24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-1329
A NUMERICAL-EXPERIMENTAL METHODOLOGY TO CHARACTERIZE THERMOPLASTIC MATERIALS SUBMITTED TO LARGE STRAINS

Natália Mühl Castoldi
Francisco Luiz Bresolin
Jakson Manfredini Vassoler
Universidade Federal do Rio Grande do Sul, Sarmento Leite, 425, Centro Histórico, Porto Alegre, Rio Grande do Sul, 90050-170, Brazil
natalia.castoldi@ufrgs.br, francisco.bresolin@ufrgs.br, jmvassoler@ufrgs.br

Abstract. *Thermoplastic materials submitted to tensile tests may suffer necking formation and propagation under large strains. These phenomena promote heterogeneous strains fields in the necking region which may mask the relation between the true stress-strain responses to the experimental force-displacement curve from a usual tensile test. A non-trivial numerical-experimental procedure is required since the resulting force data, obtained from a tensile testing, is not sufficient to assure the kinematics of the necking formation, which governs the force response. Thus, to characterize a material model, in this work a FEMU characterization methodology was employed. Experimental testing was performed on a modified polyvinyl chloride (PVC) specimen submitted to traction, where the applied displacement and the force response were obtained, respectively, from a clip-gauge and a load cell. Besides these traditional measurements techniques, the Digital Image Correlation (DIC) method was used to determine the displacement field occurring in the necking region to consider the necking kinematics. The constitutive model used to numerically characterize the material into the Finite Element Method Updating (FEMU) procedure was an elastoplastic model with multilinear isotropic hardening. The material parameter identification was performed using a hybrid optimization methodology combining genetic and gradient-based algorithms. Results obtained with the presented methodology showed that the studied model can reproduce the experimental force response. However, the cases analyzed were unable to represent the experimental displacement field from the necking region of the specimen.*

Keywords: *material characterization, thermoplastics, DIC*

1. INTRODUCTION

Engineering projects have a growing demand for thermoplastic materials due to its low manufacturing costs and diverse physical properties enabling a wide range of applications. However, thermoplastic usage in structural applications is still restrict due to the nonlinear mechanical behavior presented under high mechanical stresses, posing difficulties in the constitutive models selection and in the constitutive parameters characterization.

Thermoplastics may present nonlinear mechanical response under finite strains, viscous behavior, temperature sensitivity, anisotropy, necking and cold drawing (necking propagation) (Ward and Sweeney, 2012). In particular, necking and cold drawing observed in tensile tests may masks the true stress-strain curve relation to the force-displacement curve (Frank and Brockman, 2001) obtained from the traditional tensile test, raising difficulties to the material identification procedure. The material characterization using force response only, from a usual tensile test, may not be sufficient to characterize constitutive models under finite strains due to the necking development that governs the mechanical response. An approach to provide additional data to the constitutive characterization problem can be performed using Digital Image Correlation method (DIC) (Sutton *et al.*, 2009), which can be used to consider the heterogeneous displacement field of the necking region on the specimen.

Thereby, this work studies a numerical-experimental methodology to characterize a thermoplastic material submitted to finite strain that presents the necking and cold drawing phenomena. Experimental data of force response and the displacement field occurring in the necking region are used in a Finite Element Method Updating (FEMU) procedure (Vassoler and Fancello, 2011; Avril *et al.*, 2008) to determine the material parameters of a elastoplastic model.

2. EXPERIMENTAL PROCEDURE

An experimental tensile test with a relative grip speed of 5 mm/min was performed on polyvinyl chloride (PVC) specimen. Specimens chosen have dumbell geometry with a machined indentation to promote necking formation and propagation in a predetermined location (see figure 1). A clip gauge, with a gauge length of 50 mm, was installed to obtain a relative displacement near the necking region. The force response was obtained from a load cell and the displacement field occurring in the necking region, to consider the necking kinematics, was obtained from the Digital Image Correlation (DIC) method.

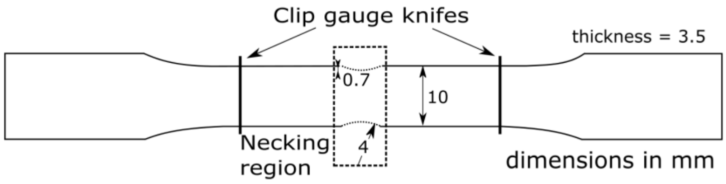

Figure 1. PVC specimen dimensions

In order to use the DIC method, a black and white random speckles pattern was applied in the specimen, as shown in figure 2 and 3. Displacement responses employed in the material characterization procedure corresponds to the relative displacement of markers A, B and C to marker M, in the y-direction of figure 3.

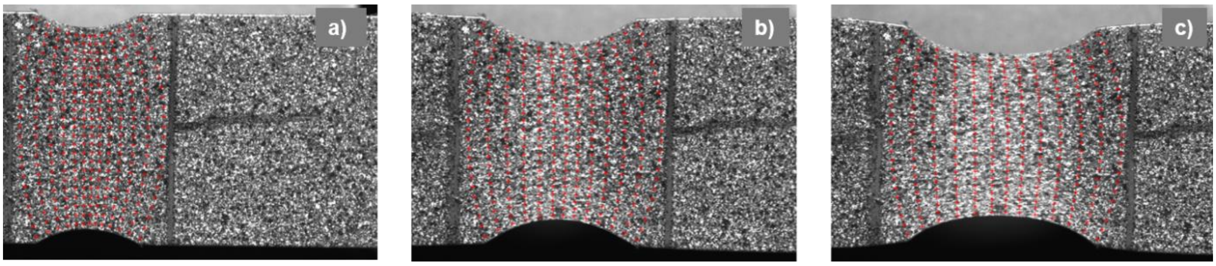

Figure 2. Frames captured from the optical acquisition system. a) Beginning of the tensile test; b) Half of the test; c) Ending of the test

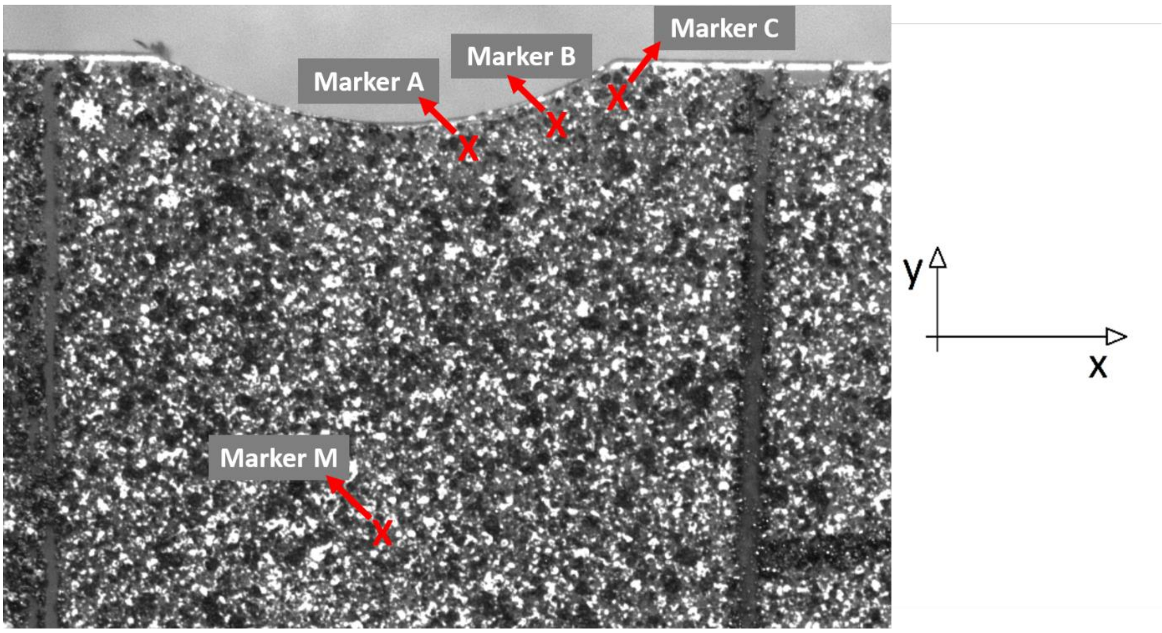

Figure 3. DIC markers

3. CONSTITUTIVE MODEL

The material model used in this work is a rate-independent elastoplastic model with multilinear isotropic hardening (Ansys Inc., 2012). This model was chosen in order to reproduce thermoplastic behavior under large strains. In this study has used ten material parameters, which are the elastic modulus E, Poisson coefficient ratio ν, initial yield stress σ_0, stress plastic increment Δ_1, hardening modulus E_1, second stress increment Δ_2 and hardening modulus E_2, hardening modulus H, threshold plastic strain ε^{ps} and hardening modulus I. Samples of the stress-strain curves of this model are presented in figure 4.

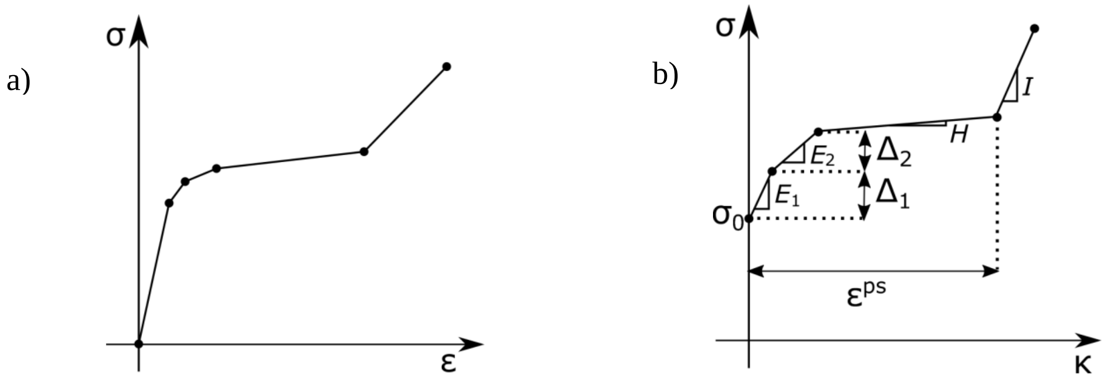

Figure 4. a) Elastoplastic with multilinear hardening behavior; b) Hardening curve.

4. INVERSE PROBLEM

Material characterization was performed with FEMU, which is presented schematically in the figure 5. The tensile test was modelled in a commercial finite element software considering only the region between the clip gauge knives. Boundary conditions used in the FEM analysis corresponds to the relative displacement measured by the clip gauge. Material parameters can be determined minimizing objective functions constructed with the numerical and experimental data. The objective functions used in this study are given by the equations 1 and 2.

$$f^F = \sum_{i=1}^{steps} \left(\frac{F_i^{exp} - F_i^{num}}{F_{max}^{exp}} \right)^2 \tag{1}$$

$$f^d = \sum_{j=1}^{mrk} \left(\sum_{i=1}^{steps} \left(\frac{d_{ji}^{exp} - d_{ji}^{num}}{d_{j,max}^{exp}} \right)^2 \right) \tag{2}$$

where f^F and f^d are respectively the force and displacement objective functions, the superscripts exp and num refers to experimental and numerical data. F_i represents the force response and d_i the relative transverse displacements of the markers. Index i refers to the evaluated time steps and index j refers to the three markers.

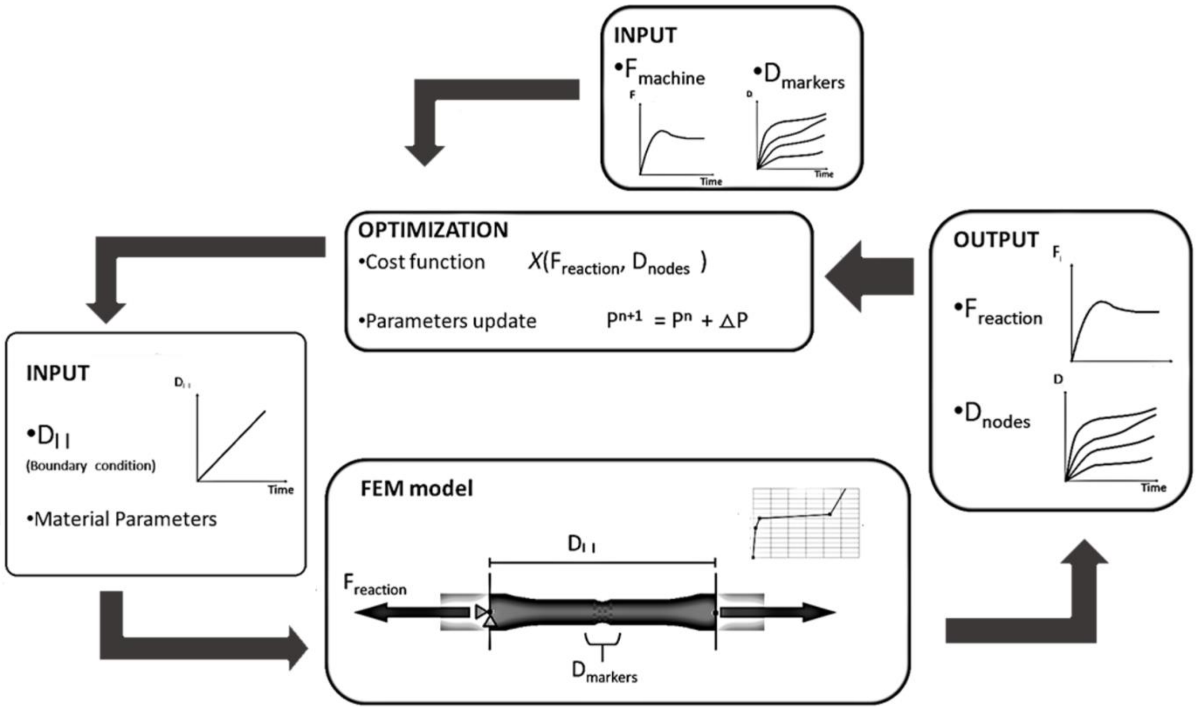

Figure 5. FEMU methodology schematic

In this work the objective functions were solved as single-objective optimization problems to determine if the constitutive model employed was adequate to represent the force response or the necking kinematics. In order to avoid local minima, the material parameter identification procedures were performed using a hybrid optimization methodology, starting with an evolutive algorithm (genetic) to obtain the starting points for a gradient-based algorithm (Levenberg-Marquardt).

5. RESULTS AND DISCUSSION

Minimum force objective response, shown in figure 6 and table 1, was able to reproduce the experimental data of force, but was unable to represent the experimental displacements from the selected markers A, B and C. For the minimum displacement objective, presented in figure 7 and table 2, the numerical response obtained was unable to represent both experimental data force and displacement from the markers. Both responses of the minimum objective functions defined were unable to represent the experimental displacement. Then, this result indicates that the constitutive model employed is unable to represent experimental data obtained for the case studied.

Table 1. Constitutive parameters and objective function values of the minimum force objective function

E	υ	σ_0	H	ε^{ps}	I	Δ_1	E_1	Δ_2	E_2	f^F	f^d
2848.6	0.43	37.8	0.0	0.505	110.8	14.8	2335.9	2.16	139.9	1.25	0.275

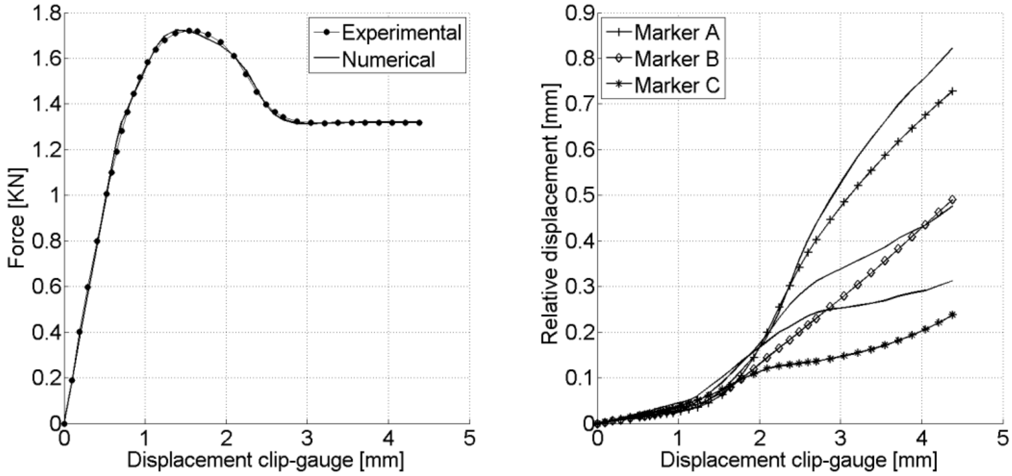

Figure 6. Minimum force objective function (f^F) responses of force and relative displacement

Table 2. Constitutive parameters and objective function values of the minimum displacement objective function

E	υ	σ_0	H	ε^{ps}	I	Δ_1	E_1	Δ_2	E_2	f^F	f^d
2394.4	0.38	28.42	0.0	0.706	1338.9	10.9	80451.8	32.2	25859	558.3	0.0863

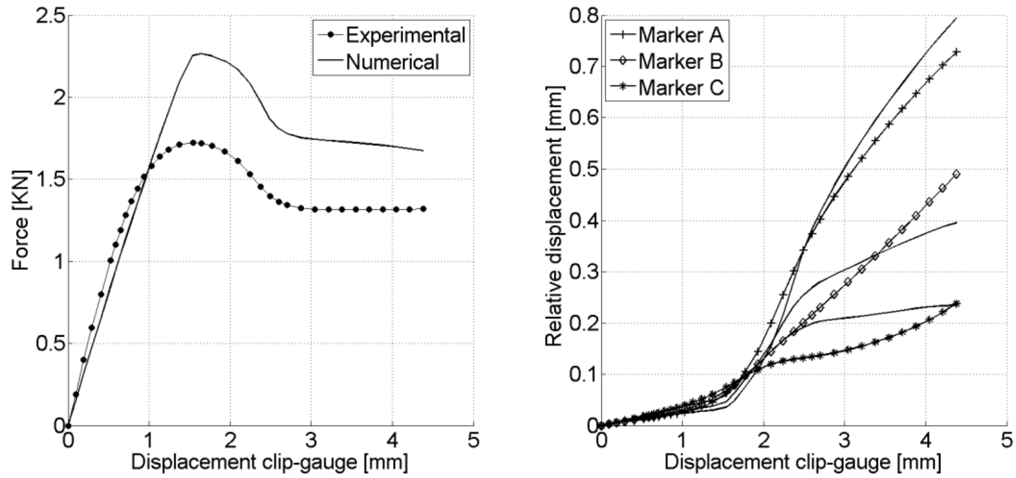

Figure 7. Minimum displacement objective function (f^d) responses of force and relative displacement

6. CONCLUSION

In this work, a FEMU methodology was employed to characterize a constitutive model using experimental data obtained from a thermoplastic specimen submitted to tensile test under finite strains. Force obtained from a cell load and displacement field data from the necking region were used in the characterization procedure. Despite the force results shown good agreement when used only the force objective function f^F, the material model was not able to reproduce the displacement field of the specimen (necking kinematics). This methodology shown the necessity to use additional experimental observations, besides the force response, in identification material procedures of thermoplastics submitted to finite strain where the cold drawing is observed.

7. REFERENCES

Ward, I.M. and Sweeney, J., 2012. *Mechanical properties of solid polymers.* John Wiley & Sons, West Sussex, 2nd edition.

Frank, G.J. and Brockman , R.A., 2001. “A viscoelastic–viscoplastic constitutive model for glassy polymers,” *International Journal of Solids and Structures*, vol. 38.

Sutton, M.A., Orteu, J.-J. and Schreier, H., 2009. *Image Correlation for Shape, Motion and Deformation Measurements*. New York, 1st edition, Springer.

Vassoler, J.M. and Fancello E.A., 2001. "Identification of elastoplastic parameters under finite strain using a digital image correlation method," in *21st International Congress of Mechanical Engineering – COBEM 2011*, Natal, Brazil.
Avril, S., Bonnet, M., Bretelle, A.-S., Grédiac, M., Hild, F., Ienny, P., Latourte, F., Lem, D., 2008. "Overview of identification methods of mechanical parameters based on full-field measurements," *Experimental Mechanics*., vol. 48.
Ansys Inc., 2012. *Theory Reference for the Mechanical APDL and Mechanical Applications*. Ansys.

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.