Viscous Nature of a Polypropylene Composite Used in Subsea Pipe as Insulator

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Abstract: The strain dependency of the stress-strain curve of a composite polypropylene used for subsea pipe insulation was investigated. The polypropylene samples for testing were obtained from an insulated pipe that was used as deep water flowline. Variation of the yield stress σ_y varied with the strain rate $\dot{\varepsilon}$ was quantified. The ductility variation with the test strain rate was also investigated.

1.Introduction

Many materials of practical interest appear to behave in a markedly viscoelastic manner over a certain range of stresses and times (Holzapfel, 2002). Polypropylene, the material of interest in this study, is a thermoplastic polymer which has a viscous behavior at large strain. The elasticity of some polymers over a large strain domain, hyperelasticity, is well established, from Mooney (1940) to Arruda and Boyce (1993). Viscoelastic response is often used as a probe in polymer science, since it is sensitive to the material chemistry and microstructure (Roylance, 2001). And the dependence of yield stress on strain rate provides evidence of the nature of viscosity law (Haward & Thackray, 1968).

In this study, the viscous behavior of the thermoplastic polymer tensile test at variable strain rates was investigated.

2. Objective

The objective of this study was to investigate the viscoelastic behavior of polypropylene used for subsea pipe insulation at low strain rate and its effect on the material failure; transition from ductile to brittle behavior.

3. Testing

The selected composite was a part of a five layers insulation. The tensile testing of the polypropylene coupons were performed following ASTM D638-03 at room temperature (ASTM, 2003). The tests were displacement control and the strain rates calculated are the average of the strain read from the strain gage divided by the duration of the test. The tests strain rate ranged from 0.1%/min to 8.9%/min, as summarized in Table 1.

Table 1: Strain rate of test vs yield stress.

σ_y (ksi)	1900	2000	2000	2200	2400
$\dot{\varepsilon}$ (%/min)	0.1	0.2	0.3	1.8	8.6

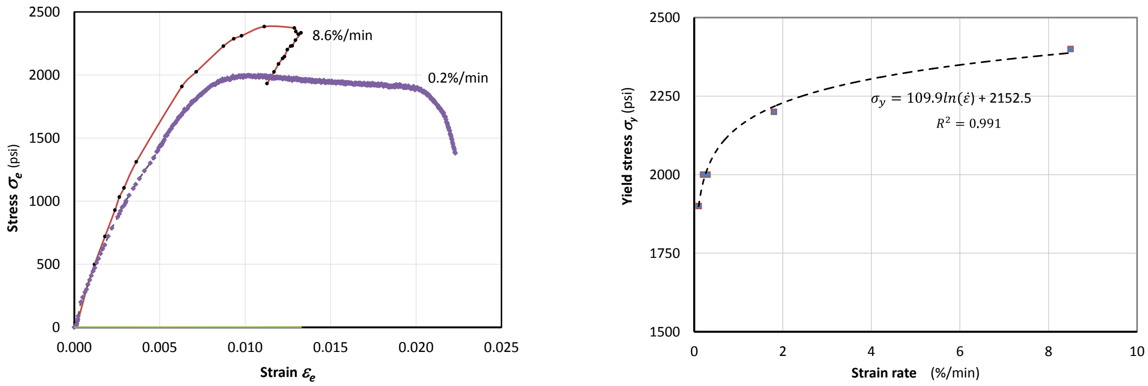
4. Result and Discussion

As shown in Fig. 1 (a.) the stress-strain relationship varied with the strain rate of testing with variation of the yield stress and of the ductility. With the tests strain rates at 8.9%/min and 0.1%/min, the yield stress varied from 2400 psi (16.5 MPa) to 2000 psi (13.8 MPa), or 20% increase. The variation was more pronounced with the ductility. At high rate the polypropylene is brittle with the yield strain ε_y equal to the rupture strain ε_u = 0.013, making the ductility μ equal to 1. At low strain rate of testing, 0.2%/min, the polymer had a ductility of 2 with ε_y = 0.01 and ε_u = 0.02. It is to be noted that the polymer showed no hardening behavior presenting an elasto perfectly plastic behavior up to fracture. The tested polypropylene is viscous.

Fig. 1. (b.) shows the variation of the yield stress with the strain rate as natural logarithmic function,

$$\sigma_y = 109.9\ln(\dot{\varepsilon}) + 2152.5 \ \ (psi) \qquad (1)$$

At low strain rate, up to 0.3%/min, the material viscous characteristic is negligible and has no effect on the yield stress, see Table 1. This justified the constant 2152.5 psi which with the small strain rate will yield about 2000 psi for yield stress, as recorded from the test.



a.) *b.)*

Fig. 1: a.) Normal stress vs. normal strain from tensile test. b.) Variation of the yield stress with the strain rate of testing.

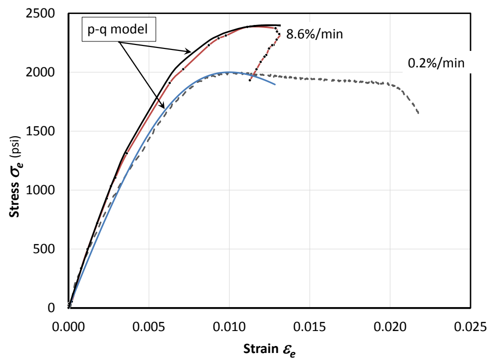


Fig. 2: p-q model fitting up to the yield point.

5. Modeling approach

The p-q model (Vipulanandian & Paul, 1990) was used to fit the curve up to the yield point.

$$\sigma_i = \sigma_y \frac{\varepsilon_i/\varepsilon_y}{(1-p-q)+q\left(\varepsilon_i/\varepsilon_y\right)+p\left(\varepsilon_i/\varepsilon_y\right)^{\frac{1-q}{p}}} \quad \text{………………….(2)}$$

The parameter p = 0.1 is constant for both cases but q = take the values of 0.32 and 0.45 successively for 0.2 and 8.6%/min strain rate, (Fig. 2).

6. Conclusion

The layer of polypropylene composite studied can characterized as viscous material. The viscous characteristic of the material was shown by the variation of the yield stress with the strain rate of testing.

7. Acknowledgements

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