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University POLITEHNICA of Bucharest, Machine and Manufacturing Systems Department
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STUDY OF THE PLASTIC DEFORMATION BY DRAWING OF THE ECOLOGICAL QUATERNARY ALLOYS

Petrică CORĂBIERU, Stefan VELICU, Anişoara CORĂBIERU,

***Abstract**: The drawing of the quaternary alloys CuNiAlSi is achieved at the temperature of ambient medium, when the plastic deformation is accompanied by cold hardening. Combined with heat treatments, the procedure of drawing improves the mechanical properties of the deformed material. The present work studies the stresses, deformations and remnant stresses in the case of the drawing of the bars of quaternary alloy CuNiAlSi.*

***Keywords:** bar, drawing, quaternary alloys, stresses, deformation, remnant stresses.*

1. INTRODUCTION

The drawing of the bars of quaternary alloy CuNiAlSi depends on a series of factors that influence the quality of the obtained items:

- drawing speed – at big drawing speeds a reduction of the mechanical characteristics takes place due to the fact that the non-homogenous deformations that are produced in the material produce high temperatures and consequently extra tensions that can not be annulled;
- degree of reduction of the section is limited by the material tensile strength, because the stresses caused in the material by the drawing force has to remain inferior by respect to its ultimate strength;
- quality of the lubrication influences directly the quality of the surfaces of the drawn wires, the reduction of the deformation force, increasing of the draw-plates endurance.

2. STUDY OF THE STRESS CONDITION

The combination between the schemes of the main unitary efforts (σ_1, σ_2 and σ_3) and of the main deformations (ε_1, ε_2 and ε_3) leads, in the drawing case, to a mechanical scheme of the plastic deformation of type S_2 - D_{III} (Fig. 1). The scheme of the main unitary efforts S_2 is of spatial type and is characterized by two radial compression stresses σ_2 and σ_3 (due to the symmetry they are equal in value), and an axial tensile stress, σ_1. The main stress, σ_1, appears as a result of the application of the drawing force P, and the stresses σ_2 and σ_3 are provided by the stress σ, the resultant of the normal compression stress σ_n and of the friction stress τ_o. Still due to the symmetry the two main radial deformations ε_2 and ε_3 of the deformation scheme D_{III}, have equal values.

3. STUDY OF THE DEFORMATIONS

In the drawing process, the deformations on the section are not uniform. The non-uniformity of the deformation and the stress condition in the material depend on the angle of penetration of the draw-plate (γ) and of the lubrication quality. It can be evaluated that the deformation on the wire section is as much uniform as the drawing force is smaller for a certain reduction. The theoretical calculations show the fact that the drawing force is minimum for a certain optimum angle γ (Fig. 2) (dependent on the degree of reduction of the section), when the yield of the quaternary alloy takes place in a laminating way, the deformations on the section getting a more reduced non-uniformity degree. Smaller values of the angle γ are considered in the case of small reductions of section and adequate lubrication (Fig. 2,*a*) and bigger values for big reductions and imperfect lubrication (Fig. 2,*c*). When the angle γ is bigger, on the inclined surface of the draw-plate a stationary area can appear that increases the non-uniformity of the deformations in the section. At inclinations even bigger of the draw-plate the scraping of the outer layer can appear, respectively its compression, resulting a bigger non-uniformity of the deformations on the section.

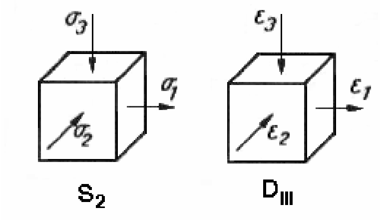

Fig. 1. Scheme of drawing deformation.

As the optimum angle of the draw-plate depends also on the degree of reduction of the section, the draw-plates

a b c

Fig. 2. Yield of the metallic material depending on the angle γ of the draw-plate: a) small values for γ; b) average values for γ; c) big values for γ.

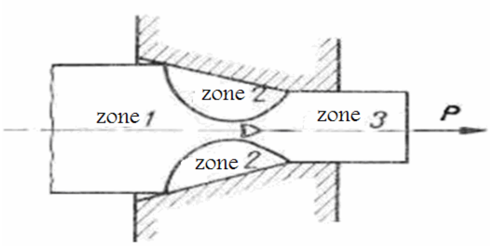

Fig. 3. Areas of deformation during drawing.

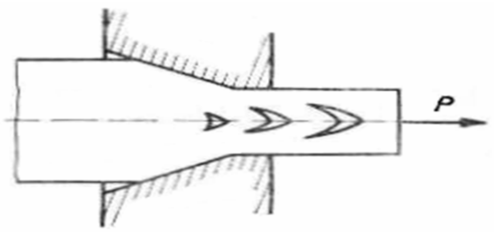

Fig. 4. Possible defects in the drawn wires.

must have a variable entering angle. The deformation during drawing is maximum on the outer zone, where there is a maximum compression effort and a minimum tensile axial effort (Fig. 3). Sometimes it is possible that the deformation zone comprise only the external part of the wire and not also the axial part. In such cases at the axis defects can appear having the shape of elongated cavities (Fig. 4). In order to avoid the apparition of these ones the deformation conditions must be modified (improvement of the lubrication, reduction of the degree of section reduction or even the replacement of the draw-plate with another of the same calibration but with another entering angle).

In the drawing process it was had in view that the total reduction of the section to be achieved in an as small as possible number of passages, this number being conditioned by the material tensile strength and the cold hardening degree, so that the stresses in the material created by the drawing force do not exceed 75 % of the tensile strength of the material, if contrary the apparition of the over-drawing being possible, that corresponds to some destroying in the external layers of the wires.

4. LABORATORY EXPERIMENTS

Before drawing, the bars of quaternary alloys CuNiAlSi have been submitted to some etching, cleaning and neutralization operations. The etching was made in order to remove the oxide layer resulted after the heat treatment, in order to reduce the wear and the deterioration of the active part of the draw-plate due to the big hardness of the oxide and to improve the quality of the drawn product. The oxide etching was made in a solution of H_2SO_4 with the concentration of 20%, at 50-60 °C. Immediately after the etching the washing of the bars in fluent water has followed, in order to remove the acid and the copper sulphate remained on the surface that make difficult the drawing or produce the point-like corrosion of the alloys. The tracks left after washing have been neutralized by the introduction of the bars in a solution of $Ca(OH)_2$, with the concentration of 90 %. By the neutralization it was had in view the forming of a protecting layer that block the oxides forming until the start of the drawing process and that, together with the lubricant, ensure a good greasing of the wire in the drawing process. At drawing, draw-plates with big opening angle at the entrance of the material (12 - 24°) and small angle at the exit (5 - 10°C) have been used, because this way big reduction of the section on passes and uniform sections of wires can be obtained.

The reduction of the section from ф 6,4 to ф 1.0 mm, it was established to be done in three steps (ф 6.4 → ф 4.0; ф 4.0 → ф 2.0; ф 2.0 → ф 1.0), each step having a number of successive passes and the total degree of reduction on a step does not have to exceed 75%. In order to don't produce the deterioration of the drawn portion of the wire, the repartition of the section successive reductions on passes has been made such a way that the reduction of diameter corresponding to one pass through the draw-plate (drawing coefficient $k = d_e / d_i$) to be at least 0.8. In order to prevent the material breaking during drawing because of its strong cold hardening, after each reduction step, a heat treatment was performed in order to eliminate the cold hardening effect and the reestablishment of the initial plasticity properties of the materials (heating during 5 - 8 min at 850°C, cooling in water), followed by etching, washing and neutralization operations. The first reduction step of the bars has been performed on a drawing stand and the following two steps on a drawing machine with drum. In the first case, in order to reduce the deformation force, silicon rubber has been used as lubricator and, in the second case a lubricator based on soap powder has been used.

The utilization of the drawing stand ensures the obtaining of straight wires, with relatively big lengths, that are used as half-products for the manufacture of parts of ecological quaternary alloys type CuNiAlSi. The continuation of the wires reduction by drawing on the machine with drum has been effected because the heat treatment of the wires that arrive at bigger and bigger lengths is easier to be made in twist shape.

In the Table 1, the intermediate diameters of the wires during the drawing process are shown, from ф 6.4 to ф 1.0 mm, for each pass and reduction step, together with the relative degrees of reduction on step. After the passing through the last draw-plate (ф =1.0 mm), by examination of the surface of the obtained wires, no scratches, cracks, chips, hollows, exfoliation, flakes and other defects that could appear in the drawing process, the wires arriving at this diameter without any breaking. It result that the replacement alloys have an enough high plasticity (the maximum reached deformation degree being of 75 %), and the applied heat treatments are of softening.

The big value of the drawing coefficient (k = max 0.94) corresponds to a soft material, easy to be processed by deformation. Theoretically, the value of the drawing coefficient k is calculated depending on the material tensile strength, σ_t , respectively compression strength, σ_c , with the formula:

$$k^2 = \frac{\sigma_c}{\sigma_c + \sigma_t}, \quad (1)$$

starting from the condition of equilibrium between the two forces that act at drawing: axial t ensile force and compression cross force (successive diameters of the

Table 1

Successive section reduction of the wires of ecological quaternary alloys

Reduction step	Nr. of passage	Diameter of entrance d_i, mm	Diameter of exit d_e, mm	Drawing coefficient $k = d_e / d_i$	Degree of reduction on step, %
I	1	6.4	5.7	0.89	
	2	5.7	5.0	0.88	
	3	5.0	4.0	0.80	60.94
II	1	4.0	3.6	0.90	
	2	3.6	3.0	0.83	
	3	3.0	2.6	0.87	
	4	2.6	2.3	0.88	
	5	2.3	2.0	0.87	75.00
III	1	2.0	1.8	0.90	
	2	1.8	1.7	0.94	
	3	1.7	1.5	0.88	
	4	1.5	1.4	0.93	
	5	1.4	1.3	0.93	
	6	1.3	1.2	0.92	
	7	1.2	1.1	0.92	
	8	1.1	1.0	0.91	75.00

drawn wires depend on this value of the drawing coefficient). The total number of successive drawings, for each of the three drawing steps is calculated with the relation:

$$n = \frac{\log(d_e / d_i)}{\log k}, \qquad (2)$$

where the coefficient k used have been taken equal to the average value of the step (0,86; 0,87; 0,92) corresponds to the data shown in the Table 1, respectively $n_I = 3$; $n_{II} = 5$; $n_{III} = 8$.

5. STUDY OF THE REMNANT STRESSES

The action of forward flow and making thin of the half-product in the drawing process is made by traction. Due to the drawing force P. the material is submitted to a condition of internal stresses bigger than in the case of rolling. The residual internal stresses or remnant stresses represent a system of stresses that can exist in a body when this one is not stressed by any external force and they appear every time when the body has non-uniform plastic deformations by non-homogeneous modifications of the volume and shape. At the drawing of the wires. the deformation is maximum outside, where the compression radial effort is maximum and the axial traction effort is minimum. This way, the peripheral zone of the wire will be more elongated than the central zone. As the wire has to remain a continuous body, the elongations of the peripheral and central zones have to adapt. The „fibers" from the wire center tend to block the elongation of the external "fibers", while the outer „fibers" try to elongate the central ones. The result consists in the apparition of a spectrum of remnant stresses in the interior of the wire, composed of compression stresses outside and elongation towards the center. The distribution of these axial stresses on the wire section and their variation on the diameter of the wire are shown in Fig. 5.

The remnant axial stresses influence the mechanical characteristics of the quaternary alloy.

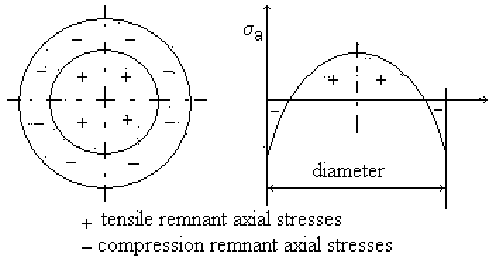

Fig. 5. Axial stresses remnant in a drawn wire.

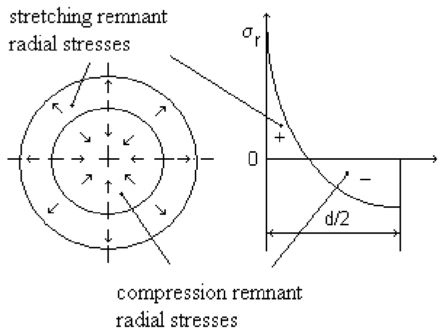

Fig. 6. The remnant radial stresses in a drawn wire.

This way, at elongation, the area with tensile remnant elongation stresses will be plastically deformed at a more reduced value of the tension applied and that with compression stresses at a bigger value by respect to the case of the traction of a material without remnant stresses (the values of the remnant stresses can not exceed the value of the yielding stress of the quaternary alloy). A remnant stress that would exceed this value, without external forces that oppose, would be overtaken by the plastic deformation of the quaternary alloy, until it will go down to the yielding limit.

The plastic deformation in the case of the drawing is permanently accompanied by an elastic deformation. After the passing of the quaternary alloy through the draw-plate, the forces that have produced the deformation don't act anymore. As a result, some of the atoms have the tendency to occupy the old positions, leading this way to a light increasing of the diameter, phenomenon that is called elastic recovery. The elastic recovery is a phenomenon that takes time; at the beginning it takes place with maximum intensity. As a result, in the peripheral area of the wire-stretching remnant radial tensions appear and to the wire center compression remnant radial tensions appear. The distribution of the remnant radial stresses is shown in Fig. 6.

The elastic recovery depends on the opening angle of the draw-plate, being smaller for big opening angles.

Except the axial and radial residual stresses in a drawn wire, in the peripheral zone of this one also circumferential remnant stresses appear, caused by the torsions of the wire during drawing process.

6. METALLOGRAPHIC RESEARCHES

The drawing of the ecological quaternary alloys CuNiAlSi influences directly the microstructure of the com plex alloys. Metallographic researches by optical microscopy have been effected on the specimens of ecological

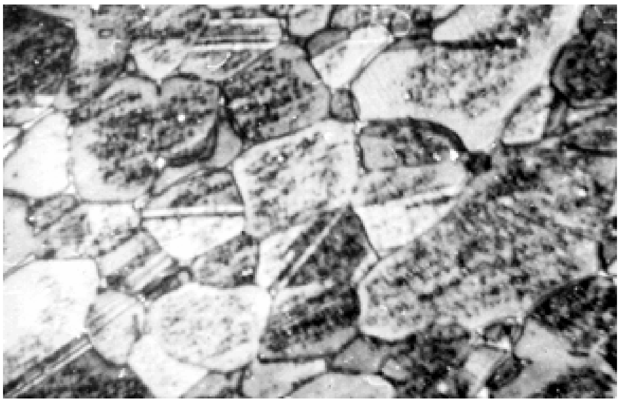

Fig. 7. Microstructure of the ecological quaternary alloys CuNiAlSi drawing: reduction step I; degree of reduction on step: 60.94% →granules elongated, (100:1)

Fig. 8. Microstructure of the ecological quaternary alloys CuNiAlSi drawing: reduction step III; degree of reduction on step: 75.00% →granules elongated, (100:1)

alloys of the peripheral layer and central layer. The peripheral layers of the wire will be more elongated than the central layers (Fig. 7 and 8).

7. CONCLUSIONS

- The traction force has a reduced value for a certain optimum angle γ, when the yielding of the quaternary alloy takes place in a laminar way, the deformations on the section getting a more reduced degree of non-uniformity.
- The remnant axial tensions influence the mechanical characteristics of the quaternary alloys type CuNiAlSi (at stretching, the zone with remnant elongation stresses will be plastically deformed at a more reduced value of the applied tension and that with compression tensions at a bigger value) by respect to the case of the drawing of a material without remnant stresses.
- The elastic recovery depends on the opening angle of the draw-plate, so that the value of the elastic recovery is smaller for big opening angles.
- Except the residual axial and radial tensions from a drawn wire, in the peripheral of this one also remnant circumferential stresses appear caused by the wire torsions during the drawing process.
- For the drawing of the ecological quaternary alloys draw-plates with big opening angles on the side of alloy entering (12 - 25°) and small angles at the exit from the draw-plate are recommended, in order to obtain big reductions of sections by a more uniform passage and repartition of the tensions
- The granules of peripheral layers will be more elongated than the granules of central layers.

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Authors:

Petrica CORABIERU, S.C. PRESUM PROIECT S.A. Iassy, Romania,
E-mail: pcorabieru@yahoo.com
PhD, Stefan VELICU, Professor, Universuty Politehnica of Bucharest, Machine and Production Systems Department,
E-mail: velstefan@hotmail.com
Anisoara CORABIERU, S.C. PRESUM PROIECT S.A. Iassy, Romania,
E-mail: acorabieru@yahoo.com