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SUPERPLASTIC BEHAVIOR OF POLYVINYLIDENE FLUORIDE (PVDF) UNDER DIFFERENT TEMEPRATURES

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Abstract. *The thermomechanical behavior of Polyvinylidene fluoride (PVDF) was studied. The experiments were performed under a range of temperatures (50 ° C up to 130 ° C). The temperature greatly influences the mechanical response of PVDF. In particular, the yield stress is increased with decrease in strain rate for the lower temperatures and the ultimate tensile strength is increased at higher temperatures. Furthermore, a one-dimensional model able to of providing a physically realistic description of curve stress vs strain sensitivity observed in tensile tests with temperature that can be used in engineering problems is proposed. Just four tests were performed at different temperatures with constant speed of testing are required to identify the parameters that appear in the model. The experimental results are presented and compared to the model and show good agreement.*

Keywords: *PVDF, Tensile, Experimental, Mathematical Model, Temperature*

1. INTRODUCTION

Over the decades various materials are being discovered for various applications in engineering. Mainly in the oil industry, where the reservations findings are in deeper layers (Sousa, 2009).

One of the connection means for exploitation of wellheads and platforms are flexible risers. A tubular set composed of metallic and polymeric layers responsible for conducting the fluid. Given that the use of flexible pipe is relatively recent, since the mid-1980s, and the analysis is therefore fairly limited, there has been exponential growth in the use of flexible pipe (Reis, 2015)

The polymeric layers made possible economically extend the life of the general structure in addition to bring with it technical challenges to improve its mechanical resistance to deeper layers of the pre-salt (Hashimoto, 2013).

The Polyvinylidene fluoride (PVDF) is a thermoplastic that has been used in the layers of the flexible pipe to be due to the pressure barrier and resist the effects of temperature operating. This is a situation very common in current applications, such as Brazil's presalt offshore exploitation. Even when used as riser or flowline, the flexible pipe structure must be able to be subjected to high external pressure value with no failure (Reis, 2015).

For a better understanding the mechanical characteristics of the material in the presence of two factors presented: high temperatures and high pressures. This article focuses on development of a one-dimensional model able to describe the influence of temperature and strain rate on the mechanical behavior. The tensile tests were conducted over a wide range of temperatures (50 ° C to 130 ° C) with constant speed of testing determined by the standard ASTM 638. Tests were conducted to four different temperatures to fully identify all of the relevant experimental parameters arise in theory. Thus, with this experimental procedure, the number of tests used to evaluate the mechanical properties of PVDF is significantly reduced.

2. MATERIALS AND METHODS

2.1 Materiais

The Polyvinylidene fluoride (PVDF) barrier was obtained from the flexible pipe itself. PVDF is a specialty plastic material in the fluoropolymer family; it is used generally in applications requiring the highest purity, strength, and resistance to solvents, acids, bases and heat and low smoke generation during a fire event. Compared to other fluoropolymers, it has an easier melt process because of its relatively low melting point of around 177 °C.

According to standard ASTM 636, the tension test specimens were machined from PVDF pipe with shape and size specified. The initial gage length l_0 and initial cross section A_0 are, respectively, 33 mm and 24 mm^2 as illustrated in Fig.1.

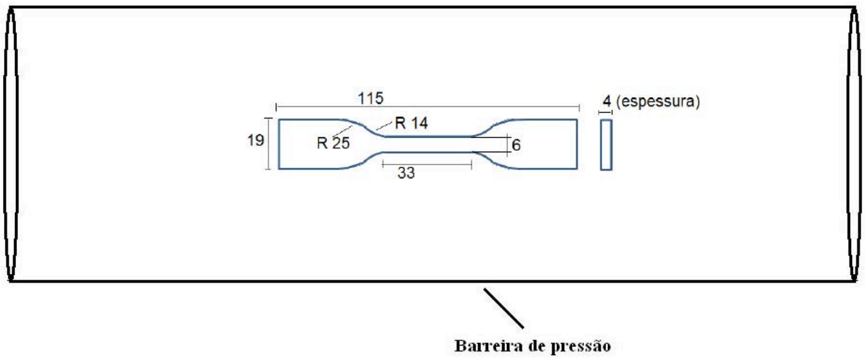

Figure 1. Tensile test specimen.

2.2 Methods

Mechanical tensile tests at different temperatures and strain rates were performed using a Shimadzu® AG-X universal testing machine at 10 t capacity with an attached thermostatic chamber and electro-mechanical sensors for the control of longitudinal strain in the active zone of the test specimens with capacity of record from -70°C until 350°C.

According to the standard, the speed of testing was 5 mm/min. Figure 2 displays the PVDF tensile test inside the thermostatic chamber.

Figure 2. PVDF tensile test

3. RESULTS AND DISCUSSION

3.1 Experiments

Considering that the specimen has an initial gauge length l_0 and an initial cross section area A_0 that is submitted to a prescribed elongation $\Delta l(t)$ and to F(t) as the experimentally measured force, the engineering stress and engineering strain can defined as follows:

$$\sigma = \frac{F(t)}{A_0} \quad ; \quad \varepsilon(t) = \frac{\Delta l(t)}{l_0} \tag{1}$$

With constant volume, the true stress and true strain can be defined as

$$\sigma_t = \sigma(1+\varepsilon) \quad ; \quad \varepsilon_t = \ln(1+\varepsilon) \tag{2}$$

Figure 3 shows the curves true stress vs. true strain to PVDF obtainable from the controlled-strain tensile tests for different temperatures.

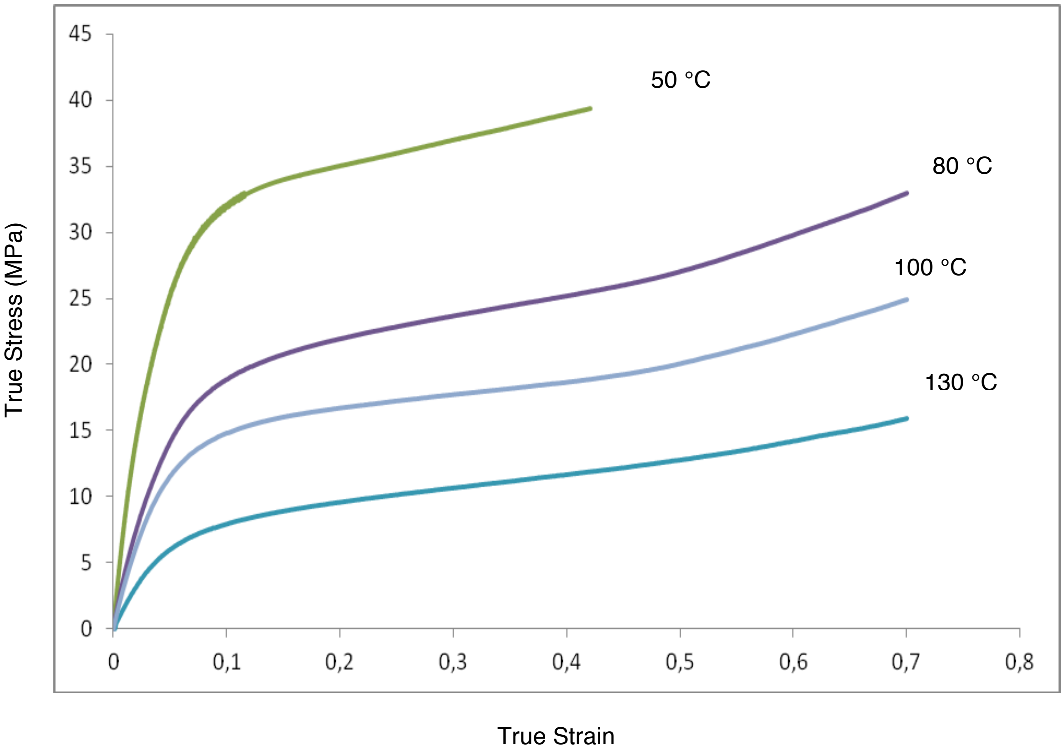

Figure 3. True stress vs. true strain curves of PVDF at different strain rates

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3.2 Model

In this section, a constitutive model for the PVDF tensile load is introduced in order to find a suitable expression modeling the mechanical behavior PVDF under tensile load performed at different temperatures, the following mathematical model is proposed,

$$\sigma = \frac{a(\theta)\varepsilon}{1+(b(\theta)\varepsilon)+(c(\theta)\varepsilon)} \tag{3}$$

The functions $a(\theta)$, $b(\theta)$ and $c(\theta)$ are defined as follows:

$$a(\theta) = a_1\theta^2 - a_2\theta + a_3 \tag{4}$$

$$b(\theta) = b_1\theta^2 + b_2\theta + b_3 \tag{5}$$

and

$$c(\theta) = c_1\theta^2 - c_2\theta - c_3 \tag{5}$$

This model is conceived for a given range of temperatures $\theta_{\min} \leq \theta \leq \theta_{\text{máx}}$. It is difficult to present a precise definition of the limiting strain rates $\theta_{\min}$ and $\theta_{\text{máx}}$. In the absence of a precise physical definition, it is suggested that a range from 50ºC to 130ºC.

3.3 Parameters identification

As mentioned in the previous section, the proposed model (see Eq. (3)), it is to find a model to represent the curves deformation strain of PVDF, which for the purpose of simplification we consider rates of up to 70% strain.

The parameters found to characterize the materials in temperatures in Tab.1. With these parameters, the theoretical and experimental curves are extremely close.

Table 1. Material parameters

a_1	a_2	a_3	b_1	b_2	b_3	c_1	c_2	c_3
0.0648	-29.956	3091.1	-0.0054	0.6976	29.467	0.0021	-0.2973	-14.25

To determine the accuracy of the model, samples of experimental results were cross-checked with the mathematical model. Figure 4 presents the experimental and theoretical true stress vs. true plastic strain curves for different strain rates.

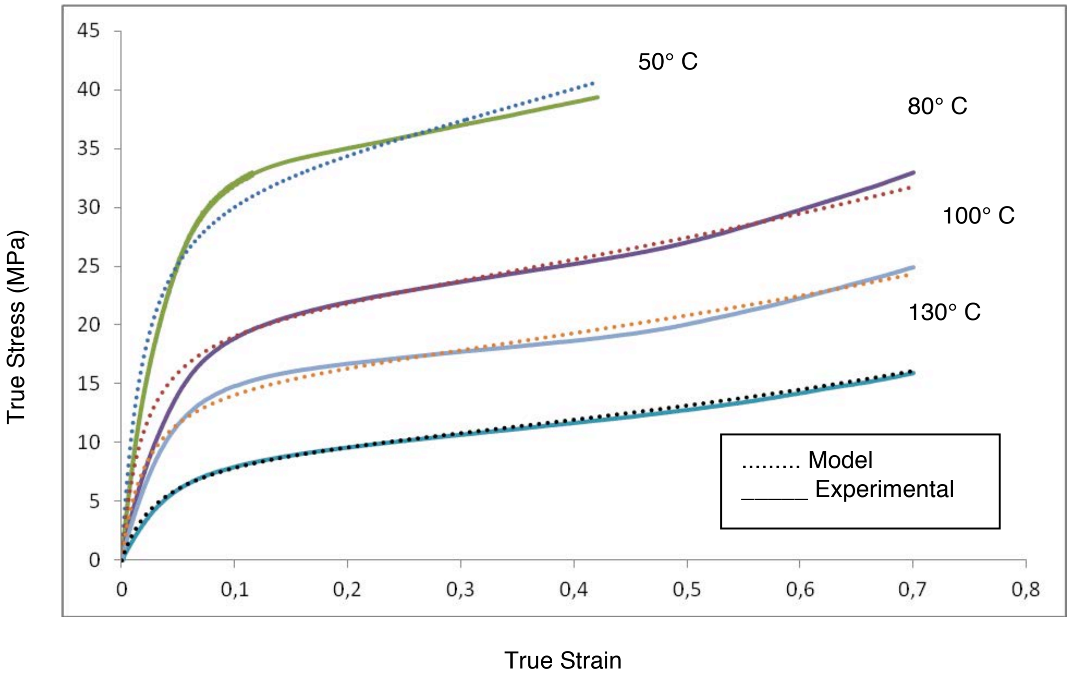

Figure 4. PVDF experimental and theoretical true stress vs. true plastic strain curves for different temperatures.

According to figure 4, it can be seen that, despite the nonlinear behavior of the material, the experimental results are in good agreement with the model predictions.

However, for an effective model, valid for higher temperature ranges. It is interesting to propose a function for the above parameters. A good approach is to consider constant ε and the other parameters as linear functions of temperature. Thus, with few tests can be performed and be sufficient to fully characterize the material temperature between 50 °C to 130 °C.

4. CONCLUSIONS

In this study, the strain rate dependency of Polyvinylidene fluoride (PVDF) barrier is analyzed. In addition, a simple model is proposed to describe the tensile behavior of PVDF at different temperatures. The temperature significantly influences tensile strength and stiffness of PVDF. The proposed mathematical model equations combine simplicity that facilitates their use in engineering problems with a physically realistic description of the mechanical behavior of PVDF pressure barrier from flexible pipes. The intent of this study is to use this model formulation to obtain the maximum amount of information possible about the macroscopic properties of PVDF from a minimum number of laboratory tests, saving time and experimental costs. To determine the parameters values of the mathematical model only three tensile tests are needed. The model predictions have a good correlation with experimental results for different temperatures.

5. ACKNOWLEDGEMENTS

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