TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering

Vol. 64, Issue IV, November, 2021

EXPERIMENTAL AND NUMERICAL ASPECTS REGARDING HOT FORMABILITY OF MILD CARBON STEEL

Mariana POP, Dan FRUNZĂ, Adriana NEAG

Abstract *In order to understand the deformation of mild steel during hot plastic deformation, compressive tests at different elevated temperatures were achieved. Using compression tests the behavior of C22 steel were studied in 700-1000 ^{0} C temperature range. Following the experiments performed, flow curves were drawn which reflect the influence of the deformation temperature on the flow stress. The influence of temperature on the non-uniformity of deformations was also established. By using the Forge simulation software, the variation of the deformation process parameters was highlighted (temperature, deformations, stresses, Latham-Cockroft breaking criterion).*

Key words*: formability, mild steel, compression, temperature, deformation energy, simulation*

1.INTRODUCTION

The use of steel in the world economy shows that it is the main material used in industry. This is based on the fact that a material to replace steel is not expected to be found very soon in industrial applications. In this situation, in parallel with concerns about increasing performance and production efficiency, intense action is being taken worldwide for the rational use of steels. Whereas practically the plastic deformation process of metallic materials and alloys presents a series of advantages in the processing industry compared to other manufacturing processes due to their quality due to the high physical-mechanical characteristics achieved by plastic deformation of materials, minimum material consumption, high precision processing, as well as high productivity. So that the formability represents the ability of metals and alloys to deform permanently without the appearance of undesirable phenomena. The most difficult problems to solve in plasticity are those related to plastic flow. The theory of plasticity deals with the methods of calculating the stresses and strains in a deformed body after a part or the whole body has crossed the material flow limit [5,6].

2.THEORETICAL ASPECTS

The determination of the formability of a material is performed by known technological tests: traction, compression, twisting, etc. To understand the behavior of metals and alloys at high temperatures during the process of hot deformation is often complex. Increasing the temperature causes essential changes in the strength characteristics of metals. In case of compression the formability of the materials is assessed by the degree of deformation at which the first crack appears on the outer surface of the specimen. The higher the degree of deformation achieved until the first crack appears, the better is formability of material [2,3].

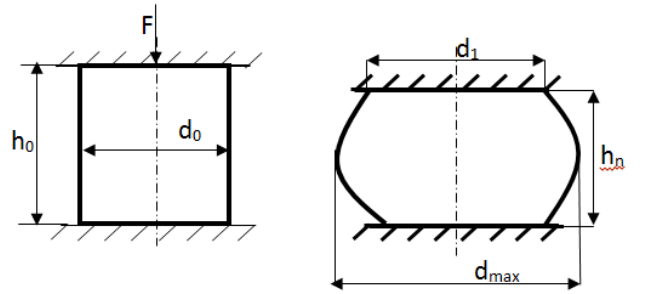


Fig.1 Compression test

$$\varepsilon_h = \frac{h_0 - h_n}{h_0} \quad (1)$$

$$\varepsilon_d = \frac{d_{max} - d_0}{d_{max}} \quad (2)$$

$$\delta_h = \ln \frac{h_0}{h_n} \quad (3)$$

$$k = \frac{A_{max}}{A_0} \quad (4)$$

where: h_0, d_0, A_0 are the height, diameter, cross-sectional area of the specimen before deformation, and h_n, d_{max}, A_{max} are the height, maximum diameter, maximum cross-sectional area at the time of the first crack on the surface of the specimen.

The disadvantage of the method is that it is not possible to notice very precisely the moment of the first crack and the degree of deformation is influenced by the friction conditions.

Thus, the more advanced the degree of machining of the deformation tool surfaces, respectively the height of the roughness and the distance between them, the lower the coefficient and the specific friction force [7].

3.EXPERIMENTAL METHOD

C22 commercial steel quenched and temperate was used. The material has the following chemical composition expressed as a percentage (wt %) according to SR EN 10250-2-2000:C 0,17…0,24; Si max 0,4; Ni max 0,4; P max 0,045; S max 0,045; Cr max 0,4;Cr+Mo+Ni<0,63. The microstructure of C22 steel shown in figure 2 is of the ferrito-perlitic type with a homogeneous distribution of the two constituents.

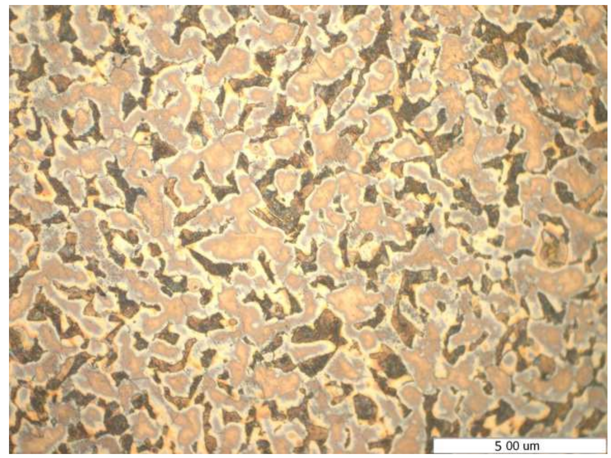


Fig.2 The microstructure of C22 steel

It can be seen that C22 steel is a non-alloy steel for hardening and tempering with an average carbon content of 0.24%. C22 steel contains nickel, chromium and molybdenum as alloying elements and can be heat treated in a wide range to offer the combined advantages of hardness, strength and ductility properties. The service life, in the case of a large number of machine parts, is also conditioned by the fracture strength under the influence of alternating loads repeated a large number of times, with constant or variable amplitude (fatigue strength), which in the case of this steel is of the order of 10^7 alternative requests. Fatigue resistance, determined primarily by the structure (which is a function of composition, purity, processing by plastic deformation and heat treatment), is strongly influenced by the degree of mechanical processing of the part surface, the presence of surface defects and the shape of the piece, which can be stress concentrations, with the direct consequence - breakage to fatigue.

The deformation equipment used for compression test is a Heckert hydraulic press, which develops a maximum force of 200 kN presented in figure 3. The heating of the specimens was performed with an induction furnace, and the temperature measurement was obtained with the help of chromel-alumel thermocouples mounted on the press in contact with the specimen.

Fig.3 Experimental device

The compression tests on the hydraulic press (fig.4) were performed on specimens with dimensions of Ø20 x 30 mm, heated to temperatures T = 800 °C, T = 900 °C, T = 1000 °C, pressing speed of 3.2 mm/s .

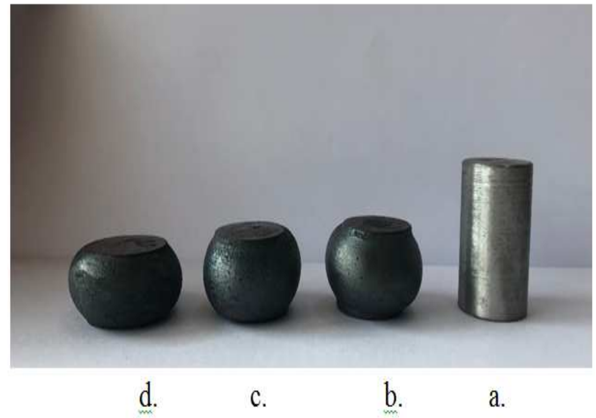


Fig.4 Hot compressed specimens
a.-initial test piece; b.-specimen subjected to compression at temperatures of 800^0C, c.-specimen subjected to compression at 900^0C; d.-specimen subjected to compression at 1000^0C

In the case of press compression, deformation strength σ_d can be determined with relation:

$$\sigma_d = \frac{F_d}{mS} \tag{5}$$

$$m = 1 + 0{,}1\frac{d_{min}}{h} \tag{6}$$

$$S = \frac{\pi d_{max}^2}{4} \tag{7}$$

where: F_d is the deformation force recorded at the end of the deformation; S is section of transversal area of the deformed specimen; m is factor that takes into account the friction forces. Friction is one of the factors that negatively influences the deformation processes by the fact that it increases the deformation effort and energy, the non-uniformity of the deformation with repercussions on the structural homogeneity and the properties of the deformed body, the wear of the plastic deformation tools.
Figure 5 shows the variation curves of the compression stress depending on the true strain for different deformation temperatures.
It can be seen the significant effects of deformation temperature on the flow behavior of

C22 steel. The flow stress gradually decreases with the increase of deformation temperature.

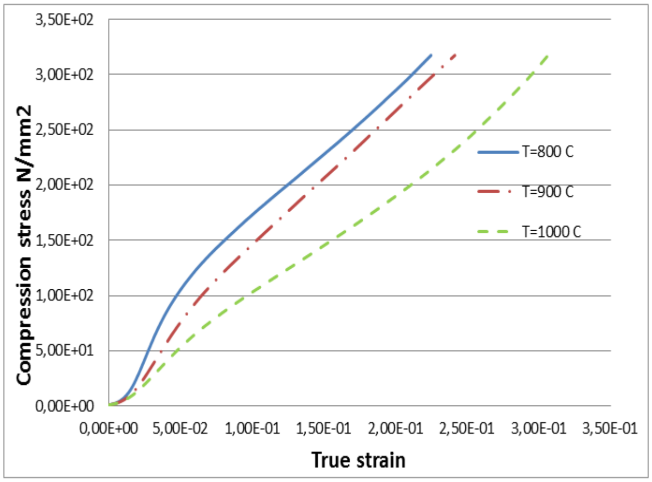


Fig.5 Variation of deformation strength with true strain for different deformation temperatures

The influence of deformation temperatures on the non-uniformity of deformation is presented in figure 6.

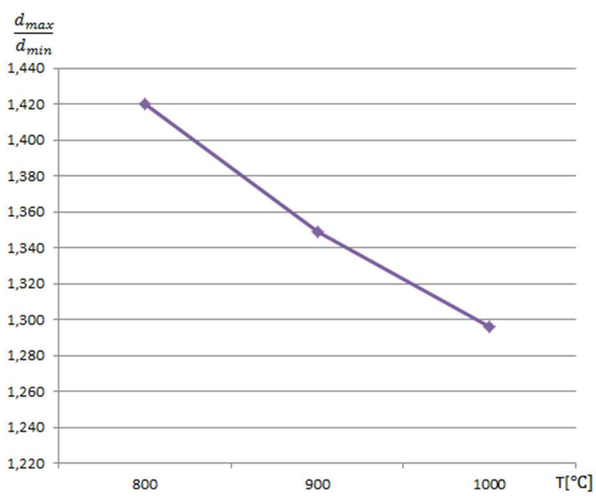


Fig.6 Non-uniformity of deformation for the compression test on the press

As can be seen, the non-uniformity of the deformations decreases by increasing the deformation temperature.

In the case of microstructures obtained after the compression test on the press, it is observed that the test temperature leads to a decrease in the size of the grains / structural constituents thus in the case of the sample deformed at 1000 °C the structure is finer (Fig.7).

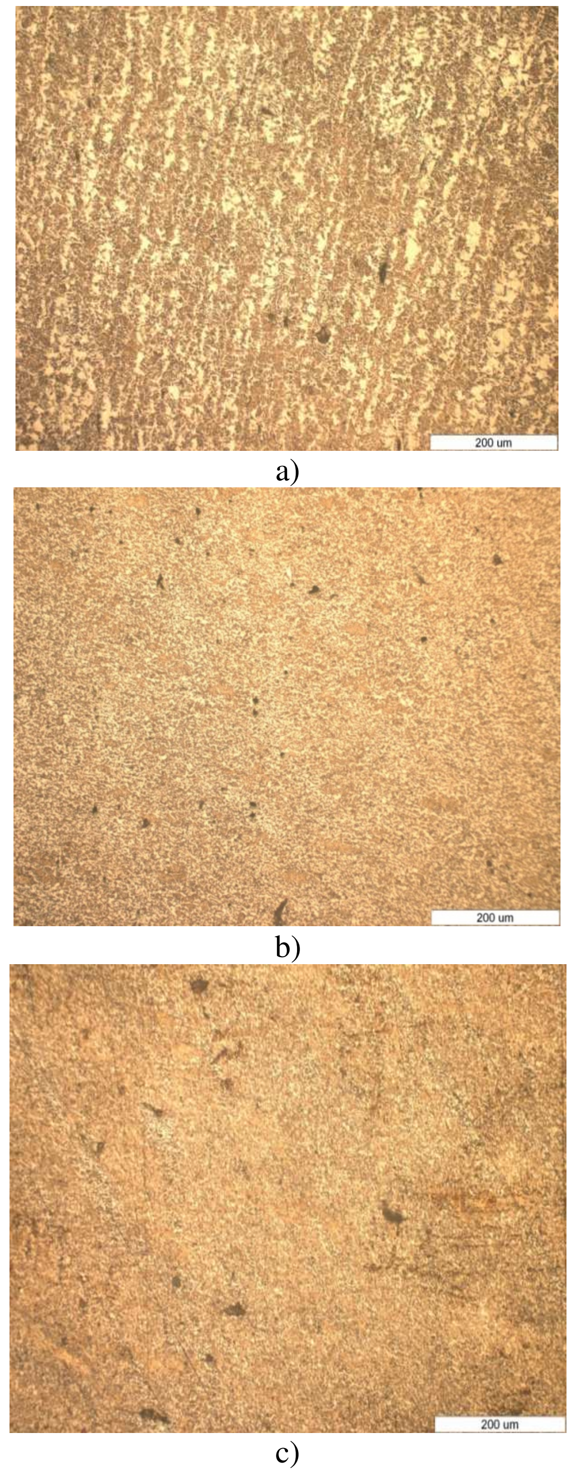


Fig.7 Microstructure of the samples tested at different temperatures: a) 800^{0}C; b) 900^{0}C; c) 1000^{0}C

4.SIMULATION DETAILS

This present study was performed using the finite element analysis program, FORGE. The use of simulation programs allowing to reduce the execution costs of new products, and the virtual study of products before their launch in execution, allows to reduce the number of tests in order to obtain quality products [1,4]. The geometric models of the semi-finished product and of the tools were made in SolidWorks. In figure 8 is presented the ensamble of the geometric models of the blank and tools. Thermal properties of C22 are presented in table 1.

Table 1

Density [kg/m^3]	7850
Thermal conductivity [W/mK]	35.5
Specific heat [J/kg K]	778
Emisivity	0.88

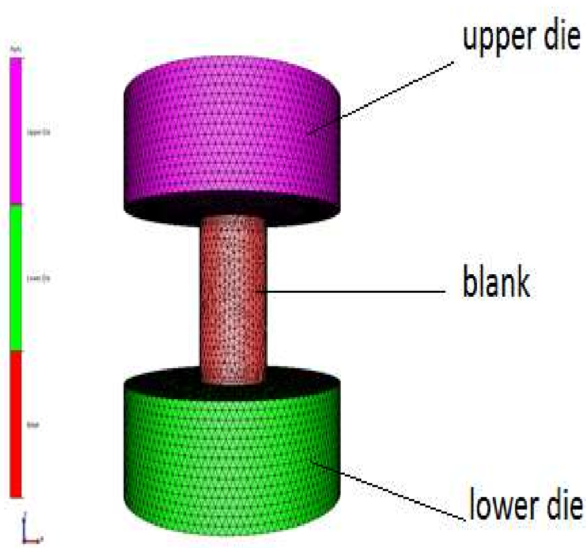
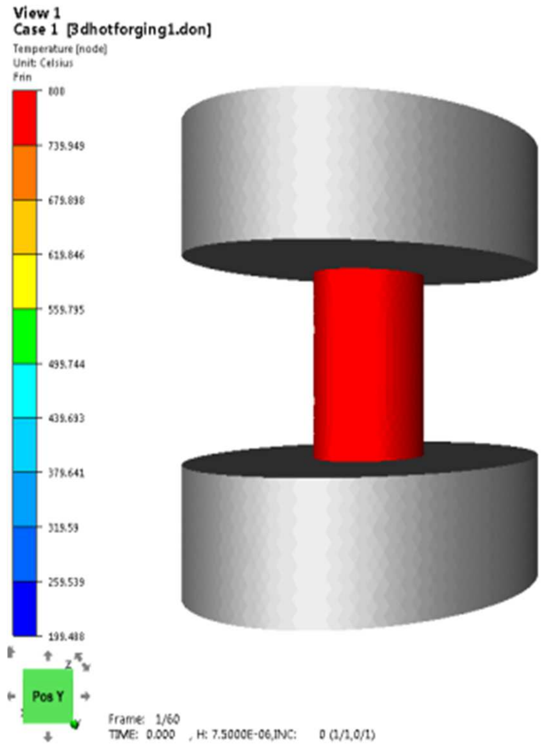
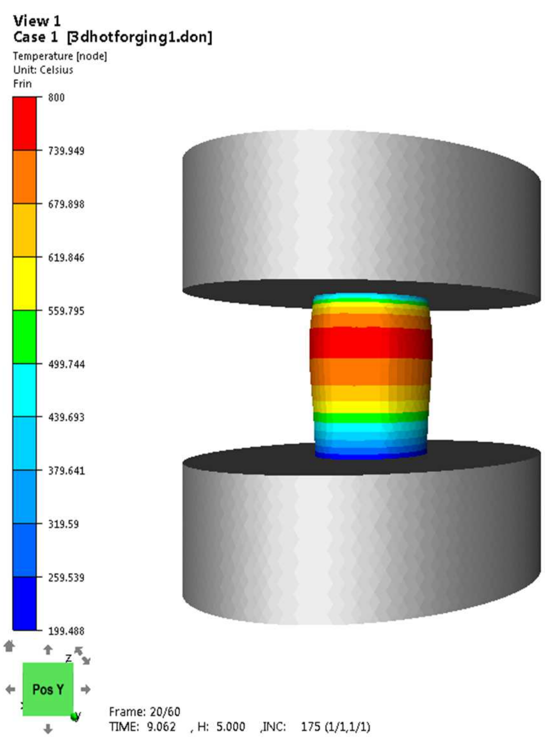


Fig.8 The geometric ensemble of the blank and the tools

The results of simulation are presented in the following figures. The analyzed parameters were temperature, stress, strain, Latham-Cockroft fracture criterion.





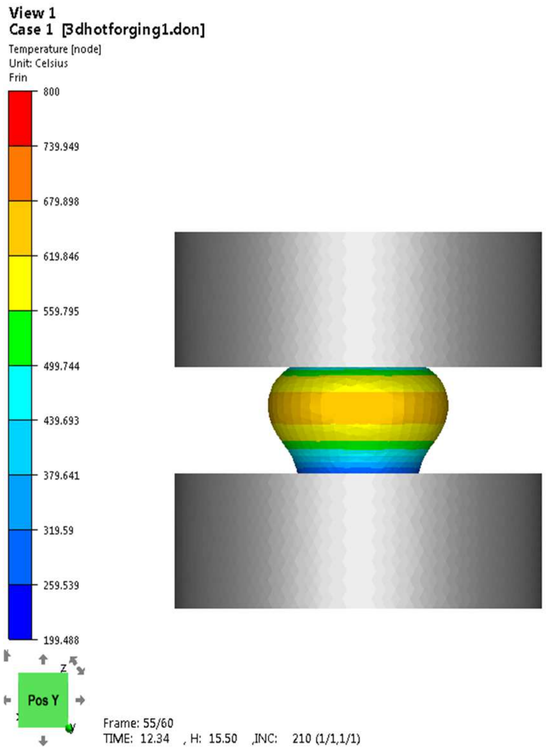


Fig. 9 Temperature variation in the case of the specimen tested atT=800°C and v=3,23mm/s

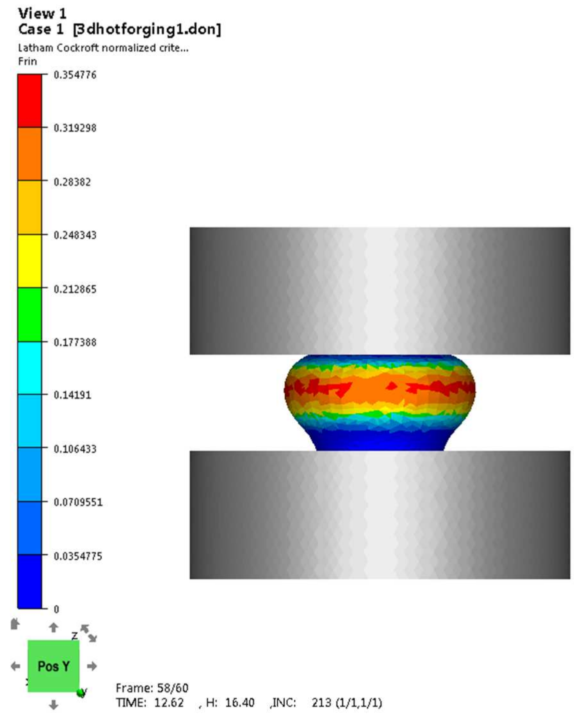


Fig.11 Variation of the Latham Cockroft breaking criterion in the case of the compression-deformed specimen at T=800°C and v=3,23mm/s

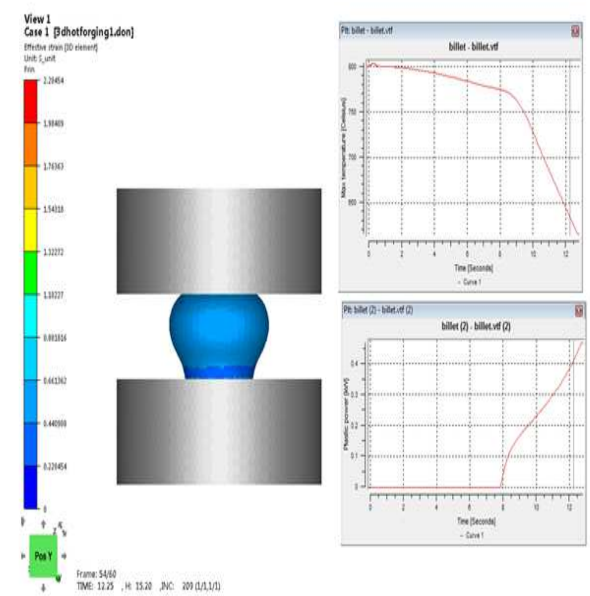


Fig. 10 Variation of equivalent strain in the case of specimen deformed at T=800°C and v=3,23mm/s

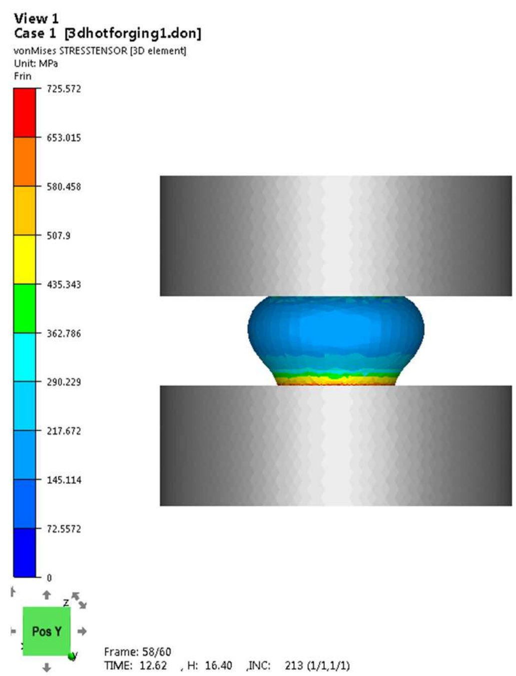


Fig.12 Von Mises stress distribution in the case of the deformed specimen at T=800°C and v=3,23mm/s

In figures 13 and 14 are presented experimental and simulated curves of the variation of force and tension for different test temperatures.

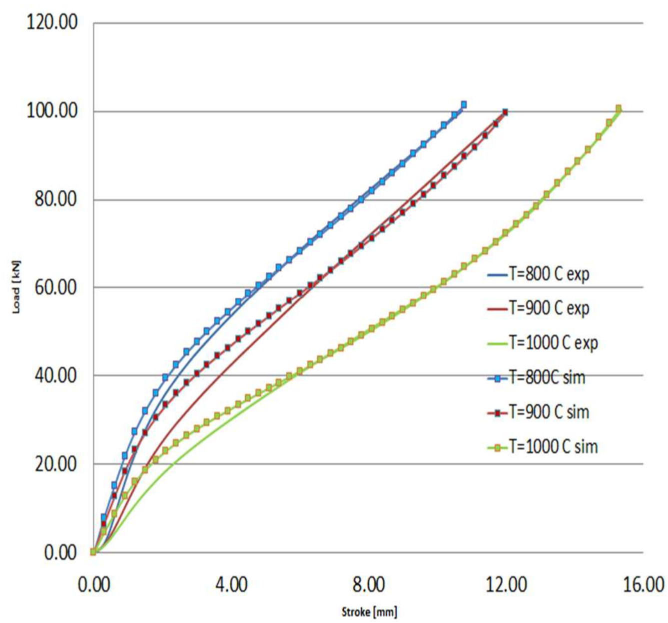


Fig.13 Compression load variation as a function of stroke- Experimental and simulated curves

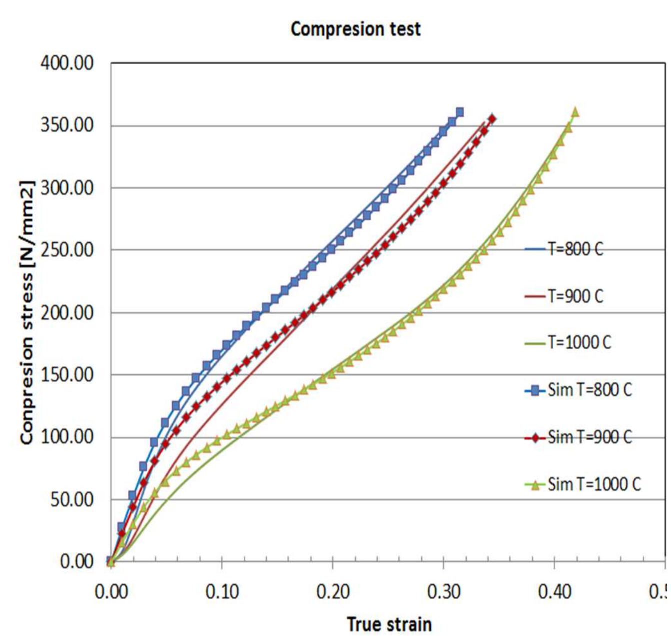


Fig. 14 Variation of compressive strength function of true strain- Experimental and simulated curves

5.CONCLUSIONS

Following the compression tests performed on C22 steel both experimentally and with the help of the Forge finite element analysis program, the influence of different parameters of the deformation process (temperature, deformation energy) on the deformation mode of the steel was studied. The deformation conditions were: temperatures (800 ° C, 900 ° C , 1000 ° C) on press and sonnet at heights of 1000 mm, 1500 mm, 1850 mm.

Following the experimental tests it was observed that:

As the deformation temperature increases, the deformation strength decreases and the formability of the material increases.

By increasing the height of the falling part, the deformation strength decreases from a value of approximately 190 MPa at a height of 1000 mm, to a resistance value of approximately 35 MPa at a height of 1850 mm.

By increasing temperatures the non-uniformity of the deformations decreases (the ratio dmax / dmin = 1).

In the paper, a study was performed by simulating the compression test at different temperatures. Following the simulation, certain parameters of the deformation process were studied: equivalent degrees of deformation, equivalent deformation stresses, temperatures and the value of the Latham-Cockroft criterion.

Following these simulations it was found that the shape of the simulated curves is approximately similar to the experimental curves obtained for the same deformation conditions.

6. REFERENCES

[1] Li H., Fu M.W., Lu J., Yang H., *Ductil fracture: Experiments and computations*, International Journal of Plasticity, 27 (2011)

[2] Pop M., Neag A., Frunza D., Popa F., *Thermomechanical study on 42CrMo4 steel formability*, Acta Technica Napocensis Series: Applied Mathematics, Mechanics, and Engineering, Vol 62, No 2, pp 287-294 (2019),
[3] Pop M., Frunza D.,*Aspects regarding the influence of external friction conditions on materials formability*, Acta Technica Napocensis Series: Applied Mathematics, Mechanics, and Engineering, Vol 63, No 4, pp 367-372, (2020),
[4]Y.C. Lin, M.S. Chen, J. Zhong, *Study of Static Recrystallization Kinetics in a Low Alloy Steel*, Comput. Mater. Sci., 44, pp 316–321,(2008),
[5]Y.C. Lin, M.S. Chen, *Study of Microstructural Evolution During Static Recrystallization in a Low Alloy Steel*, J. Mater. Sci., 44, pp 835–842, (2009),
[6]Y.C. Lin, X.M. Chen, *A crtitical review of experimental results and constitutive descriptions for metals and alloys in hot working*, Material Design, 32, pp 1733–59, (2011),
[7] ASM International , Mechanical Testing and Evaluation, vol.8, (2000.

Aspecte privind deformarea la cald a oţelului cu conţinut scăzut de carbon

Rezumat: Pentru a înțelege comportarea la deformare la cald a otelului cu continut scazut de carbon s-au realizat încercări de compresiune la diferite temperaturi. Comportarea la cald oțelului C22 a fost studiat în intervalul de temperatură 700-1000^0 C. În urma experimentelor efectuate, au fost trasate curbe de curgere care reflectă influența temperaturii de deformare asupra tensiunii de curgere. A fost stabilită și influența temperaturii asupra neuniformității deformaţiilor. Prin utilizarea software-ului de simulare Forge, a fost evidențiată variația parametrilor procesului de deformare (temperatură, deformaţii, tensiuni, forte, criteriul de rupere Latham-Cockroft).

Mariana POP, Associate Prof. Dr. Eng., Technical University of Cluj-Napoca, Department of Materials Science and Engineering, 103-105 Muncii Blvd, 400641 Cluj-Napoca, Romania, E-mail: mariana.pop@ipm.utcluj.ro, , Phone: 0040 264 401 628
Dan FRUNZA, Associate Prof. Dr. Eng., Technical University of Cluj-Napoca, Department of Materials Science and Engineering, 103-105 Muncii Blvd, 400641 Cluj-Napoca, Romania, E-mail: dan.frunza@ipm.utcluj.ro, Phone: 0040 264 401 628
Adriana NEAG, Associate Prof. Dr. Eng., Technical University of Cluj-Napoca, Department of Materials Science and Engineering, 103-105 Muncii Blvd, 400641 Cluj-Napoca, Romania, E-mail: adriana.neag@ipm.utcluj.ro, Phone: 0040 264 401 628