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STUDY OF MECHANICAL BEHAVIUOR FOR DC05 STEEL USING TENSILE TEST

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ABSTRACT

A study about this material has been done in order to find its characteristics. First, tensile tests have been done for the main parameters, like the Young modulus. Then, tensile tests with specific captors have been done in order to find the Poisson parameter. The following parameters, which were found, will be used in order to identify the mechanical behaviour of the material: Young modulus, Poisson coefficient, elastic limit, fracture limit, true strain/true stress curves. The considered thickness of the material is 1mm.

From the true strain/true stress curves, only the plastic zone will be used in order to identify the elasto-plactic behaviour of the material. In fact, the Young modulus and the elastic limit are enough to have the elastic zone, of the true strain/true stress curve, in the element finite simulation. A power law, with A and m identified parameters is used to describe the plasticity of the DC05 material.

KEYWORDS: tensile test, mechanical behaviour, identification, plasticity

1. INTRODUCTION

1.1. Problem definition

Mastery of materials is the basis of engineering. To achieve this, a series of standardized tests is recommended. Of all the mechanical tests, the tensile test is certainly the most fundamental test. It is used to determine the main mechanical characteristics such as Young modulus, Poisson ratio, elastic limit, tensile strength, true stain and necking coefficient. The tensile test is very useful also for the identification of the constitutive law of the material.

DC05 is usually performed as cold rolled sheet. It is mainly used for stamping and cold forming process including deep drawing. The main objective of this study is to determine with great precision, the influence of the sheet thickness and strain rate on the constitutive law of the material. A uniaxial tensile test is therefore retained at a constant speed. The latter will apply on a series. It should be noted for calculation that the material is supposed to be isotropic. Thus, from a stress-strain curve resulting from the tensile test, the following quantities can be calculated or deduced.

1.2. Young modulus

Young modulus or longitudinal elasticity modulus is the constant that relates tensile stress (or compression) and the beginning of the deformation of an isotropic material. The modulus of elasticity is the slope of the linear part of the stress-strain curve [1-2]. The modulus of elasticity is a measure of the stiffness of a material and its units are in terms of stress. The tensile stress applied to a material and the resulting deformation (a relative elongation) is constant, as long as this deformation remains small and the yield strength of the material is not reached, which allows us to deduce through Hooke’s law:

$$E = \frac{\sigma}{\varepsilon}; \quad \varepsilon = \frac{L - L_0}{L_0} = \frac{\Delta L}{L_0} \tag{1}$$

1.3. Elastic limit and yield strength

The elastic limit is the stress from which a material stops deforming in an elastic, reversible manner and thus begins to irreversibly deform. In some materials, the stress at which the material changes from elastic to plastic behaviour is not easily detected. In this case, the offset yield strength is determined. A line is constructed parallelly to the initial portion of the stress-strain curve but offset by 0.002 in/in (0.2%) from the origin. The 0.2% offset yield strength (equivalent to the elastic limit of the material) is the stress at which the constructed line intersects the stress-strain curve:

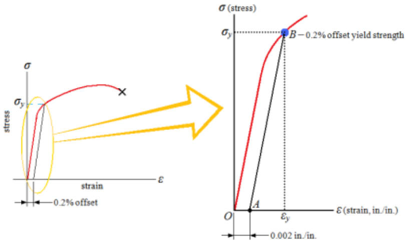

Fig.1: Determination of the yield strength/elastic limit using the offset method [2]

$$\sigma_y = R_{p0.2} = \frac{P}{A_0} = E * \varepsilon \tag{2}$$

In the plastic field, the evolution of the stress as well as the deformation no longer evolves in a linear way due to the large variation during the test of the length and section of the material. Two modes of calculation are possible: in nominal and in real [3]. Assuming that the deformation is at constant volume, we can write the following equations:

Engineering or nominal stress is the applied load, *P*, divided by the original cross-sectional area of a material, A_0, and the engineering or nominal strain is the amount that a material deforms per unit length in a tensile test (eq. 3).

$$\sigma = \frac{P}{A_0}; \varepsilon = \frac{L - L_0}{L_0} = \frac{\Delta L}{L_0} \tag{3}$$

True stress is the applied load, *P*, divided by the actual cross-sectional area, *A*, (the changing area with respect to time) of the specimen at that load and the true strain equals the natural log of the quotient of current length over the original length as given by the equation (4):

$$\sigma_t = \frac{P}{A}; \varepsilon_t = \ln\frac{L}{L_0} \tag{4}$$

True stress and strain are often not required. When the yield strength is exceeded, the material deforms. The component has failed because it no longer has the original intended shape. Furthermore, a significant difference develops between the two curves only when necking begins. But when necking begins, the component is grossly deformed and no longer satisfies its intended use. True stress continues to increase after necking because, although the load required decreases, the area decreases even more.

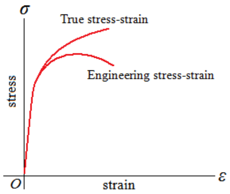

Fig. 2: True vs. engineering stress-strain curve

1.4. Tensile strength

Tensile strength is the maximum allowable stress before fail or the value of nominal stress obtained when the load carried by a tensile specimen at the time of fracture is divided by its cross-sectional area [1-2].

At this point necking begins. Necking is the local deformation of a component when the area of the middle portion of a specimen may begin to decrease, because of local instability. Necking is commonly associated with ductile materials as DC05 steel.

1.4. Poisson's ratio

Poisson's ratio is the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force. Tensile deformation is considered positive and compressive deformation is considered negative. The definition of Poisson's ratio contains a minus sign so that normal materials have a positive ratio.

$$\nu = -\varepsilon_{trans} / \varepsilon_{longitudinal} \tag{5}$$

2. EXPERIMENTAL SETUP

The tensile test was performed considering the following geometrical parameters of the specimen [4]:

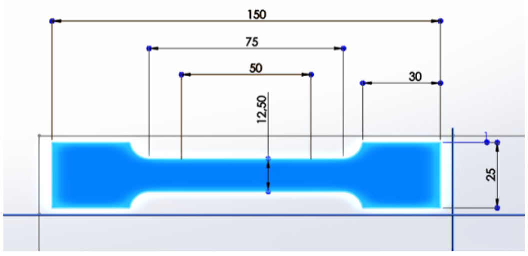

Fig. 3: Tensile test specimen

The strain rate sensitivity [5] of DC05 steel in this study was analyzed considering the real deep drawing process which is a high speed forming process. It results a recommended strain rate between 10^{-4} and 10^{-2} [s^{-1}] corresponding to the punch speed between 5 and 50 [mm/min].

For each considered thickness of DC05 sheet and each strain rate, tree tests were performed with respect to the table below [6]:

Tab. 1

Thickness (mm) / Strain rate (mm/min)	0.4	0.6	0.8	1
5	Case1	Case3	Case5	Case7
50	Case2	Case4	Case6	Case8

The Poisson's rate is determined by applying tree resistive sensors (figure 4).

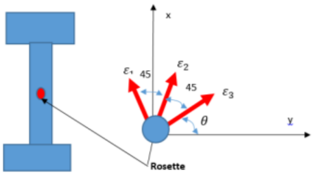

Fig. 4: Poisson's ratio determination

2. RESULTS AND DISCUTIONS

One of the objectives of this study was the determination of the material parameters: Young modulus, Poisson ratio, elastic limit, tensile strength, true stain and necking coefficient. The results are presented in the table 2.

Tab. 2: Experimental results [6]

N°	Thickness (mm)	Speed (mm/min)	Yield strength (Mpa)	Young Modulus (Mpa)	Tensile strength (Mpa)	Elongation (%)	Necking %
1	0.4	5	191.8	176908.2	327.97	33.4	25
2	0.8		170.6	216265.3	323.94	36.8	26.9
3	1		139.5	191595.3	280.93	38.5	27.8
4	0.4	50	228.5	[redacted]	337.36	32	24.2
5	0.8		195.5	[redacted]	325.12	32.9	24.8
6	1		165.09	[redacted]	292.89	37	27

The quantities such as the Young's modulus and the deformation remain in the same order of magnitude for all the thicknesses at the same speed. We obtain a Young modulus of 194922 MPa and a Poisson's ratio of 0.33 for the DC05 sheet steel [6].

Different stress-strain curves were obtained with respect to the experimental setup. At the tensile machine speed of 5 mm/min we see that the material behaviour is similar for 0.4 and 0.6 mm thickness. The increase of thickness determines the decrease of parameters yield and tensile strength.

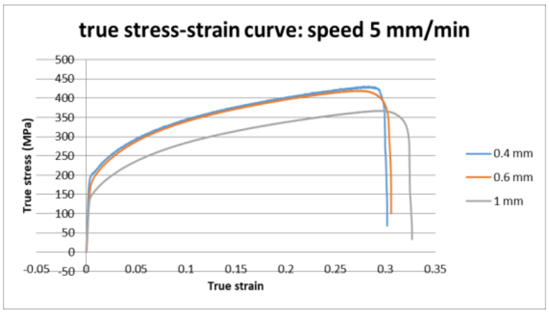

Fig. 5: Stress-strain curve at 5mm/min speed [6]

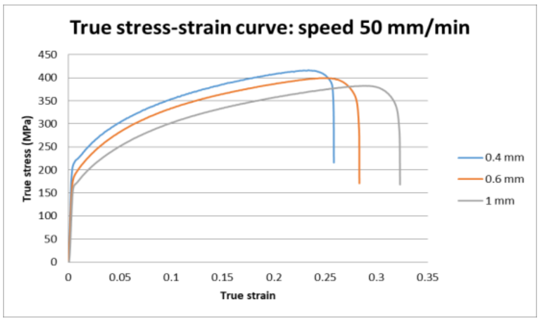

Fig.6: Stress-strain curve at 50 mm/min speed[6]

At 50 mm/min speed an important difference appears between 0.4 mm and 0.6 mm of thickness.

The strain rate sensitivity is presented in the figure 7:

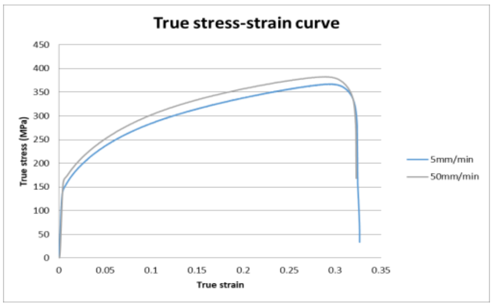

Fig. 7: Strain rate sensitivity for 1 mm thickness [6]

In the same way, the results obtained from the Vickers half-hardness confirm the quasi-homogeneity of the different thicknesses in terms of mechanical properties.

However, the values of the yield and tensile strength increase as a function of the imposed strain rate.

Also, it remains to note that there is a difference in constitutive law according to the calculation method chosen whether it is true stress-strain or nominal stress-strain. Indeed, on the graphs in true stress-strain, the tensile strength is increased by approximately 20% with respect to the limit in nominal stress.

It can be retained in general at the end of these tests, that the constitutive law of the materials is only a function of the applied boundary conditions. And that the speed of solicitations has a considerable impact on the latter. The higher the speed, the greater the material tensile strength are increased.

In the case of the analyzed material a power law is considered [7] as a mathematic relation which uses two different coefficients, *A* and *m*.

$$y = Ax^m \tag{6}$$

This law can be used in order to describe the plastic zone of the true strain/true stress curve for a material, during finite element simulations [7]. In order to find these two coefficients, the logarithm is used. In fact, thanks to the logarithm, an affine function can be found.

$$\ln(y) = \ln(A) + m\ln(x) \tag{7}$$

The true strain/true stress curve is obtained in the form:

$$\sigma = A\varepsilon^m \tag{8}$$

starting from the true following stress-strain curve

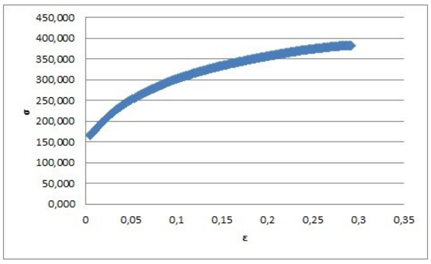

Fig. 8: Plastic zone of true stress-strain curve

So, first ln(σ) and ln($\varepsilon^{\varepsilon}$) have to be calculated.

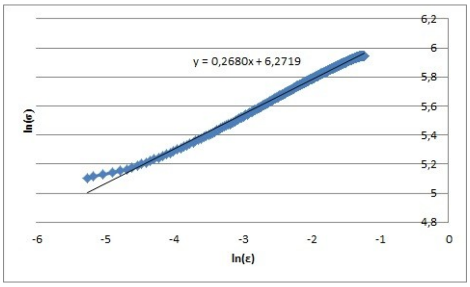

Fig. 9: Power law identification [7]

Using linear regression (Fig.8) it results ln(A) = 6.2719. So A = 529.5 MPa and m = 0.268. The identified constitutive law of DC05 sheet steel will be used in finite element simulation of material forming processes.

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