



DETERMINATION OF POISSON'S RATIO OF A LOW CARBON STEEL IN DIFFERENT PLASTIC STATE OF DEFORMATION USING A MICROSTRUCTURAL METHOD

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The paper presents a method to determine the Poisson's ratio of a low carbon steel in plastic state of deformation. It was used a microstructural measuring method of the ferrite grains size, in the diametral section of the cylindric specimens subjected to tensile stress. The measurements have been made using a scanning electron microscope, in the longitudinal and transversal direction of an orthogonale lattice of 1×1 mm, with 0.2 mm interspace between the lines. So, 90 measurement areas were used. Initially, these areas were subjected to plastic deformation, in the range $\psi/Z=0.05\div0.95$, where Z represents the fracture shrinkage. The obtained result has a double statistical signification, one by the number of ferrite grains in the measurement area, and another by the number of the measurement areas. After the data statistical processing, it was obtained the mean value and the standard deviation of Poisson ratio. These values are significantly lower than the theoretical value and not depending on the degree of plastic deformation, ψ .

Key words: tensile stress, Poisson's ratio, plastic deformation, statistical evaluation, grain size.

1. GENERALITIES

Poisson's ratio is an intrinsic characteristic of a solid body, as well as Young modulus of elasticity or shearing modulus. This coefficient is very important in the theory of elasticity and plasticity, in the theory of ductile fracture, in the materials resistance, in the theory of stresses concentration, in the fracture mechanics, etc. Also, it has a great importance in the field of nanotechnologies and processing technologies by heat or cold deformation and for the composite materials having a cellular structure.

The value of Poisson's ratio is depending on the material type and its degree of deformation. Usually, for metals, the values of Poisson's ratio are between 0.25 and 0.50 [1, 2].

Poisson's ratio is defined as the ratio between the specific transversal strain and the specific longitudinal strain of an homogeneous and isotropic solid body:

$$\nu = -\frac{\varepsilon_t}{\varepsilon_l}. \quad (1)$$

In the case of a cylindric body having the length (l) and the diameter (d) subjected to monoaxial tensile:

$$\nu = -\frac{(\Delta d / d)}{(\Delta l / l)}. \quad (2)$$

For large plastic deformations of steels, over 10% [3] ($\psi \approx 0.1$), the deformation process is located and amplified in the zone of reduction of area of the specimen subjected to elongation.

In accordance with the plasticity hypothesis of Bridgmann [4], in the minimum section, the deformations are quasi-uniform, and they are formed from one longitudinal strain and two equal transversal strain of area. They are characterized by the specific true (natural) strain value.

In this situation, the specific natural elongation is:

$$\varepsilon_l' = \int_{l_0}^l \frac{dl}{l_0} = \ln \frac{l}{l_0} = \ln(1 + \varepsilon_l) \quad (3)$$

and the transversal (or radial) specific strain is:

$$\varepsilon_t' = \varepsilon_r' = \int_{d_0}^d \frac{dd}{d_0} = \ln \frac{d}{d_0} = \ln(1 - \varepsilon_t) = \ln(1 + \nu \varepsilon_l). \quad (4)$$

In accordance with the invariance condition of the volume:

$$\varepsilon_l' + 2\varepsilon_r' = 0 \quad (5)$$

resulting

$$\varepsilon_l(1 - 2\nu) = 0 \quad (6)$$

and the theoretical value of Poisson's ratio 0.5.

In order to determine the Poisson coefficient, many methods have been elaborated. Most of them are adjusted to different types or states of materials.

In the case of steels and metallic alloys, there are known the direct, standardized methods, which are based on the specific deformations measurement, resulted from the relation of definition (1). The indirect methods are based on the measurement of the materials elastic constants [1, 2, 3] and on the static and dynamic relations of definition.

The acoustic interferometry, the method of wave pulses (longitudinal and transversal), the determination of propagation speeds in the specific environment [5], and also the method based on the variation of the waves propagation frequency [5] are the most used methods.

In the case of viscoelastic materials, it is used the method of complex modulus determination in a large field of frequency variation [6], and also the method of beta radiation absorption [7].

In some special cases, important for the technologies of thin layers depositions, now it is used the method of digital images [8]. In the case of silver nanofibres, it was used an electro-mechanical method in order to determine the correlation between the voltage and the mechanical strength [9].

The method applied in this paper is based on the measurement of the main components of specific microdeformations, which are characteristic to the metallographic constituents. So, the used method has the advantage of the classical method [10], and also two other advantages, like the statistical interpretation of the measurements and the possibility to be used in different stages of deformation, beyond the uniform deformation limit of materials.

2. EXPERIMENTAL CONDITIONS

The experimental program was performed using a low carbon steel, type S 235 N, having 0.11% C and UTS = 400(MPa), also a homogeneous structure specific to annealing of steels from the grain size number G 8–8.5 [11].

The measurements of the grains size have been made in the minimum diametral section of the cylindric specimens having $d = 8\text{mm}$, and subjected to plastic deformation until to values of cross shrinkage:

$$\psi = 1 - \left(\frac{d}{d_0} \right)^2 \quad (7)$$

between 0.25 and 0.65, representing $0.35 < \psi/Z < 0.95$, where Z is the fracture shrinkage. Practically, 4 levels have been used: $\psi = 0.25 \div 0.33$ – 5 values, $\psi = 0.40 \div 0.48$ – 5 values, $\psi = 0.50 \div 0.55$ – 5 values and $\psi = 0.5 \div 0.65$ – 4 values.

The measurements of the ferritic grains size have been made by JEOL-SEM on the axial and radial direction of the orthogonal lattice of 1×1 mm, and 200×200 mm in microscope, on 10 equidistant lines (9 interspaces). The restraint of the lattice to these dimensions was made in order to obtain the most precise calculation of the degree of deformation in the measuring zone, in the same time with the decreasing of the radius of curvature in zone of minimum area.

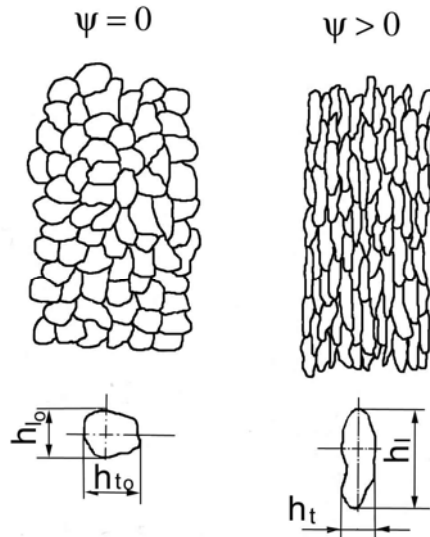


Fig. 1 – Scheme of crystalline structure deformation on two main directions, longitudinal (h_l) and radial (h_r).

The intersect of grain boundary procedure was used [11] and a magnification, $M = 200\times$ in microscope. The average size of the grain (h) was calculated using the relation $h = 200/n \cdot M = 1/n$ [mm], where (n) is the number of intersections of grains boundaries, on 200 mm length. In the initial state, the mean size of the grains was $h_0 = (18-21) \mu\text{m}$.

After deformation, in accordance with Fig. 1, the grains dimensions will be:

$$h_l > h_0 > h_r. \quad (8)$$

The specific longitudinal, and the specific radial strain are:

$$\varepsilon_l = h_l / h_0 - 1, \quad (9)$$

$$\varepsilon_r = 1 - h_r / h_0. \quad (10)$$

In order to determine the maximum values, some correction coefficients can be applied.

3. RESULTS AND DISCUSSIONS

The structure aspect after the deformation, for different values of ψ , is shown in Fig. 2.

Based on the measurements made on 90 areas, the mean values of the longitudinal specific strain (ε_l) and radial specific strain (ε_r) have been established. These values allowed to determine the frequency to enclose the ratio $\varepsilon_r/\varepsilon_l$ in 11 interspaces of 0.2 in the range $0.34 \div 0.56$ (Table 1).

The obtained results on 5 areas have been eliminated, based on the Chauvenet criterion. So, the experimental data were obtained on the real linear dimension of $1 \times 9 \times 90 = 810$ mm, equivalent to intersection of approx. 45,000 undistorted grains.

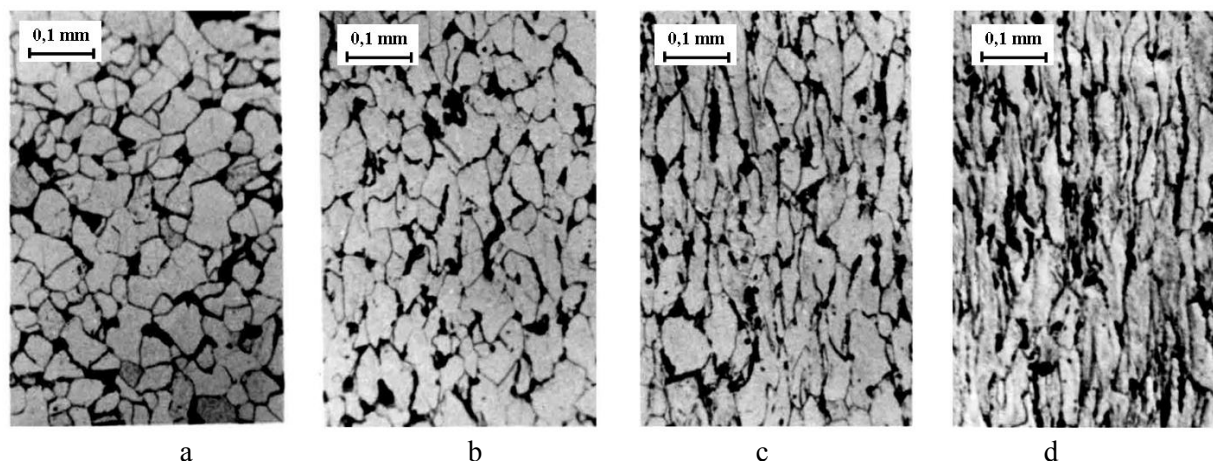


Fig. 2 – Ferrite structure of investigated steel after the deformation, for: a) $\psi = 0.02$; b) $\psi = 0.21$; c) $\psi = 0.48$; d) $\psi = 0.62$.

Table 1
Statistical parameters of ν

Interspaces values of ν	Frequencies f^*			
	f_{abs}	f_{cum}	f_{rel}	$f_{rel-cum}$
0.34–0.36	3	3	0.035	0.035
0.36–0.38	5	8	0.059	0.094
0.38–0.40	6	14	0.070	0.164
0.40–0.42	10	24	0.118	0.282
0.42–0.44	14	38	0.165	0.447
0.44–0.46	14	52	0.164	0.611
0.46–0.48	12	64	0.141	0.752
0.48–0.50	9	73	0.106	0.858
0.50–0.52	6	79	0.070	0.928
0.52–0.54	4	83	0.048	0.976
0.54–0.56	2	85	0.024	1.000

*Abbreviations: abs – absolute, cum – cumulated, rel – relative, rel-cum – relative – cumulated

In Fig. 3, it is presented the probability of Poisson's ratio, based on the relative cumulated frequency values, $p = f(\nu)$.

This distribution allows to determine the mean value (ν) and the standard deviation (s) corresponding to the given probability of the mean value. So, for (ν), it was established the value 0.434, and the confidence interval $2s = 0.088$. and

$$\nu = 0.434 \pm 0.044 = 0.390 \div 0.478. \quad (11)$$

The possibility to obtain lower values to 0.5 was evinced in another way, in other papers, as [12] and [13]. This situation can be explained by the small variations of the volume during the plastic deformation, that are determined by:

- crushing processes of grains, in smaller grains of 1–2 μm , that was demonstrated by the authors mentioned in paper [14];

- producing of density variations [15] by processes of dislocations storage, owing to increasing the degree of deformation, to intersection of slip bands, and to microcavities appearance [16]. So, it was demonstrated in paper [17], that if the nominal specific strain is increased from $\varepsilon = 0.21$ to $\varepsilon = 0.70$, the dislocations density is increased by more than 10^4 times.

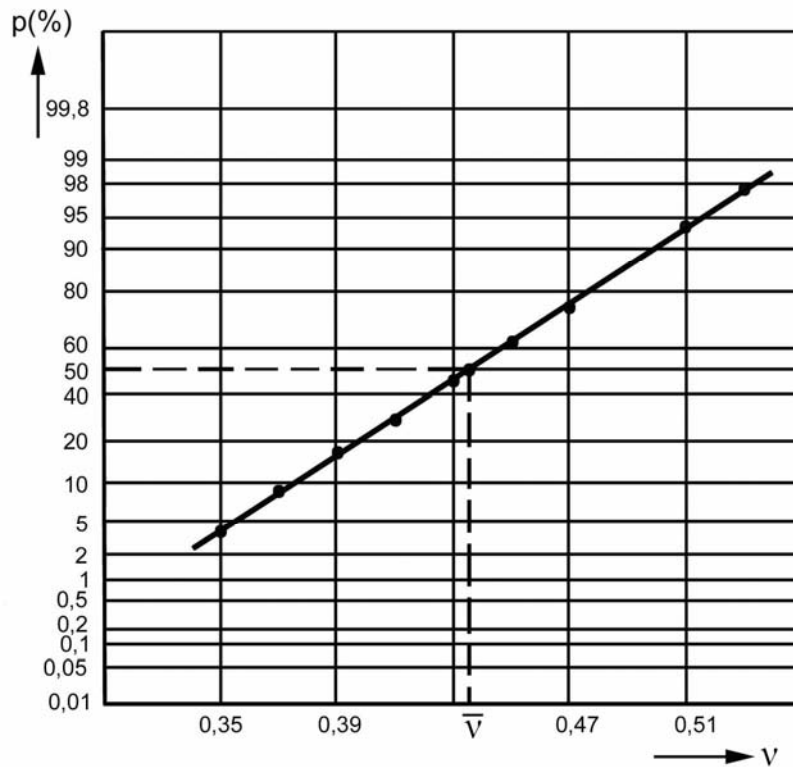


Fig. 3 – Probability distribution of Poisson's ratio.

No correlation was established after the data statistical processing depending on the degree of plastic deformation, ψ .

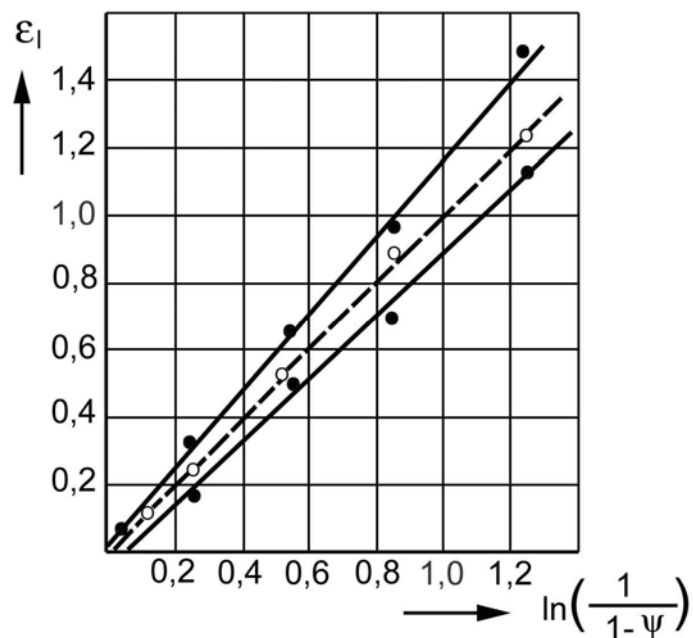


Fig. 4 – Correlation $\varepsilon_l - \ln[1/(1-\psi)]$.

In Fig. 4, it is presented the linear correlation between the minimum and maximum longitudinal strain, obtained by microscopic measurements, and the natural strain (logarithmic), determined by macroscopic

measurements. The obtained area of dispersion is more than 30%, but it is well centered towards the variation of the natural strain.

4. CONCLUSIONS

The method to determine the Poisson's ratio using the measurement of the ferrite grains size is valid in conditions of double statistical signification, both the size and the number of investigated areas.

In comparison with the classical method [10], the method approached in this paper offers large possibilities of application, in the case of processing technologies by plastic deformation.

In the situation of using a large range of degree of plastic deformation for a low carbon steel subjected to tensile stress, it was evinced that the value of Poisson ratio is significantly different from the theoretical value. The mean value determined on $45 \cdot 10^{-3}$ undistorted ferrite grains and the confidence interval of the mean value corresponding to the probability of 90%, were under the theoretical value.

The volume variation corresponding to the deviation from the theoretical value was approx. 15%.

Also, a good correlation between the dispersion area of the values of longitudinal strain, determined by microstructural measurements, and the values of natural strain (logarithmic), was established.

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