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Relaxation and Compressive Characteristic in Composite Glass Fiber reinforced Pipes

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Abstract— Pipes made from glass fiber reinforced polymer (GRP) have a competitive role in the petroleum industry. The need for evaluating the mechanical behavior of (GRP) pipes is an essential object. Compression and stress relaxation tests are preformed to obtain the main effective mechanical properties of petroleum pips. Experimental results showed that stress relaxation illustrates how polymers relieve stress under constant strain. Static relaxation test is carried out at room temperature. The material shows a poor static relaxation strength with two loading cycles which have been observed for the tested specimen. However, the compressive strength measured in radial direction of curved wall of composite is better than that measure through hoop direction.

Index Terms—GRP; Sandwich composite material; Static relaxation; Stress relief, compressive strength, glass fiber,

1 Introduction

The importance of studying the viscoelastic behavior of composite materials is well recognized, as more and more composites are being used as structural materials. Viscoelastic properties of composites with polymeric constituents are also temperature dependent. This behavior's manifests itself in different ways, including creep under constant load, stress relaxation under constant strain and damping dynamic response, etc. [1].

Tong et al. [1] investigated experimentally the relaxation of composites laminates as well as the decay of relaxation at different initial stress. It was concluded that relaxation of a composite material increases with increasing the initial stress.

Masuko and Kawai [2] studied the relaxation characteristic as a function of strain rates and fiber direction of cured unidirectional carbon/epoxy composites. They carried out experimental procedures at an elevated temperature (100 oC) with different strain rates. It was found that high strain rate has a significant effect on the stress relaxation behavior of angle-ply laminates.

Oskouei and Taleie [3] proved that not only resin in composite material is a primary source of the viscoelastic nature of laminates, but also reinforcing phase is an important factor in relaxation induced in this type of material.

Mohammed et al. [4-7] investigated the fracture properties of Viscoelastic composites laminates in static case but did not discuss the relaxation case.

Lee et. al [8] investigated relaxation of thin-film aluminum beams using a piezoelectric-actuated mechanical tester, The results show that the relaxation strength and relaxation time change markedly with a decreasing grain size.

Kalkman et al. [9] suggested that significant stress relaxation during testing in the free-standing materials causes the smaller Young's moduli of the freestanding films. By using a dynamic bulge testing technique, they demonstrated that the Young's moduli for various metals (in the form of free-standing thin films) are close to their bulk values at a high-modulation frequency but dropped by more than 20% at a lower modulation frequency [9].

Other workers [10-12] studied the behaviors of relaxation stress in different materials, they give good reports about the failure occurred at such serous stress.

The novelty of the present study is to obtain the relaxation behavior patterns and the compressive strength of such material which is commonly used in the petroleum field where hard environmental ground, bad humidity, high moisture content and increasing temperature in summer are exist.

2. Stress Relaxation

Stress relaxation describes how polymers relieve stress under constant strain. Because they are viscoelastic, polymers behave in a nonlinear, non-Hookean fashion.[13] This nonlinearity is described by both stress relaxation and a phenomenon known as creep, which describes how polymers strain under constant stress. Viscoelastic materials have the properties of both viscous and elastic materials and can be modeled by combining elements that represent these characteristics. One viscoelastic model, called the Maxwell model predicts behavior akin to a spring (elastic element) being in series with a dashpot (viscous element), while the Voigt model places these elements in parallel. Although the Maxwell model is good at predicting stress relaxation, it is fairly poor at predicting creep. On the other

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hand, the Voigt model is good at predicting creep but rather poor at predicting stress relaxation. The following image shows the response of a Standard Linear Solid material to a constant stress (σ_o) , over time (t_o) from to a later time (t_f). For times greater than the load (t_f) is removed. The curvature of the model represent the effects of both creep and stress relaxation.

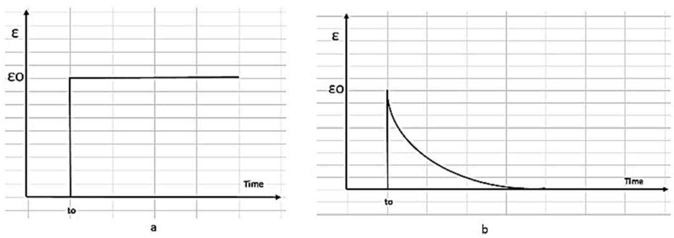

Fig. 1 relaxation as functions of time for a viscoelastic material a) Applied strain and b) induced stress [13]

3 Experimental Work

3.1 Material and methods

The present study used glass fiber reinforced polymer pipes of heterogeneous structure and it are consists of roving, random matt, polyester resin and sand according to the values displayed on Table 1. These constituent compositions are obtained using ignition removal technique according to ASTM D3171-99 standard [14]. These types of pipe are used in pipeline of chemical waste water used in petroleum field. They have composition shown in Fig. 2 and Table 1. The grains of the quartz sand have randomly shapes, the quartz and glass fiber are shown in Fig.1. The pipes serves in industry as shown in Fig. 3.

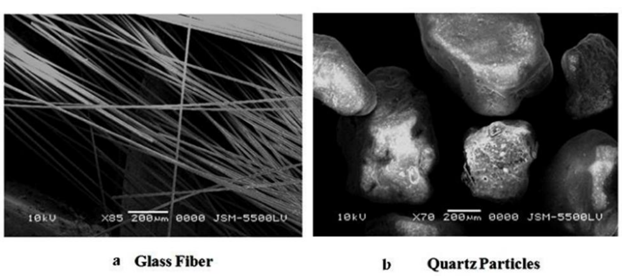

Fig. 2 Composition of glass fiber reinforced pipes

Fig. 3 In-service Waste Petroleum GRP [15]

Table 1 Composition of GFR pipes

constituents	Average %
Thermosetting polyester (Matrix)	30.2%
Roving	11.8
matt	13.5
sand	44.5

3.2 Relaxation Characteristic

.The relaxation test of GRP material carried out manually according to ISO 6914 [16]. A stander tensile test specimens of 8 mm width, 13 mm thickness and gage length 210 mm are loaded to 35% of failure load which measured from tension test specimen. The load reduction with time is taken each 1 minutes using stop wash. The test continued until load was stable and reduction stopped. Then the specimen is loaded again and repeated the pervious sequences till failure occurred. The mode of failure for the test optically observed. Total number of used specimen for this test is five [17]. Fig 4 show test set up.

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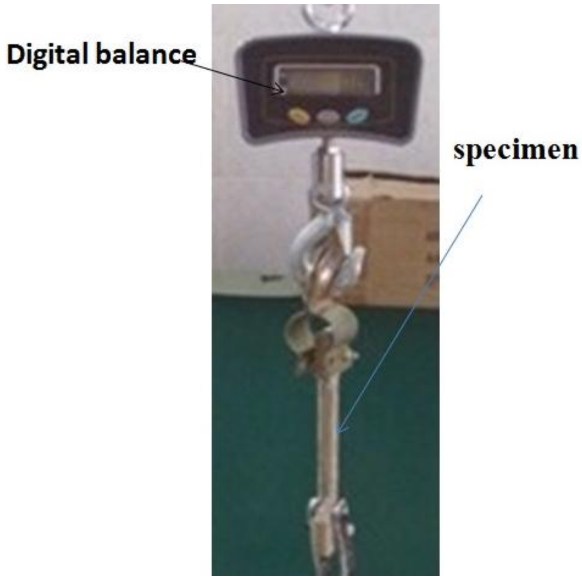

Fig. 4 Manual relaxation set up

3.3 Compression test

Compression tests were carried out on glass fiber composite petroleum pip specimens according to ASTM D695-91 [18] through both radial and hoop directions of curved wall of the pips as shown in Fig. 5. The compression test is performed on a universal testing machine with dry conditions without lubricant. The tests were carried out using a strain control protocol where the machine cross head velocity is controlled at 2mm / min. the compression specimen is short of length equal width.

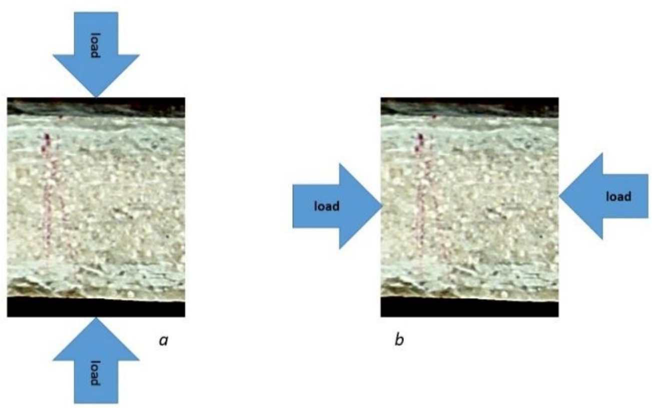

Fig.5 compressive loading through specimen a) radial b) hoop

3.4 Results and Discussion

Fig. 6 shows relation between the relaxation stress and time. The material life under relation test was nearly 1.23 hr. Tow cycle of loading was carried out and continued until material failure occurred. The material response is linear up to a constant stress, σ_0., refer to Fig. 7. The curvature of the model represents the effects of stress relaxation. The relaxation stress in composite martial based polymer depends mainly on magnitude of selected initial loading, temperature and loading speed. The low relaxation properties of GRP may be attributed to the high brittle nature of the quartz particles. Non-homogeneity of manual starting loading system seems to have an effect on the relaxation behavior of GRP. For fiber reinforced composite with multiple layers, the strain rate and the extent of applied strain affect the interfacial stress transfer between fibers and matrix resin and thereby their mechanical properties [1]. Partial interfacial failure and rearrangement of fibers is one of the most important relaxation mechanisms for fiber-reinforced composites. The number of cycle increases with decreasing the upper starting relaxation stress as shown in both Figs. 7 and 8. At a certain stress level the fiber rearrangement during the application of stress would lead to a partial internal failure of the composite. The failure mode of GRP laminates was pure tension as illustrated in Fig. 9.The compression stress strain relation is shown in Fig. 10 for both radial and hoop directions. It is clear that radial strength is much greater than that in the hoop direction, which may be attributed to that loading through radial direction creates a normal stress over quartz particles which are stronger in such condition, while loading through hoop direction of the curves specimen, make quartz particles to push out through glass fiber epoxy layer leading to delamination between sandwich layers and the sand particle as illustrated in failure modes Fig.11. Another important observation is that the failure strain in radially loaded specimen is higher than those loaded through circumference. This can be attributed to the brittle behavior and bearing strength of quartz sand particle.

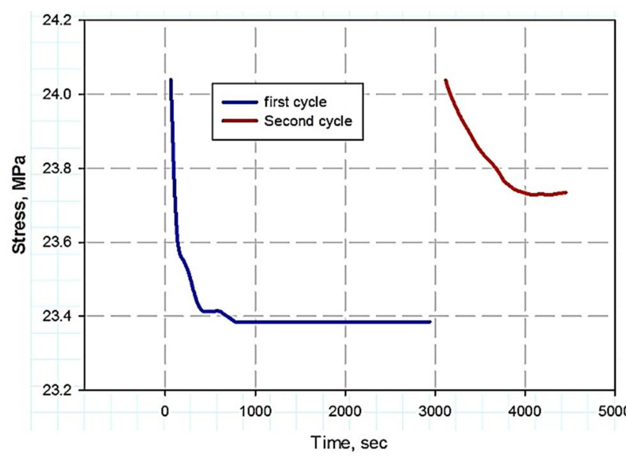

Fig.6 Relaxation stress and time relation for glass fiber reinforced pipes (2cycles upper stress 24 MPa)

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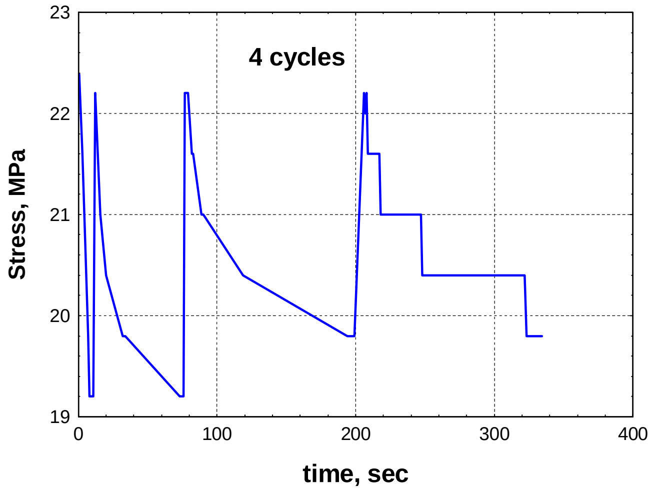

Fig.7 Relaxation stress and time relation for glass fiber reinforced pipes (4 cycles upper limit 22.3)

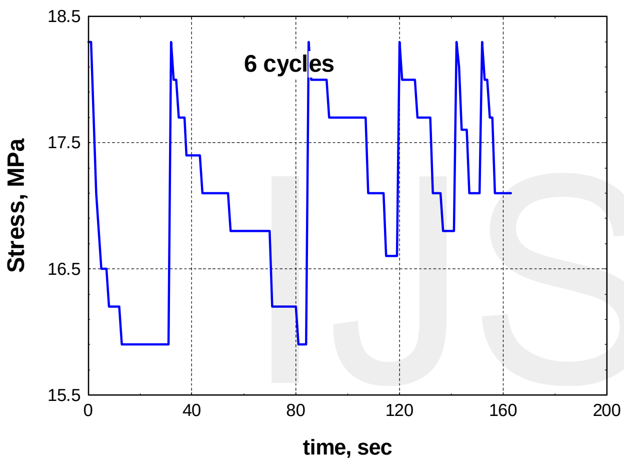

Fig.8 Relaxation stress and time relation for glass fiber reinforced pipes (4 cycles upper limit 18)

Fig. 9 Mode of failure in relaxation specimen

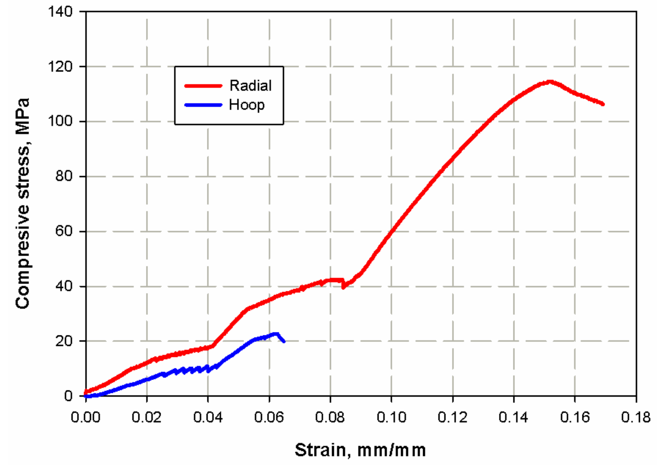

Fig. 11 Compressive stress verse strain relation

4 Conclusion

The relaxation behavior of glass fiber reinforced pipes is limited. It is mainly depended on the selecting of the initial loading. The quartz content leads to an increase of brittleness of the material which lead to a decrease in material strength. The interfacial bonding between glass fiber layers and quartz particles initiates an internal crack which lead to failure in subsequent loading stages. Pure tension failure mode is observed for this type of materials. The compressive behavior of quartz particle in the radial direction is much higher than those loaded in the circumference direction.

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