INFLUENCE OF RELATIVE SPEED DRAWING ON THE MECHANICAL CHARACTERISTICS ULTRASONIC METAL WIRE DRAWING

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Abstract: *The paper presents the influence of the relative rate of drawing* $\left(v_{dr}/\overline{v_v}\right)$ *to the plasticity and resistance mechanical characteristics during the ultrasonic drawing-UVD of the cylindrical symmetry metallic wires able to be work-hardening, when the die is placed in the maximum of the wave oscillation and it is activated along the drawing direction.*

Keywords: *cylindrical symmetry metallic wires, work-hardening, ultrasonic drawing, relative rate of drawing, plasticity and resistance mechanical characteristics*

1. Introduction

Classical Technology-CT used for the obtaining of the metallic wires processed by cold plastic deformation (at the environmental temperature) is called drawing.

The drawing process is characterized by a work hardening phenomenon (an under stress hardening) which goes to the increasing of the resistance mechanical characteristics with the decreasing of the plasticity characteristics, in the same time.

When the plastic deformation takes place at high degrees, the integrity of the metallic material may be destroyed (the generating of smooth fractures). In this condition, the drawing process (big reductions of cross section, obtained by drawing) becomes possible after the applying of a structure remaking thermal treatment [1].

As a rule, special phenomena may happen in the industry of high resistance steel wires.

For these situations, the authors recommend "the ultrasonic vibration drawing"–UVD, because this process allows the technological checking of the work hardening mechanical resistance, in dependence with the relative rate of drawing.

The technological scheme of the ultrasonic drawing-UVD of the metallic wires with cylindrical symmetry, with the die placed in the maximum of the wave oscillation (antinode) and activated along the drawing direction, is presented in Fig.1.

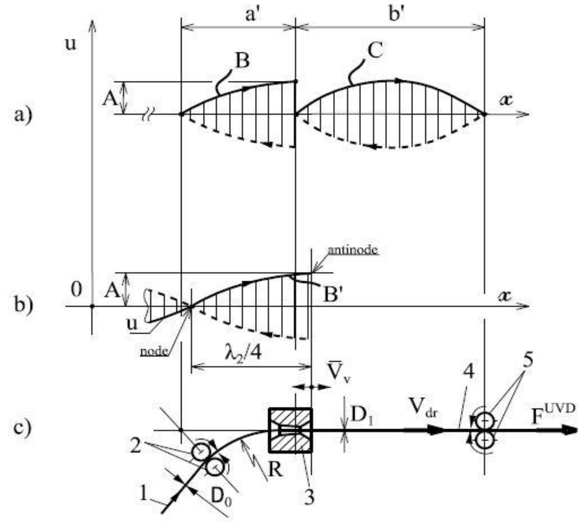

Figure 1: *Technological scheme of the metallic wires with cylindrical symmetry ultrasonic drawing-UVD*:
a) wave oscillation in wire: B-wave oscillation in the semi-finished wire; C- wave oscillation in the s wire;
b) wave oscillation at the oscillator system level;
c) proper technological scheme: 1-semi-finished wire; 2, 5-ultrasound energy reflector; 3-die; 4-drawn wire; O-x-drawing and propagation of the ultrasonic waves direction; A-amplitude of the wave oscillation at the oscillator system level and in wire; B'*-wave oscillation for the oscillator system;* D_0, D_1*-diameter of the semi-finished, respectively, of the drawn wire; R-radius of the semi-finished wire; u-wave movement for the active/oscillator system;* $\overline{v_v}$ *-maximum of the die vibratory rate;* v_{dr} *–rate of drawing;* F^{UVD}*-drawing force, UVD technology;* a' *and* b'*-positioning distances of the ultrasonic energy reflectors: ——— running wave; ------- regressive wave.*

The plastic deformation with ultrasonic vibrations means the activation of the deformation tool with high frequencies (more than 16000 Hz), along the plastic deformation direction or normally on it. The ultrasonic drawing along the drawing direction, with the die placed in the maximum of the wave oscillations (antinodes), goes to the reduction of the metal-tool contact friction, respectively of the work hardening in the same proportion, based on “the ultrasound surface effect”; this effect is explained based on the Severdenko’s model and considering “the reversal of the mean friction mechanism”, as a function of the relative rate of drawing.

The ultrasonic energy reflectors (the pressure rolls), placed at well defined distances, are used to generate a stable system of standing waves into the wire (vertexes and antinodes generating), [2, 3].

The relative rate of drawing is expressed using the ratio between the rate of drawing (v_{dr}) and the maximum of the die vibratory rate ($\overline{v_v}$), meaning $v_{dr}/\overline{v_v}$, [3].

2. About the relative rate of drawing during the ultrasonic drawing of the metallic wires with cyllindrical symmetry, able to be work hardened

For the relative rate of drawing $\left(v_{dr}/\overline{v_v}\right)$defining, Fig.2 gives a schematic presentation of the drawing plastic deformation process, in the UVD case, of the metallic wires with cylindrical symmetry and it shows especially, sdeformation kinetics: the variation of the die vibratory rate (v_v) at the level of one oscillation complete period (T), the metal slip rate on the element of the die cone (v_s)-direction A-B, the axial rates v_0, v and v_{dr}-before the deformation area, in the deformation area and respectively, the rate of drawing.

The hypothesis of the UVD plastic deformation process are: the metallic material is incompressible; the die is a rigid body; the metal deformation is realized in the Von Mises condition; the field of rates provides the Bernoulli type continuity; the metal-tool contact friction is a Coulomb type one (it is a constant one for a given drawing process); only longitudinal waves, as standing waves, action at the level of the oscillator system (vertexes and antinodes are generated); the plastic deformation process is an isothermal one.

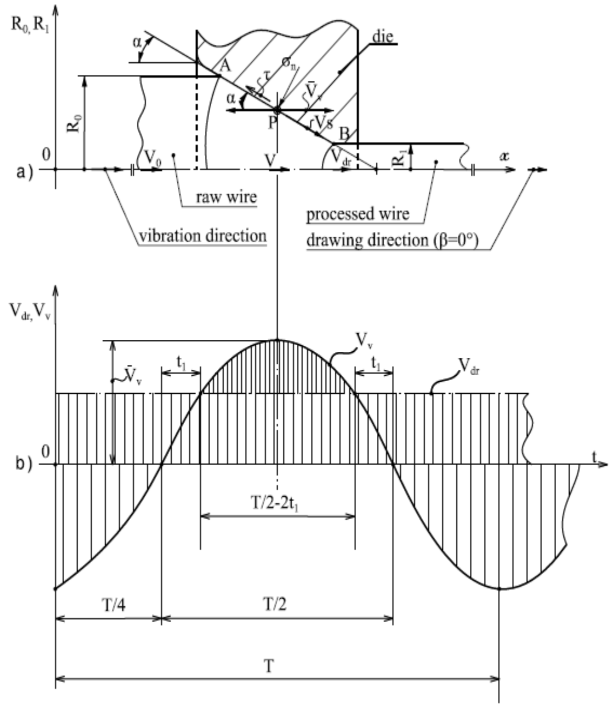

Figure 2 *Procedure of plastic deformation by drawing, during the ultrasound drawing-UVD of the metallic wires with cylindrical symmetry*:

a) scheme of the plastic deformation procedure by ultrasound drawing-UVD, along the drawing direction, the activation angle $\beta=0^o$;

b) variation of the vibratory rate (v_v) during one period (T) of the ultrasound oscillation, the rate of drawing (v_{dr}) being a constant-the case $\left(\overline{v_v}\rangle v_{dr}\right)$; P-point arbitrary chosen at the metal-tool interface; τ-tangential stress; σ-normal stress; α-half-angle of the die cone; R_0, R_1-half-thickness of the semi-finished wire, respectively the rate of the drawn wire.

The kinetics of the plastic deformation and the influence of the relative rate of drawing to the metal-tool contact friction are expressed based on the Severdenko’s model, “Theoretical model”, as a completion of the classical model, and taking into account “the reversal of the mean friction mechanism”, meaning: the friction is positive ($F_f^{\,+}$) during $T/2\text{-}2t_1$ time, when $\left|\overrightarrow{v_s}\right|\langle\left|\overrightarrow{v_v}\right|$; the friction is negative ($F_f^{\,-}$) during $T/2+2t_1$ time, when $\left|\overrightarrow{v_s}\right|\rangle\left|\overrightarrow{v_v}\right|$, at the level of a complete period of oscillation (T), Fig.3, [2].

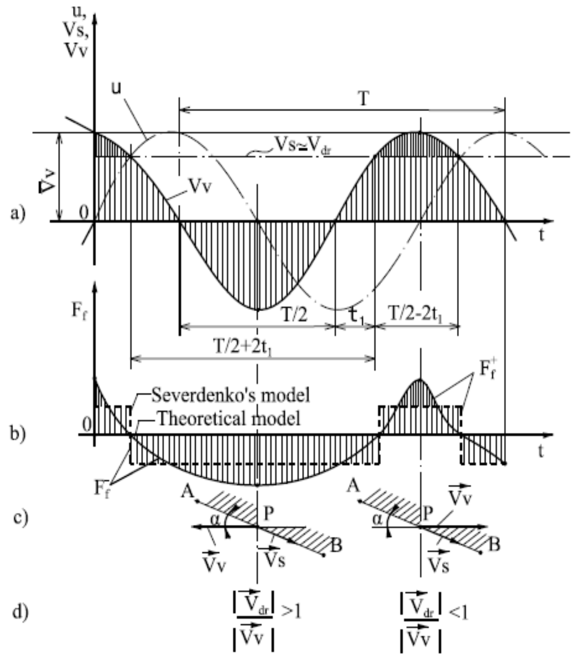

Figure 3: *Kinematics of the plastic deformation by drawing-U VD technology***:**

a) wave movement (u), metal slip rate (v_s) and vibratory rate (v_v);

b) mean friction reversal (F_f^+ and F_f^-), based on the Severdenko's model : - - - - classical variant ; ——— theoretical variant;

c) movement directions of the velocities vectors $\overrightarrow{v_v}$ and $\overrightarrow{v_s}$, in point P placed at the metal-tool interface;

d) values of the relative rate of drawing in the considered point P, during $T/2+2t_1$ and $T/2-2t_1$ times.

The Figure 3 shows that in the deformation area, the metal realizes isochronal oscillations with a certain vibratory rate given by die rate $\left|\overrightarrow{v_v}\right|$ superposed over the slip rate $\left|\overrightarrow{v_s}\right|$, which is a constant one.

As those previously presented, any point P arbitrary chosen in the plastic deformation area, at the metal-tool interface, has two motions: one of them is a feed motion and it is along the die cone element, A-B, with a rate $\left|\overrightarrow{v_s}\right|$ and the other is a vibratory motion with a rate $\left|\overrightarrow{v_v}\right|$.

The friction vector, $\left|\overrightarrow{F_f}\right|$, in the case of the classic drawing technology-CT, is opposed to the direction of the metal moving velocity $\left|\overrightarrow{v_s}\right|$ and in the case of the ultrasonic drawing technology-UVD, it is opposed to the direction of the resultant velocity (the resultant vector of the composition between the two vectors $\left|\overrightarrow{v_s}\right|$, $\left|\overrightarrow{v_v}\right|$).

During the ultrasonic drawing technology-UVD, the resultant vector of the relative rate will change the moving direction of the point P, in function of the senses of the two vectors $\left|\overrightarrow{v_s}\right|$ and $\left|\overrightarrow{v_v}\right|$, and of the sizes of their projections on the die cone element or on the friction direction A-B.

During the $T/2$-$2t_1$ time of the oscillation period (T), the displacement of point P is identical with that of the metal when the projection of the vibratory rate vector $\left|\overrightarrow{v_v}\right|$ on the friction direction A-B is bigger than the projection of the slip rate $\left|\overrightarrow{v_s}\right|$ on the same direction, $\left|\overrightarrow{v_v}\right|\rangle\left|\overrightarrow{v_s}\right|$; the same displacement is in a contrary sense during the $T/2+2t_1$ time of the oscillation period (T), when the ratio between the two vectors projections on the friction direction A-B is an inverse one, $\left|\overrightarrow{v_v}\right|\langle\left|\overrightarrow{v_s}\right|$.

Knowing that, in the case of the drawing of the wires made of metallic materials able to be hardened, the half-angle of the die cone $\alpha \leq 10^o$, meaning $\cos\alpha \to 1{,}0$, it can approximate $\left|\overrightarrow{v_s}\right| \cong \left|\overrightarrow{v_{dr}}\right|$ because $\left|\overrightarrow{v_{dr}}\right| = \cos\alpha\left|\overrightarrow{v_s}\right|$, [3, 4].

Considering the waves movement (u) which follows the motion law, relation (1):

$$u = A\sin\left(\frac{2\pi}{\lambda}x - \omega t\right). \qquad (1)$$

the vibratory rate (v_v) is obtained based on the time derivative, relation (2):

$$\frac{du}{dt} = A \cdot \omega \cdot \cos\left(\frac{2\pi}{\lambda}x - \omega t\right). \qquad (2)$$

with the maximum value $\left(\overline{v_v}\right)$ for $\cos\left(\frac{2\pi}{\lambda}x - \omega t\right) = 1$.

where: $2\pi/\lambda$ – wave factor; λ – wave length; ω – wave angular frequency, $(\omega=2\pi f)$.

So, the maximum of the vibratory rate ($\overline{v_v}$) is given in the relation (3):

$$\overline{v_v} = 2\pi \cdot f \cdot A. \qquad (3)$$

where f is the resonant frequency at the oscillator/active system level.

In other words, in the case of the ultrasonic drawing-UVD, the plastic deformation takes place in pulses in this way: during the $T/2+2t_1$ time, the proper plastic deformation takes place; during the $T/2-2t_1$, mostly the metal elastic deformation takes place.

Assuming the Severdenko's model for the reduction of the metal-tool contact friction developing, the ratio φ expressed in the relation (4), [2]:

$$\varphi = \frac{(T/2+2t_1)+(T/2-2t_1)}{(T/2+2t_1)-(T/2-2t_1)} . \tag{4}$$

represents the reduction degree of the mean friction in point P, arbitrary chosen at the metal-tool interface, in the deformation focus.

Equalizing the two rates, $v_{dr}=v_v$, it results the relation for t_1, (5):

$$t_1 = \frac{1}{\omega}\arccos\frac{v_{dr}}{v_v \cdot \cos\beta} . \tag{5}$$

Substituting both t_1, given in the relation (5) and T $(T=1/f)$, in the relation (4) and knowing that $\beta=0$ (meaning that $\cos\beta=1$) when the die is activated along the drawing direction, (see Fig.2), it results the relation (6), [2]:

$$\varphi = \frac{\pi}{2}\cdot\frac{1}{\arccos\frac{v_{dr}}{\overline{v_v}}} . \tag{6}$$

Considering the mean value for the rate of drawing (v_{dr}) (based on the equation of the metal flow continuity), the input-output sections in the focus area of the plastic deformation, the reduction degree of the mean friction (coefficient φ) on the entire metal-tool contact friction is given in the relation (7):

$$\varphi = \frac{\pi}{2} : \frac{v_{dr}\frac{\lambda_i\cdot\cos\alpha+1}{2\lambda_i\cdot\cos\alpha}}{\overline{v_v}} . \tag{7}$$

where λ_i is the wire elongation by pass, calculated using the relation (8), [1, 3]:

$$\lambda_i = \frac{S_0}{S_1} = \left(\frac{D_0}{D_1}\right)^2 . \tag{8}$$

For example, Fig.4 shows the variation $\varphi = f\left(v_{dr}/\overline{v_v}\right)$ for a given UVD drawing process (relation (7)), [2, 3].

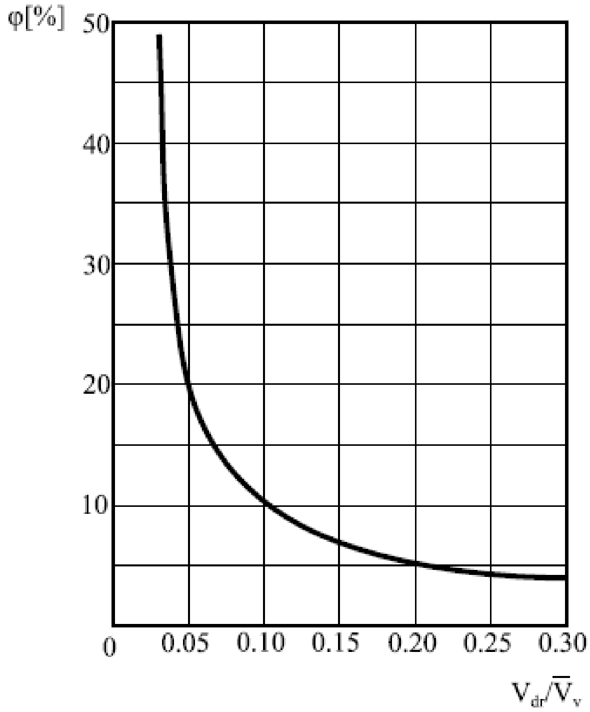

Figure 4: *Variation of the coefficient (φ) in function of the relative rate of drawing $\left(v_{dr}/\overline{v_v}\right)$, for a given ultrasound drawing process-UVD: D_0=3.50mm; D_1=3.00mm; $\alpha=8^o$; δ_i=19%; f=22000Hz; λ_i=1.18; v_{dr}=0.06m/s; A=25μm; $\overline{v_v}$ =3.45m/s.*

The maximum of the vibratory rate $\left(\overline{v_v}\right)$ is calculated with the relation (3) and for the determination of the section reduction degree by pass (δ_i) it is used the relation (11), [2, 3]:

$$\delta_i = \left[1-(D_1/D_0)^2\right]\cdot 100[\%] . \tag{9}$$

3. Material and research methodology

3.1 Researched material

The research has used the samples made from hot rolled hardened wire Φ 3,50mm, C80, manufactured by S.C. CORD S.A. Buzau / www.cord.ro. The chemical composition of the steel C80 was determined using a spectrometer with optical emission DV6 – BAIRD type, made in USA, (belonging to S.C.ARCELOR MITTAL S.A. Iasi).

Chemical composition of the steel C80 (mean values), [%] is presented in Table1 *).

The chemical composition is according to EN 10016-2/1994.

Table 1 *The chemical composition of the steel C80 (mean value) [%]*

C	Mn	Si	P	S	Cu	Cr	Ni	Al	N	As	Sn
0.82	0.52	0.20	0.009	0.014	0.01	0.04	0.01	0.003	0.0026	0.001	0.001

[*)] The chemical composition is according to EN 10016-2/1994

3.2 Research methodology

The objective of the experimental study is to give a characterization for the ultrasound drawing technology / UVD Technology, of the wires which have cylindrical symmetry and high resistance, through convergent conical dies, in comparison with the classic technology / CT (without ultrasound activation of the die).

The scheme of the oscillator system / OS used in the research process is presented in Fig. 5.

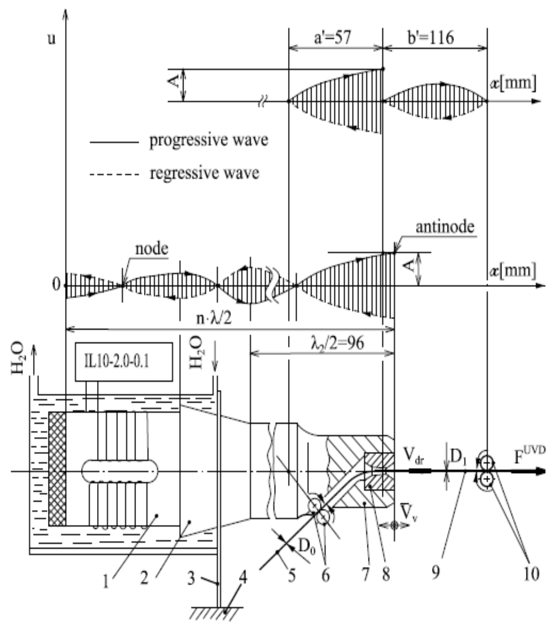

Figure 5: *Scheme of the oscillator system used for the experimental research:*

a) wave oscillation in the semi-finished and drawn wire;

b) wave oscillation at the oscillator system level (magnetostrictor transducer, conical concentrator and graded cylindrical concentrator/working part);

c) proper scheme: 1-magnetostrictor transducer; 2-conical concentrator; 3-noduled flange; 4-experimental hydraulic wire-drawing bench BTL-01.000; 5-semi-finished wire; 6, 10-ultrasonic energy reflector (pressure roll); 7- graded cylindrical concentrator/working part; 8-die; 9-drawn wire.

The researches were made based on the singular drawing principle / through one single die, on a drawing equipment UDZSA TO631 type.

There were used dies with cores made from metallic carbides, (WCr), belonging to S.C. MECHEL S.A. Campia Turzii, and which had the half-angle of the die cone $\alpha = 8^0$.

4. Determination of the resistance and plasticity mechanical characteristics, (R_m, $R_{p0,2}$, and A_{10})

The characterization of the plastic deformability for the hardened tyre cord C80, Φ3mm – classic drawing technology / CT / A and ultrasonic drawing technology / UVD / B, C and D, (B / A = 15 μm; C / A = 20 μm; D / A =25 μm) was made based on the results obtained after the drawing rupture test; the test was made using the universal machine MTS 824.10, (the rate of stress was 20mm/s).

Variation of the resistance and plasticity mechanical characteristics, in the case of the CT and UVD Technology processed samples, f = 17500Hz; D_0 = 3,50mm; D_1 = 3mm.

Experimental results obtained for tensile testing according SR EN 10002, are presented in table 2 and figure 6.

Table 2

Sample symbol	$v_{tr} / \overline{v_v}$ -	R_m [MPa]	$R_{p0,2}$ [MPa]	A_{10} [%]
A/TC	-	1575	1485	3,60
B/UVD, 15 μm	0,036	1535	1425	3,66
C/UVD, 20 μm	0,027	1475	1356	3,84
D/UVD, 25 μm	0,021	1405	1255	4,04

Cumulative diagram of the tension stress for the four types of test pieces: A, B, C and D.

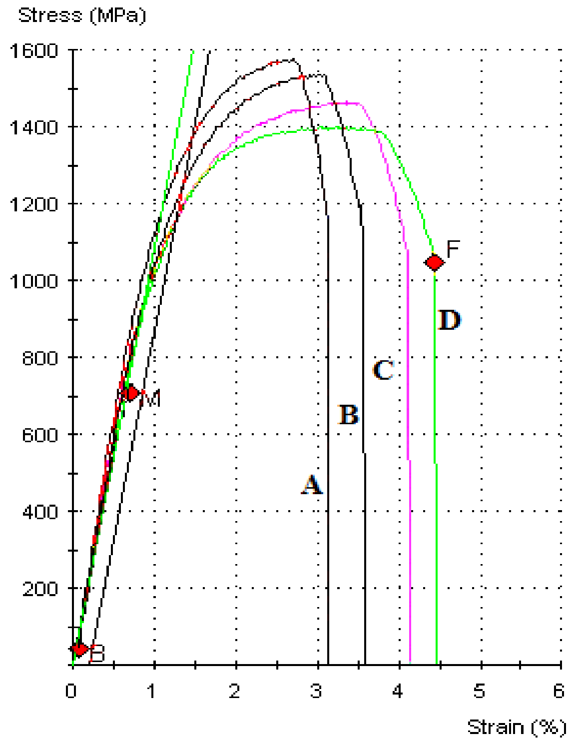

Figure 6: *Cumulative diagram of the drawing stress, samples A, B, C, and D.*

5. Conclusions

The modifications of the resistance and plasticity mechanical characteristics, (R_m, $R_{p0,2}$, and A_{10}), are analyzed in dependence with the relative rate of drawing, ($v_{tr}/\overline{v_v}$). It was observed that the values of the mechanical characteristics, (R_m and $R_{p0,2}$), decrease and the value of the plasticity characteristic (expressed by the elongation, A_{10}) increases in the same time with the decreasing of the relative rate of drawing.

This means that, when both, v_{tr} and f, have constant values, the amplitude of the die oscillation must increase. The modification of the resistance and plasticity mechanical characteristics, depending on the relative rate of drawing, ($v_{tr}/\overline{v_v}$), goes to an eventual control of the strain hardness for the wires drawn in ultrasound field.

References

[1] Cazimirovici E. et. al., *Teoria și tehnologia deformării prin tragere,* Editura tehnică, București, România, 1990.

[2] Severdenko,V.P.,Klubovici, V.V., Stepanenko, A.V., *Prokatkia i volocenie c ulitrazvukom*, Nauka Tehnika, Minsk, 1970;

[3] Susan, M.,*Tragerea metalelor cu vibratii ultrasonice*. Editura Cernei, Iasi, 2007.

[4] Iliescu V., *Ph.D Thesis*, Faculty of Materials Science and Engineering, The "Gh.Asachi" Technical University from Iași, 2010.

[5] Susan M., et al., *Rev. Metal*, Madrid 40 (2004), pp.109-117