Extraction of tensile properties from material test: true stress-plastic strain curve for polymers

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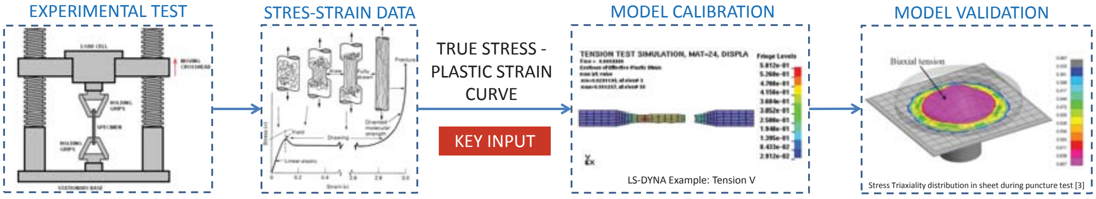
INTRODUCTION

In the automotive industries, thermoplastics have been replacing metals in crash components due to their remarkable combination of density and **high toughness**. [1] Thermoplastics improve the energy absorbing capability during impact. However, the complexity to model their mechanical behaviour is increased. Metal-based constitutive models are no more suitable because **softening** does not induce fracture. Instead, **cold drawing** leads to **large deformations** before failure. [2]

The goal of this work is to develop an accurate methodology to extract the true stress-plastic strain curve from uniaxial **tensile tests** to calibrate advanced material models implemented in FE codes.



1. EXPERIMENTAL TEST

- Quasi-static uniaxial tensile test was performed on mineral-filled Polypropylene.
- The electro-mechanical Instron 5989 was used to measure the **force** and the DIC system to capture the **elongation** field on the spackled dog bone specimen.

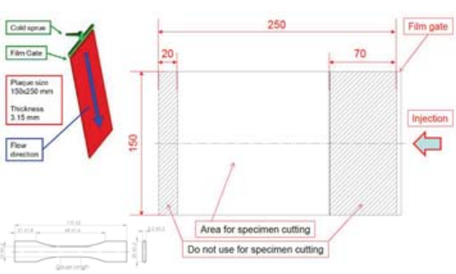


Figure 1. Plaque and specimen dimensions and cutting area on injection moulded plaques manufactured by LyondellBasell Italy.

Figure 2. Uniaxial tensile test set-up.

2. ENGINEERING STRESS - STRAIN

- Tensile **engineering stresses** are derived from $\sigma_{eng} = \frac{F}{A_0}$ (Measured Load F; Original specimen cross-sectional area A_0)
- Longitudinal **engineering strains** are calculated by post-processing DIC readings.
- Local strains were extracted at 5 mm gauge length (optimum). $\varepsilon_{eng} = \varepsilon_{eng}(t)$

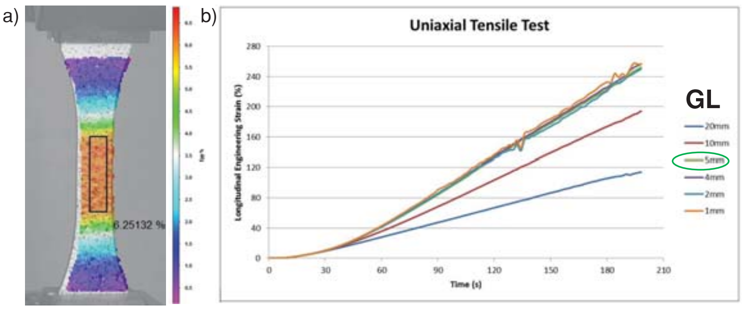


Figure 3. a) DIC longitudinal strain map using DaVis 8.3; b) Gauge Length (GL) study to extract local engineering strain during uniaxial tensile test.

3. TRUE STRESS-STRAIN

- The **instantaneous cross-sectional area** is required to calculate the true stresses.
- An element of dimensions X0, Y0 and Z0 is considered on a Cartesian reference frame within the undamaged solid. Infinitesimal variations of its dimensions occur along the three axes.

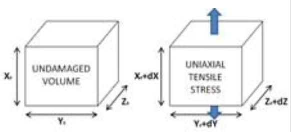


Figure 4. Element of the solid material

- The cross-sectional area is estimated from:

$$A = (y_0 + dy)(z_0 + dz) \longrightarrow A = y_0 z_0 (1 + \varepsilon_{eng,Y})(1 + \varepsilon_{eng,Z})$$

- The Poisson effect is assumed to equally affect the Y and Z directions.
- The **true stress** for **compressible** materials is

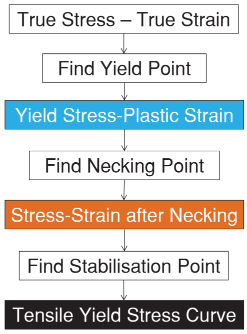
$$\sigma_{true} = \sigma_{eng} \frac{1}{(1 + \varepsilon_{eng,Y})^2}$$

- The **true strain** is derived from the definition of infinitesimal strain tensor. The longitudinal strain acting on the element in Fig. 4 is

$$\varepsilon_{true} = \frac{dX}{X} \rightarrow \varepsilon_{true} = \ln(1 + \varepsilon_{eng})$$

4. TENSILE YIELD STRESS CURVE

- The elastic modulus and the yield point are calculated to extract the yield stress-plastic strain curve that is required for material models in FE codes.
- The following reverse engineering methodology is adopted to extrapolate the true-plastic strain curve to include the **necking** and **softening** behaviour of thermoplastics during uniaxial tensile test.



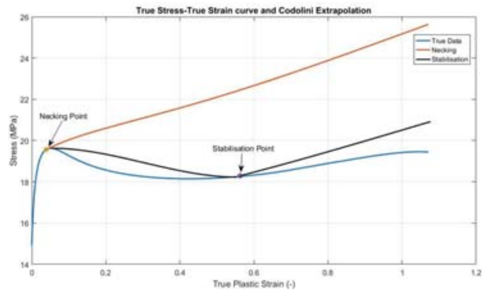
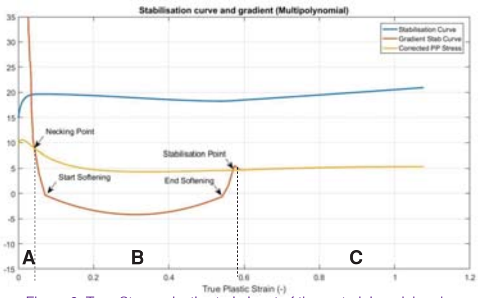


Figure 5. Tensile hardening curves for material model calibration.

- The **stabilisation point** is defined the point where the material has redistributed the polymer chains and allows the spread of diffuse necking along the gauge length.

5. NUMERICAL SIMULATION

- To avoid the premature failure of the specimen during FE simulations, the condition of strain localisation is analysed in order to have the **re-homogenisation** of strains.



A. STRAINS UNIFORMLY DISTRIBUTED

$$\frac{\partial \sigma_t}{\partial \varepsilon_t} > 2\nu_t \sigma_t$$

B. STRAINS LOCALISE

$$\frac{\partial \sigma_t}{\partial \varepsilon_t} < 2\nu_t \sigma_t$$

C. NECKING OCCURS

$$\frac{\partial \sigma_t}{\partial \varepsilon_t} = 2\nu_t \sigma_t$$

Figure 6. True Stress-plastic strain input of the material model and strain evolution during the FE simulation of tensile tests.

NECKING + SOFTENING + COLD DRAWING

NO SOFTENING
Necking condition is forced.

PREMATURE FAILURE
Strain localises until rupture

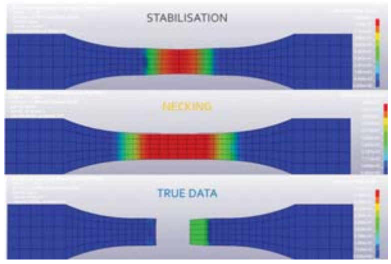


Figure 7. Von Mises strain distribution in tensile specimens in LS-DYNA

CONCLUSIONS

- The true stresses of compressible materials need to be estimated using the transverse strains calculated by post-processing the DIC readings.
- A new methodology is required to extract the true stress-plastic strain curve in order to capture **necking**, **softening** and **cold drawing** of thermoplastic materials when the uniaxial tensile test is simulated in FE codes.

ACKNOWLEDGEMENTS

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[2] Huang, J. C. "Mechanical Properties", Engineering Materials Handbook: Engineering Plastics, Volume 2. ASM International, Ohio, USA, 1997.
[3] Shinya Hayashi, "Prediction of Failure Behaviour in Polymers Under Multiaxial Stress State" 12th International LS-DYNA Users Conference.