0**
Literature [7]	2.00	47.6	52.4	*	62.28	37.72

The SEM analyses were performed to analyze the quality of impregnation into composite polymeric. The main feature of the impregnation of glass fibers into the epoxy resin may be attributed to specific parameters of the filament winding manufacturing process.

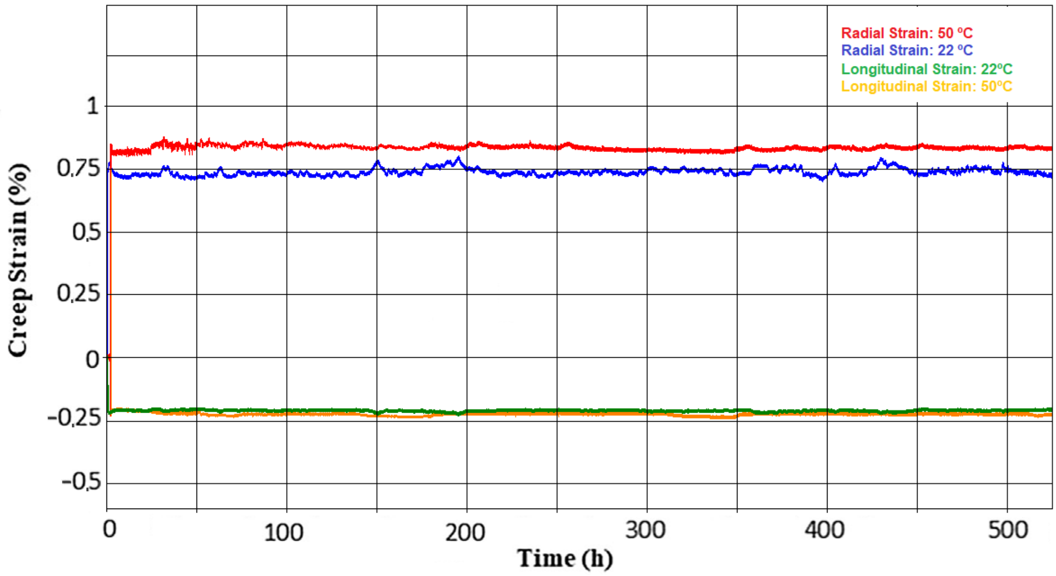
As presented in Figure 2a SEM analysis of a sample of composite removed from the radial region of the cylinder presenting various filament of glass fiber jointed in a good quality of impregnation that may indicate certain parameters applied during filament winding manufacture process. It also showed uniformity of the type of fiber cross-sections promoted by high radial tensile level through rupture test on the cylinder. Figure 2b showed a view of the type of failure of the filament with a 90º winding angle. It also showed fiber-matrix adhered on the fiber surface followed by perpendicular breakage direction of the fiber filament.

Figure 2 - a) Micrography of fiber/matrix adhesion, b) Filament cross-section failure type



The creep strain test shows a higher initial level in the radial direction (stress) around four times higher than creep strain measured in the longitudinal direction (compression). When the cylinder specimen was subjected to heat at 50ºC the creep strain gets increased in radial and longitudinal directions. This fact suggests that the final creep strain increases when subjected to the temperature at the same pressure levels.

Figure 3 - Creep strain curves of cylindrical composites



4 CONCLUSIONS

Despite fiber layers' presence in the radial direction (90º layers), the results showed strain levels associated with E-glass fiber's low elasticity modulus, regardless of allowing high pressures due to their high strength properties. In the test with a temperature of 50ºC, the polymer matrix showed a loss of stiffness, which contributed to increased strain levels in the composite material.

The SEM analyses presents good agreement with the filament winding manufacturing parameters and showed the excellent quality of impregnation between glass fiber and epoxy resin applied on the cylinder specimen. Also, showed uniformity of the type of fiber cross-sections promoted by high radial tensile level through rupture test on the cylinder.

The structure did not show a significant creep effect after 500 hours, ensuring good dimensional and structural stability from the cylinder. For the total time measured in the experiment, there were no significant creep behavior indications in this composite for the specific fiber layer configuration applied.

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