Analysis of rheological properties of metals during tensile test

1. Introduction

The characterization of the material mechanical behavior in the metal sheet forming process consists of the identification of the anisotropy, the limits of plastic deformation up to fracture, and the identification of coefficients to calibrate the models that describe the plastic flow curve of the material.

For this purpose, the tensile tests are usually conducted since they allow to:

- obtain a mono-axial tensional state from which it is easy to derive the stress-strain relation.
- characterize the material behavior in tensile and deformation conditions similar to those arising in the metal sheet forming processes.

2. Tensile test

The tensile test is done by applying a tensile state under controlled conditions on a sample whose geometry is fully known using two clamps controlled by a press. Along the test, the actuator's ride, and the magnitude of the applied force are registered. This way, the stress-strain curve can be derived using the definition of engineering strain ε_{ing} and stress σ_{ing}, reported in Eq 1 and 2.
It is worth noting that L stands for the actual length of the sample while L_0 stands for the initial length, F is the actual force, A_0 is the initial cross-section. The real stress-strain curve can be obtained by applying the definition of real stress and real strain, namely using Eq. 3 and 4.
Fig. 1 shows an example of the stress-strain curves, both real and engineering.

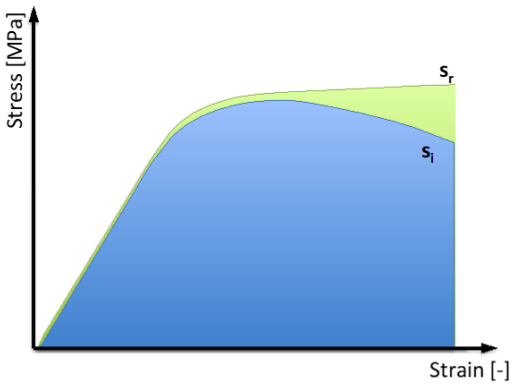


Fig. 1. *Real and engineering stress-strain curve.*

$$\varepsilon_{ing} = \left(\frac{L - L_0}{L_0}\right) \quad (1)$$

$$\sigma_{ing} = \frac{F}{A_0} \quad (2)$$

$$\sigma_{real} = \sigma_{ing}(\varepsilon_{ing} + 1) \quad (3)$$

$$\varepsilon_{real} = ln(\varepsilon_{ing} + 1) \quad (4)$$

In cold processes the stress-strain curve, as derived above, can be implied to compute the constants of the Hollomon rheological model.
Within the cold regime, the flow stress of the material is a function of the strain and it is not influenced by temperature or by the strain rate.
Within the hot regime, the flow stress is influenced by the strain, the temperature and the strain rate; they all must be considered using more complicated models to describe the flow curve.

1. Determining the anisotropy level

The anisotropy level of a material expresses how uniformly the material behaves along the three directions when a load is applied. Normal anisotropy definition is given in Eq 5, where the different parameters are shown in Fig.2; they refer to the initial and final thickness, t_0 and t_f, and the initial and final width, w_0 e w_f.

$$R = \frac{\varepsilon_w}{\varepsilon_t} \quad (5)$$

$$\bar{R} = \frac{R_0 + 2R_{45} + R_{90}}{4} \quad (6)$$

$$\Delta R = \frac{R_0 - 2R_{45} + R_{90}}{4} \quad (7)$$

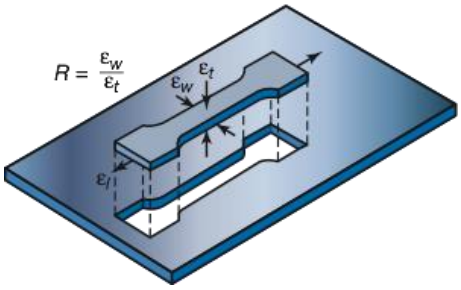


Fig. 2. *Sheet metal anisotropy definition.*

Normal anisotropy is usually measured along three directions at *0deg*, 45*deg* and *90deg* concerning the rolling direction and indicated with R_0, R_{45} and R_{90}.
Combining these three measurements, the average anisotropy, $\bar{R}$ can be calculated. $\bar{R}$ represents a useful parameter to express the formability of the sheet (Eq.6).
Another combination of the normal anisotropy measurements provides the value of plane anisotropy, ΔR, useful to determine the uniformity of the sheet deformation (Eq. 7).
The average anisotropy is related to the formability of the material by means of the diagram in Fig.3 which is experimentally derived:

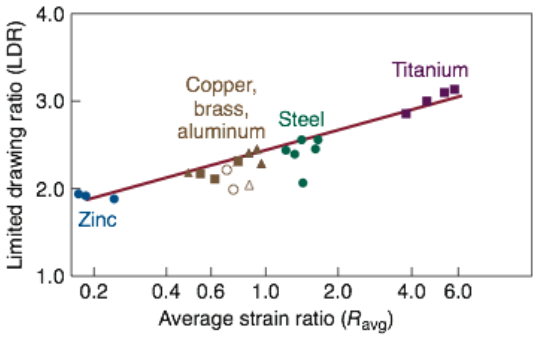


Fig. 3. *Relation between anisotropy and the limiting drawing ratio (LDR).*

2. Gauge length influence

The experimental procedure and the relations mentioned above are valid under the assumption that the tensile test is driven in a mono-axial tensile state. This remains valid, as long as the deformation of the gauge length is homogenous; when the necking starts this hypothesis is lost and some corrections must be made. The homogeneity of the tensile state in the gauge length influences:

- the computed value of the tensile stress.
- the computed value of the strain of the sample.

3. Experimental procedure

The MTS-322 hydraulic dynamometer with a maximum load of 50 kN (5t) and maximum stroke of 150 mm. The MTS-322 can be equipped with an MTS-651 environmental chamber, enhancing its capability to test materials under various temperature conditions.

Fig. 4 shows an example of tensile test performed on the MTS-322. where the sheet specimen is mechanically fixed to the upper and lower grippers, which are connected to the dynamometer load cell and hydraulic piston, respectively. Both the specimen and the upper and lower grippers are inside the environmental chamber to ensure a homogeneous thermal field along the sample gauge length.

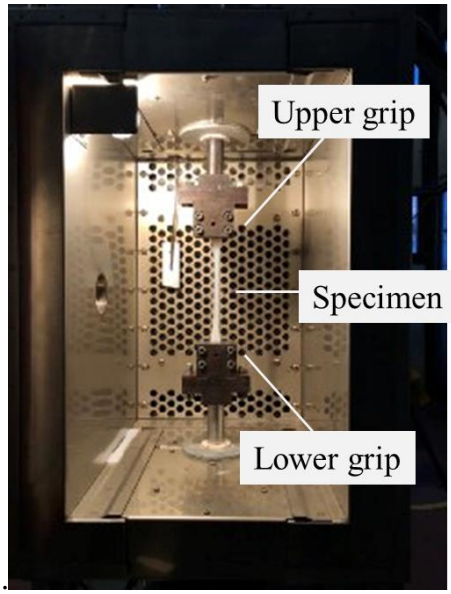


Fig. 4. *Tensile test setup.*

4. Lab experience

The laboratory experience consists of carrying out some cold tensile tests on metal sheet samples of different material which are characterized by different anisotropy.
The objectives of the test are:

- To determine the whole flow curve of the material;
- To evaluate the maximum strain at which homogeneous deformation occur;
- To repeat the tensile test until the maximum strain at which homogeneous deformation occur is reached;
- To calculate (if possible) the R parameter;

Table 1. *Laboratory tests results.*

	UTS (MPa)	ε_{UTS} (-)	ε_w (-)	ε_w (-)	R
Aluminium					
Magnesium					

5. Rheological constants identification

In the following pages, will be given two flow curves of 316 stainless steel obtained at two different rolling directions.
For each temperature, it is asked to graphically obtain the reological constant of the material, on the basis of the following model:

$$\sigma = K\varepsilon^n$$

Flow curves at fixed stain rate but at different rolling directions at different axis magnification are given in Fig- 5 and 6, respectively.

For a fixed strain of 0.3 and 0.35, it is asked to draw the straight line on the log-log chart given in Fig. 7 corresponding to the following Eq:

$$\log(\sigma) = \log(K) + n\log(\varepsilon)$$

Subsequently calculate *K* and *n* values to properly complete Table 2.

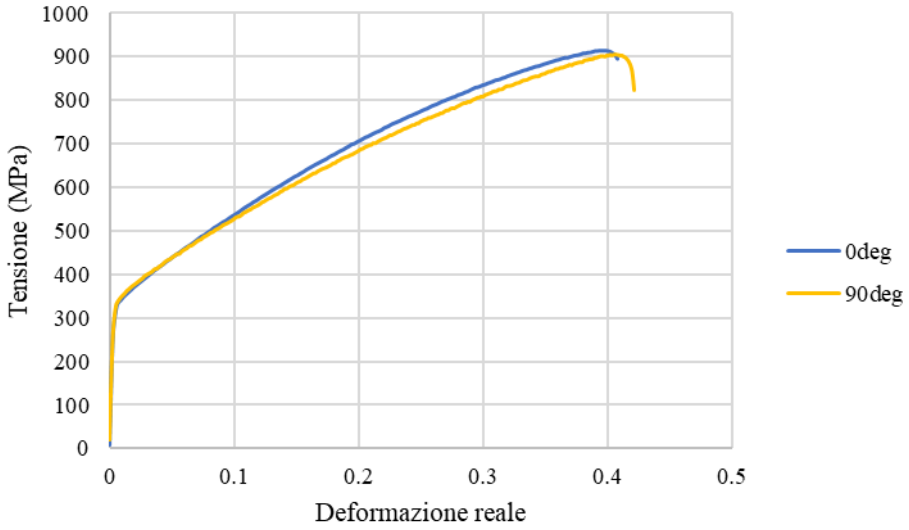


Fig. 5. *316 flow curves for different rolling directions.*

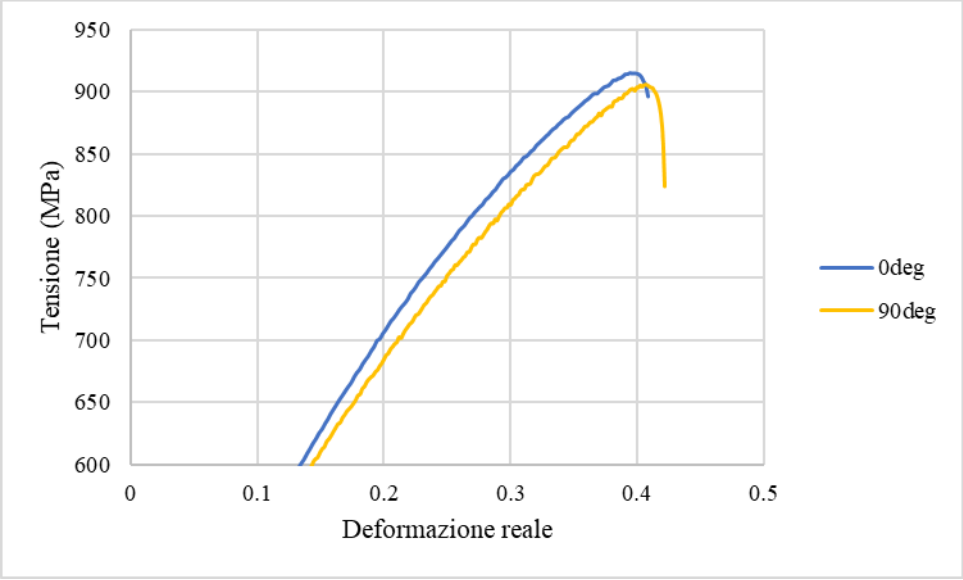


Fig. 6. *Magnification of Fig. 4.*

Table 2. *Rheology constant identification.*

Temperature (°C)	K (MPa)	n(-)
0deg		
90deg		

What are the conclusions related to *K* and *n* values obtained?

