TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 63, Issue II, June, 2020

THERMOMECHANICAL ANALYSIS OF PLASTIC DEFORMATION BEHAVIOUR IN DIELESS DRAWING OF METALLIC MATERIALS

Mariana POP, Adriana NEAG, Dan FRUNZA, Florin POPA

ABSTRACT: *The dielesss drawing of wires and bars is incremental plastic deformation process that has some significant advantages compared to the classic ones. In the process, the temperature and plastic deformation affect each other, so the deformation behavior is very complicated. The maximum reduction of the diameter, the influence of the drawing speed and the temperature are investigated. Changes in microstructure and hardness were investigated. As a result of the process, the grain structure was very deformed in the direction of the drawing. Any defects occurred were due to interruptions in the material microstructure caused by a high necking rate, shorter exposure time to the process temperature and low heating and cooling rates.*
KEYWORDS: *dieless drawing, plastic deformation, temperature, drawing speed*

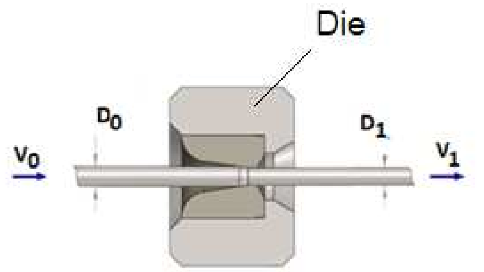
1. INTRODUCTION:

In conventional metal forming processes, high plastic deformation is given to a material using dies. In the drawing process, the cross-sectional area and / or the shape of a wire, bar, tube is reduced by drawing through a die. The cross-sectional area of the drawn product and the reduction of the area are determined by the geometry of the die [1]. Adequate lubrication is very important in materials drawing.The section reduction per single pass is limited by material properties and the drawing conditions (friction coefficient, angle of the die). Also a high friction force acts on the interface between the material and the die, which has a negative influence on the process. In order to increase the material ductility hot working is often used.

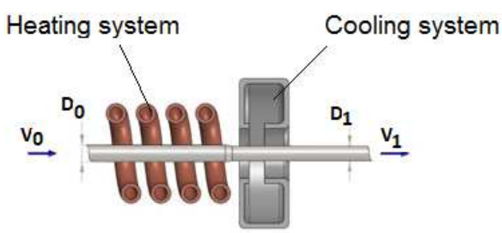
The dieless drawing is an incremental process of plastic deformation, which allows the deformation of wires, tubes, bars by controlling the temperature of local heating/cooling. The concept of this process is to cause the neck of the semi-finished product by local heating and to stop the subsequent deformation, the heated part is rapidly cooled (Fig.1).The aim of the dieless drawing is to produce wire of same quality to that of conventional drawing, without the use of mechanical tools.

The first experimental research on dieless drawing dates back to 1969 and was developed by V. Weiss and R. Kot [2]. To perform dieless drawing on low carbon steel, studies were conducted by Tiernan et. Al. [3,4,5,6]. Twohig et. Al. studied the effect of the process on commercial nickel-titanium rods by changing the established critical parameters of the process (temperature, cooling rate, drawing rate) [7,8].

O. Pawelski, W. Rasp, W. Wengenroth developed an analytical method for determining the temperature distribution and designed an experimental equipment that allows the control of process parameters to ensure stability [9,10]. The process was applied to the production of microtubes by Furushima and Manabe [11,12,13].



a.



b.

Fig.1 Drawing scheme
a.classical drawing; b. dieless drawing

In this paper, the thermal and mechanical loading profile of the wire during processing and the resulting changes in microstructure and hardness were investigated.

2. DIELESS DRAWING:

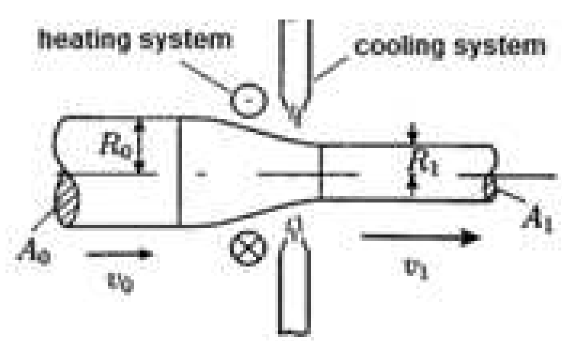
Dieless drawing is a process of forming bars, wires, tubes by using local heating. Figure 2 shows the principle of the process.

The advantages of this process compared to the classic design are: the absence of the die that makes the process less expensive; there are no intermediate heating and surface preparation operations; absence of lubrication problems; a higher surface reduction can be achieved (up to 80% in a single pass) compared to practical reductions which are limited to 20 or 30% per step and rarely greater than 30 to 35%. The main disadvantage of dieless drawing technology is the instability during the process, which leads to an unwanted irregularity of the diameter along the length of the product. The parameters that influence the dieless drawing process are: temperature, drawing force, velocity, strain, strain rate, material properties (density, heat conductivity, specific heat capacity), mechanical parameters(yield stress) [14].

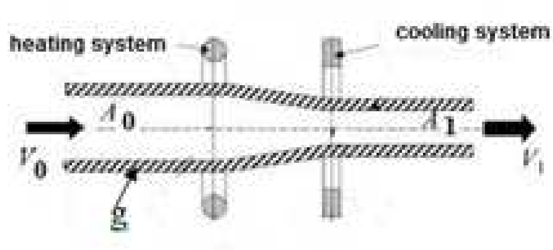
The physical/mechanic properties and the dimensional precision of the products resulted from dieless drawing are chiefly determined by three groups of parameters: mechanical parameters, thermal parameters and geometrical parameters of the semiproduct and of the heating/cooling device [3-11].

For successful deformation heating temperature and cooling rate are the most important factors. Induction heating is superior to any other heat method, given the requirements of local heating, the ability to produce high heating rates and due to the reduction of oxidation and decarburization.

The cooling rate can be changed by selecting the coolant. Dieless drawing technology relies on an increase in the temperature of the wire to lower the yield stress of the axially loaded part material and to cause local plastic deformation. The wire is passed through a controlled air flow which subsequently cools it to stop the deformation and fracture of the material (Fig.2). The tensile force or the pulling force may not exceed the strength of the drawn wire or rod (otherwise, unstable fractures or deformations would occur) [15,16].



a.



b.

Fig.2 Principle of dieless drawing

a. Dieless drawing of wire/bars; b. Dieless drawing of tube

The maximum reduction in area is:

$$r = \frac{\Delta A}{A_0} = \frac{A_0 - A_1}{A_0} = 1 - \frac{A_1}{A_0} = 1 - \frac{\sigma_0}{\sigma_1} = 1 - \frac{V_0}{V_1}$$

3. EXPERIMENTAL RESULTS

The experimental setup features is shown in figure 3. Local induction heating is provided by an induction coil consisting of four turns of 6mm copper wire and a high frequency generator, while cooling is activated by means of air compressors directed on a sample. The system for measuring the temperature, force and displacement consists of transducers, amplification and recording devices. The temperature is measured using a Pyromet optical pyrometer.

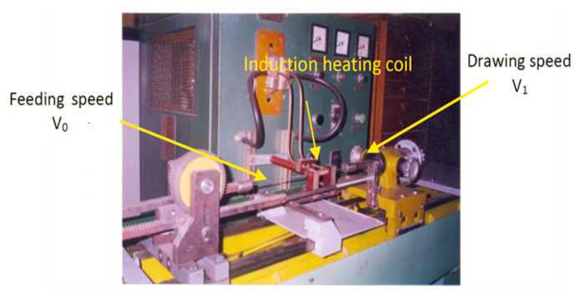


Fig.3 Experimental device

The material used was steel EN 1668-W4Si1. OK Tigrod 12.64 is a solid M4-Si rod, W4Si1 / ER70S-6, coated with copper, for tungsten arc welding of non-alloy steels, used in general construction, pressure vessel manufacturing and ship building. The material EN 1668-W4Si1 chemical composition and thermo-mechanical properties are presented below:
C 0,09 %; Si 1 %; Mn 1,7 %; P 0,025 %; S 0,025 %; Ni 0,15 %; Cr 0,15 %; σ_c=390 MPa; σ_t= 525 MPa; ε=26%; λ=45W/mK.

The deformation was performed in the following speed and temperature ranges:
v_1= 0,75-2,5 mm/s; v_0= 0,46 – 1,5 mm/s;
T_0 = 700-1100 °C. The samples diameters used were: D_0= 3,2 mm; 2,4 mm; 1,6 mm and length l_0= 400 mm.

Figure 4 corresponds to the initial strips microstructure of samples with ferrite grains being elongated after the deformation direction.

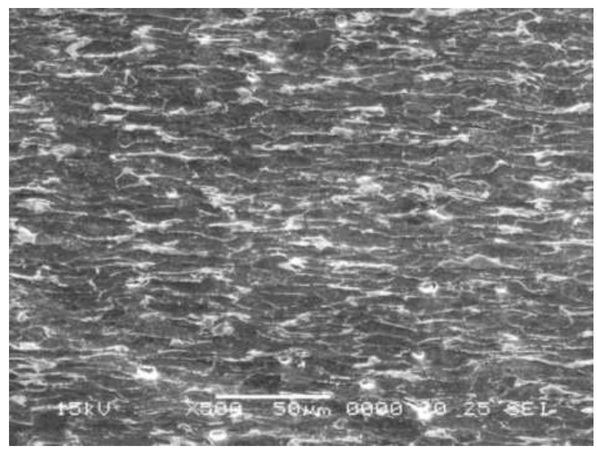


Fig. 4 Initial material microstructure

a. Mechanical characterization

Figure 5 shows the variation of the drawing force for three diameters of the sample.

It can be seen that by increasing the temperature the force required for deformation decreases. For all diameters at drawing speeds of v_1 = 2.5 mm/s the samples fractures.

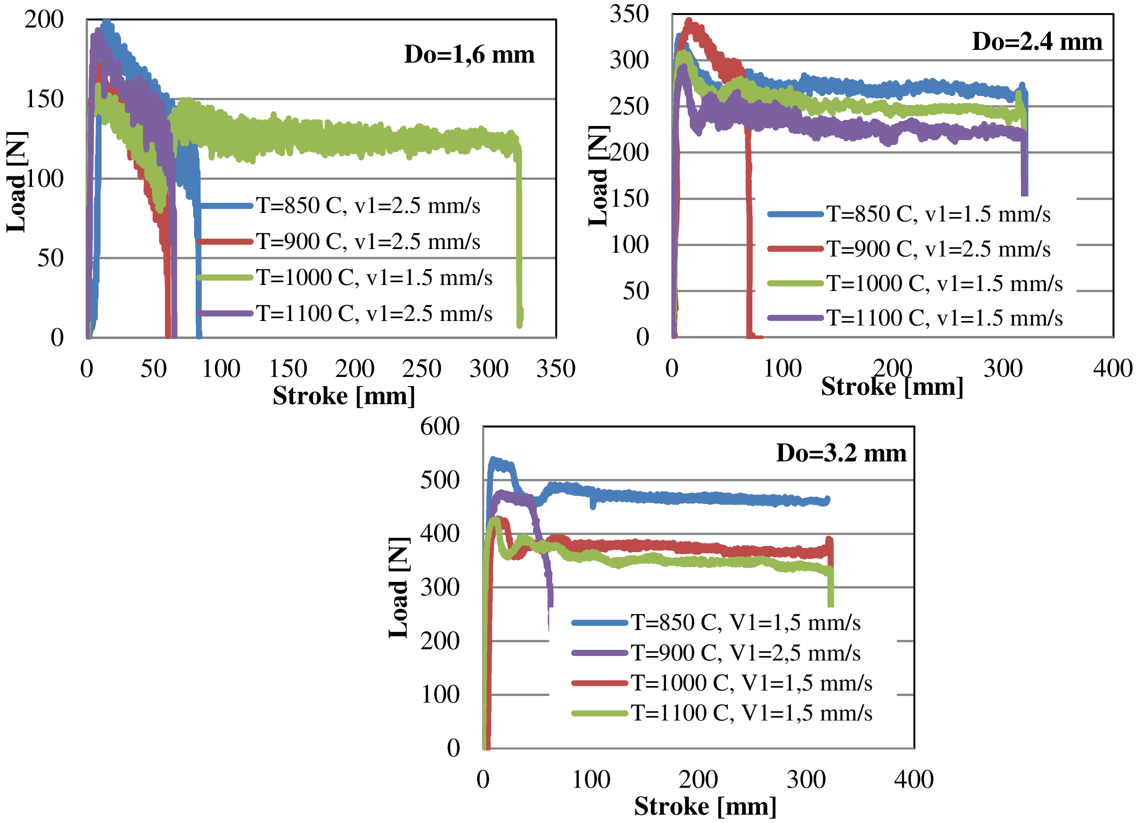


Fig. 5 Variation of drawing load for different temperatures and drawing speed

For the studied material, the process was stable for drawing speeds below 2 mm / s and for all deformation temperatures. Above 2 mm/s drawing speeds, the process was unstable, leading to wire fracture. This phenomenon can be explained either by insufficient time that allowed the propagation of the temperature and uniform heating on the section of the wire, or by the too low cooling rate.Based on the load-stroke records the stress-strain variation curves were plotted in figure 6.

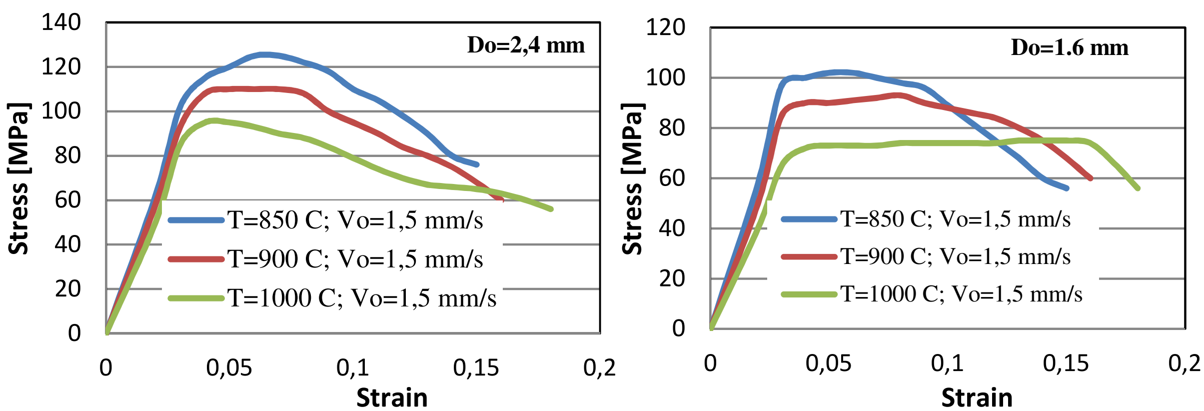


Fig. 6 Stress-strain curves

It can be seen that by increasing the deformation temperature the stress required for deformation decreases. A particular influence on the stress has also the value of the degree of deformation (reduction of area). For the studied material it was observed that by increasing the degree of deformation, the deformation effort increases.

Figure 7 shows the influence of the deformation temperature on sample hardness. Increasing the diameter causes the wire hardness to increase for the same deformation temperature.

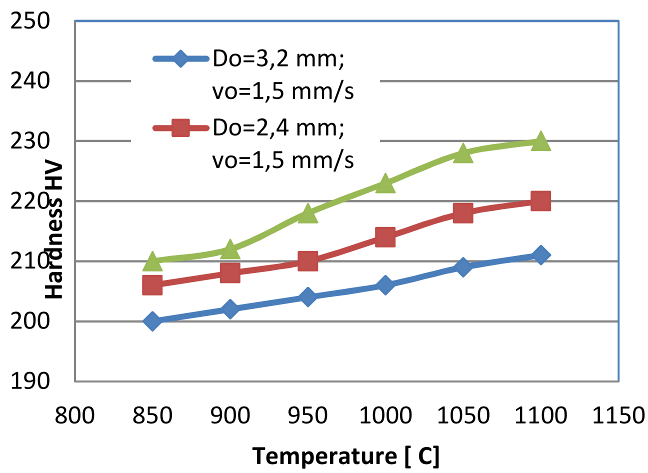
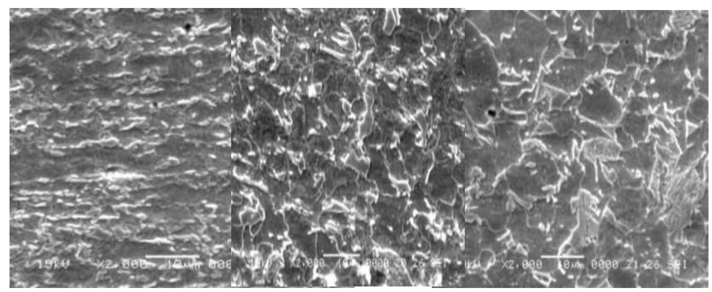


Fig.7 Influence of the deformation temperature on sample hardness

To examine the evolution of the microstructure and fracture mechanisms, the samples were cut and the cross section in the longitudinal direction of the failed samples was polished and investigated in the scanning electron microscope. After deformation with a drawing speed of 1.5 mm/s at 850°C the recrystallization did not occur throughout the structure of the material, being observed both equiaxial and deformed grains. At 900°C the dynamic recrystallization occurred, at 1000 °C, an increase by coalescence of the grains can be observed (Fig. 8).

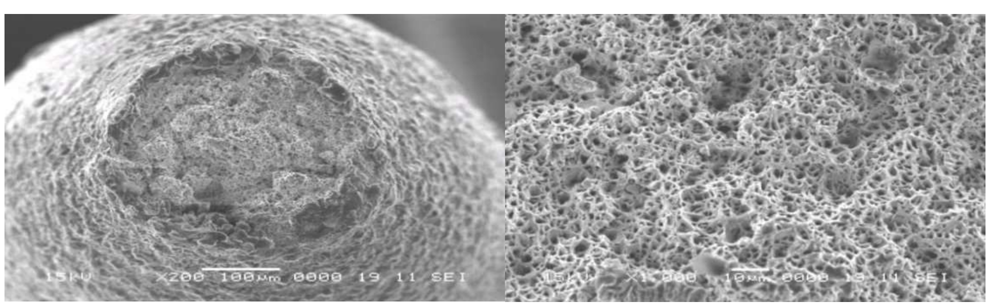


a) b) c)

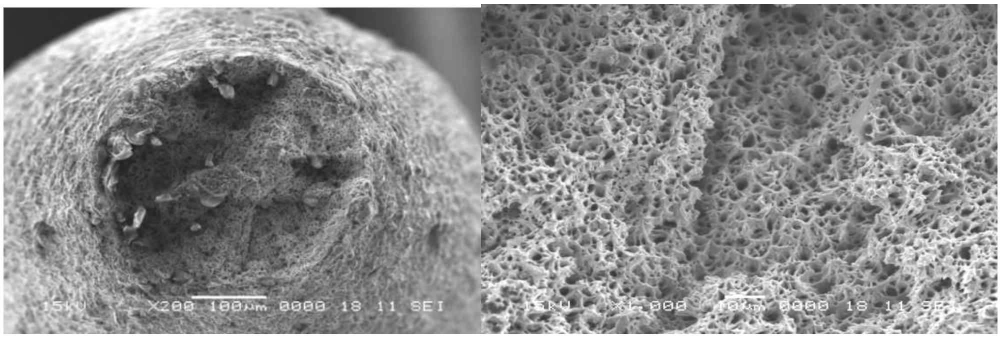
Fig. 8 Microstructure of the 3.2 mm sample diameter deformed at 1.5 mm/s and a) T=850°C; b) T=900°C; c) T=1000°C.

Typical fracture surfaces of the dieless drawn specimens for different deformation conditions are shown in Fig. 9.

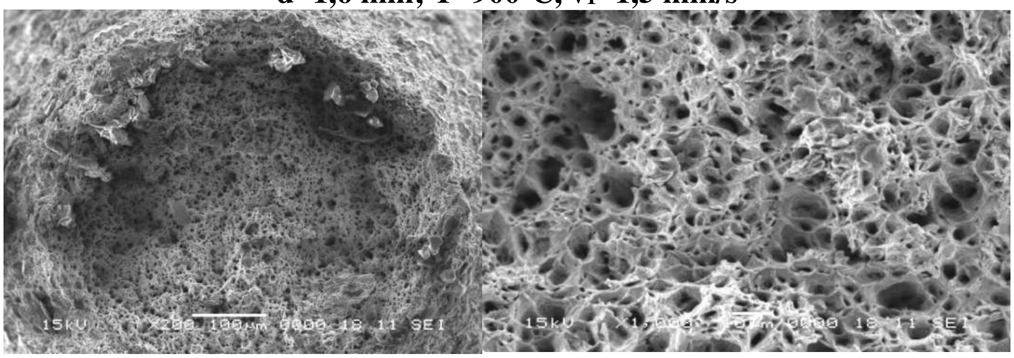
b) SEM microstructure and fractography



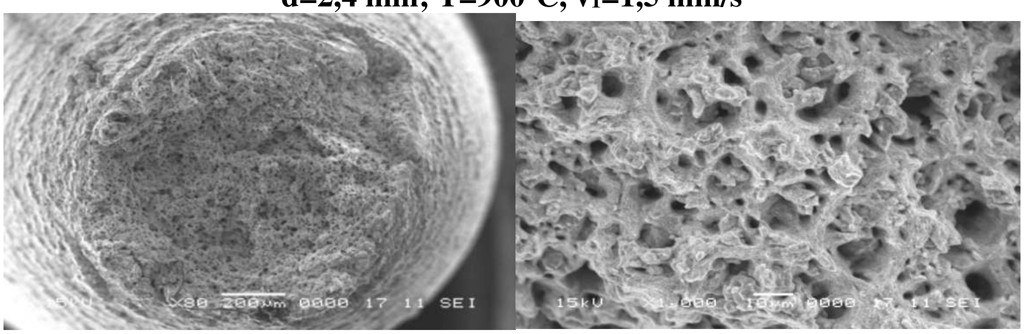
d=1,6 mm; T=850^{0}C, v_1=1,5 mm/s



d=1,6 mm; T=900^{0}C, v_1=1,5 mm/s



d=2,4 mm; T=900^{0}C, v_1=1,5 mm/s



d=3,2 mm; T=900^{0}C, v_1=1,5 mm/s

Fig.9 Fractography of drawn wires

In all cases the fracture mode is cup-and-cone. The cross-sectional area at fracture decreases with Fracture surfaces are covered with typical equiaxed dimples.Failure occurs through the formation and coalescence of the microvoid.

increasing deformation temperature due to the increase in ductility.

4. CONCLUSIONS

1. The objective of the present work was to demonstrate the suitability of dieless drawing for the steel EN 1668-W4Si1.
2. The research investigated the effect of the process parameters on the material mechanical behaviour, hardness, microstructure and fracture.
3. The cross-sectional area of wire of nominal diameters between 1,6 and 3,2 mm was successfully reduced. Uniform reductions of up to 40% were achieved in a single pass.

4. At drawing speeds above 2 mm / s, wire breaks became frequent, with a fracture, on average, after 50-80 mm of wire production. These wire breaks were due to insufficient control of the wire temperature.
5. As a result of the process, the grain structure was very deformed in the direction of the drawing. The failures that occurred were due to interruptions in the material microstructure caused by a high necking rate, shorter exposure time to the process temperature and low heating and cooling rates.
6. Temperature, drawing speed, cooling speed are very important to reduce the variation in diameter, to improve the surface reductions and to prevent the fracture of the workpiece.
7. Temperature, cooling rate, drawing speed influenced the material structure and hardenss.
8. In the conventional wire drawing process, a heat treatment is required between each cold drawing stage to soften the material before it can be cold worked again. In the dieless drawing, the material softens during the process.

5. REFERENCES

[1] Handbook of Workability and Process Design, Edited by George E. Dieter Howard A. Kuhn S. Lee Semiatin, ASM International, 2003;

[2] Weiss, V, Kot, R., Dieless wiredrawing with transformation plasticity, Wire Journal (9), p.182, 1969*;*

[3] Tiernan, P., Hillery, M.T., Dieless wiredrawing-an experimental and numerical analysis, Journal of Materials Processing Technology, Volumes 155-156, 2004, Pg 1178-1183;

[4] Tiernan, P., Hillery, M.T., An analysis of wire manufacture using the dieless drawing method, Journal of manufacturing processes, 10, 2008, pp 12-20;

[5] Tiernan, P., Carolan, R., Twohig, E., Tofail, S.A.M., Design and development of a novel load control dieless rod drawing system, Journal of manufacturing science and technology, 4, 2011, 110-117;

[6] Tiernan, P., Hillery, M.T., Experimental and numerical analysis of the deformation in mild steel wire during dieless drawing**,** Journal of Materials Design and Applications 216 (3), pp. 167-178, 2002 ;

[7] Twohig, E., Tiernan, P., Tofail, S.A.M., Experimental study on dieless drawing of nickel-titanium alloy, Journal of the Mechanical Behaviour of Biomedical Materials, 8, 2012, pp 8-20;

[**8**] Twohig E., Tiernan P., Butler J., Dickinson C., Tofail S.A.M., Mechanical, microstructural and thermal properties of a 50:50 at.% nickel–titanium alloy subjected to a dieless drawing process, Acta Materialia, 68, 140-149, 2014;

[8] Pawelski, O., Kolling, A., Calculation of temperature distributionin dieless drawing, Steel Research(66), pp.50, 1995**;**

[10] Pawelski, O., Rasp, W., W. Wengenroth, Investigation into processing of bars with variable cross-sections by dieless drawing, Proc. Of the 6th International Conference on Technology of Plasticity, 1999**;**

[11] Furushima, T., Manabe, K., Experimental and numerical study on deformation behaviour in dieless drawing process of superplastic microtubes, Journal of Materials Processing Technology, Volumes 187-188, 12, pp 236-240, 2007;

[12] Furushima, T., a Manabe,K., Experimental study on multi-pass dieless drawing process of superplastic Zn-22%Al alloy microtubes, Journal of Materials Processing Technology, 12, 2007;

[13] Furushima, T., Sakai, T., Manabe, K.,Finite element modeling of dieless tube drawing of strain rate sensitive material with coupled thermomechanical analysis, Proc. of 8th Int. Conf. on Numiform, p.522, 2004;

[14] Rus A., Frunză D., Hot deformation behavior for a thermomechanical processed 2014 aluminum alloy by tensile test, Acta Technica Napocensis, Series: Applied mathematics, mechanics and engineering, Vol 58, Issue III, 2015;

[15] Rus A., Effect of thermo-mechanical treatments on the hot deformation, Acta Technica Napocensis, Series: Applied mathematics, mechanics and engineering vol 60, Issue III ,2017,

[16] Mureşan C., G. Achimaş, N.Mihăilescu, Means for improving the quality of large diameter bent pipes with numerical simulation in the deformation process, Acta Technica Napocensis Series: Applied Mathematics and Mechanics Vol. 56, Issue I, 2013.

Studiu termo-mecanic asupra comportarii materialelor metalice la tragerea fara filiera

REZUMAT: Tragerea fara filiera a sarmelor și barelor este un proces de deformare plastică incrementală care prezintă avantaje semnificative în comparație cu procedeele clasice. În proces, temperatura și deformarea plastică se influenteaza reciproc, de aceea comportamentul deformării este foarte complicat. In lucrare s-au studiat reducerea maximă a diametrului, influența vitezei de tragere și a temperaturii asupra reducerii. A fost studiata influenta parametrilor de process asupra microstructurii și duritatii. Ca urmare a procesului, structura grauntilor a fost deformată în direcția deformarii. Ruperea materialului s-a datorat discontinuitatilor prezente in microstructura materialului, cauzate de o viteza mare de gâtuire, timpul de expunere redus la temperatura procesului și vitezele de încălzire și raciere reduse.

Mariana POP, Ass. 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

Adriana NEAG, Ass. 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

Dan FRUNZA, Ass. 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

Florin POPA, Ass. Prof. Dr. Eng., Technical University of Cluj-Napoca, Department of Materials Science and Engineering, 103-105 Muncii Blvd, 400641 Cluj-Napoca, Romania, E-mail: Florin.POPA@stm.utcluj.ro.