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THE STRUCTURAL STATE OF HYDROSTATICALLY EXTRUDED NON-FERROUS METALS

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ABSTRACT

It is well known that during cold plastic deformation of metals at high pressure, some important mechanical and electrical properties of the deformed material are modified as well as structural changes typical to nanomaterials take place. X-ray diffraction was used to investigate texture, internal stresses, grain size and dislocation density in Al 99,5 % and CuE, subjected to hydrostatic extrusion. Evidence of favourable influence of the hydrostatic pressure on the material properties is presented.

KEYWORDS: hydrostatic extrusion, X-ray diffraction, cold plastic deformation

1. INTRODUCTION

Researches made up to present unanimously emphasize that hydrostatic extrusion is one the methods that extends a lot the limits of cold plastic deformation process. It is based upon the favourable effects that appear during the plastic deformation of metals and alloys under high pressures. The tri-axial state of the compression stresses created during the process leads to a considerable plasticity behaviour.

The hydrostatic method differs from the conventional one, since it is used a hydraulic medium that interposes between the billet, that is to be deformed, and the extrusion punch.

To set in the process, and respectively to make the billet to pass through the orifice of the forming tool active die, it is needed an indirect action of the extrusion punch upon the liquid, which constitutes the hydraulic medium.

In this way it results a hydrostatic pressure, *p*, of a certain level that is uniformly distributed over the whole surface of the billet that gets into contact with the liquid, Fig. 1.

Using the hydrostatic pressure, the crystalline structure of the metals is modified firstly by diminishing the constant of the network, transition towards another type of structure being possible. Together with an increase in pressure one can notice the tendency of reaching a structure with a higher level of packing. Exceptions to this rule might appear as a result of the compressibility of the atoms which at high pressures cannot still be considered as rigid spheres. The anisotropy of the crystals, determined by the different density of the atoms in different areas, is modified since at a high pressure it takes place a modification of the ratio of the crystal sides. Also the modifications of some physical characteristics of the metals are also possible to appear.

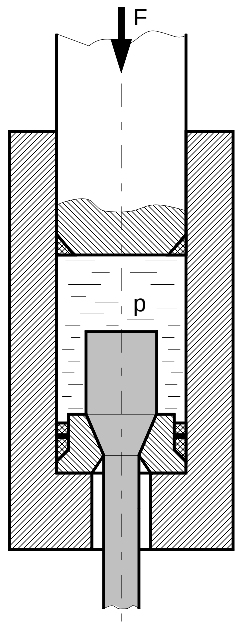

Fig. 1. – Hydrostatic extrusion process

In Fig. 2 [2], the influence of the extrusion ratio upon the size of the crystalline grains of the Al 99.5% is presented. It is to be noticed the constant diminishing of their dimensions alongside with the increase of the value of the extrusion ratio *R*, in the case of hydrostatic pressing.

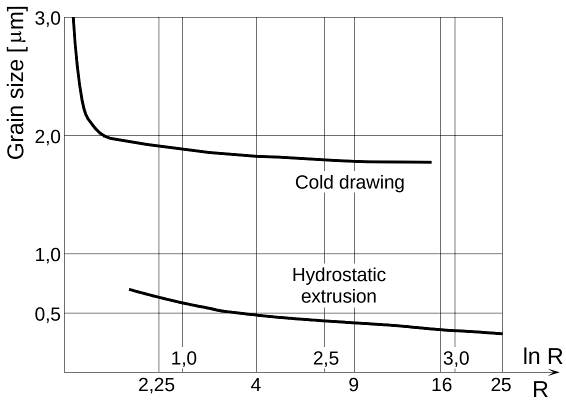

Fig. 2. The influence of the extrusion ratio upon the size of the crystalline grains of the Al 99.5%

2. EXPERIMENTAL RESEARCHES

To study details of the deformation process, two experimental tests using X-ray diffraction have been carried out. Using this method of investigation it is possible to establish the correlation among the parameters of the crystalline network of the material at the anterior or posterior state of the extrusion, the deformation process parameters and the finished piece characteristics.

By taking into account the way in which the difractometer is working, this means that the investigations can be made only upon the superficial layer of the body and not along the entire section, a mechanical preparation of the billet was performed by dividing the billet in the two identical in shape and dimensions halves, Fig. 3, that were stuck in their separation plane.

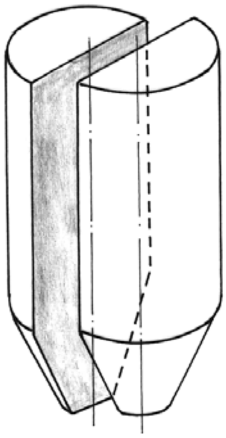

Fig. 3. Sample for Hydrostatic extrusion

The sample thus obtained could be extruded having the shape and the dimensions of the billets normally used during other experiments tests. Figure 4 presents the extrusion device.

After extrusion, the two halves of the extruded piece were separated without affecting the superficial layer above the median surface, so that the investigations made on these surfaces can be considered investigations on an undivided sample section.

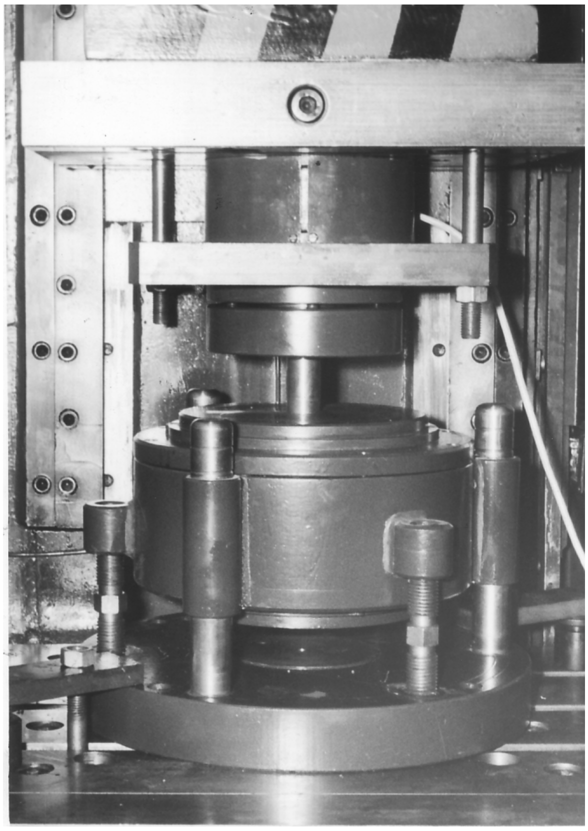

Fig. 4. Hydrostatic extrusion device

The experimental tests were performed in two ways [1]:

a) *Tests made on the section* – where a sample of *Al 99.5 %* was investigated on the section obtained as a result of the separation of the two halves of the extruded piece, according to the facts presented above.

There were thus determined the values of the parameter *P (pole density)* which appreciates the degree of material texturing following the crystallographic direction *hkl*: if $P_{hkl} > 1$ appears a material texturing in comparison with the initial state, and if $P_{hkl} < 1$ there is a retexture contrary to the initial state.

The parameter *P* was calculated with the relation:

$$P_{nkl} = \frac{\dfrac{(I_{nkl})_{pr}}{(I_{nkl})_{et}}}{\dfrac{1}{n}\dfrac{\sum_{i=1}^{n}(I_{nkl})_{pr}}{\sum_{i=1}^{n}(I_{nkl})_{et}}} \qquad (1)$$

where: $(I_{nkl})_{pr}$ is the intensity of the diffractions line from the extruded sample; $(I_{nkl})_{et}$ is the intensity of the same diffraction line from the standard sample; n – the number of the diffractions lines (in our case line which represent the crystallographic direction *[111], [200], [220],* and *[311].*

With references to the extruded pieces there were investigated the areas marked in Fig. 5. The cubic elementary cell is considered to be with one of its side parallel to the plane surface of the sample.

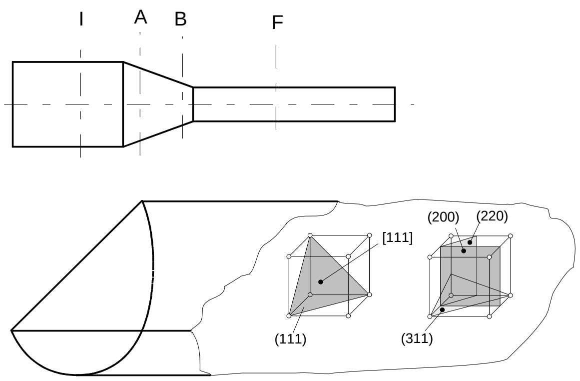

Fig. 5. Investigated areas of the hydrostatic extrusion sample

The resulted values of the P parameter are presented in table 1 and graphically in figure 6.

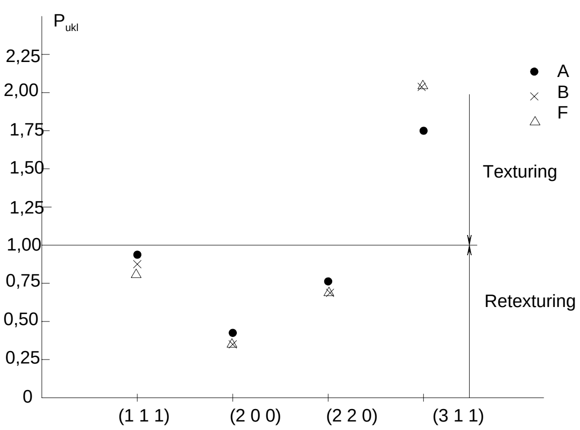

Fig. 6. Variation of the P parameter

After the interpretation of the data given in the Fig. 6 it results that during the hydrostatic process two phenomena take place: one of retexturing the crystalline grains after the crystallographic direction *[111], [200], [220]* and the other texturing, that is of partial, preferential orientation of the crystallographic planes following direction *[311].*

Table 1. Calculated values of the P parameter

Zone	P_{111}	P_{200}	P_{220}	P_{311}
I (initial)	1	1	1	1
A	0,94	0,457	0,848	1.75
B	0,91	0,340	0,730	2,01
F (final)	0,90	0,340	0,730	2,02

The predominant sliding takes place following this direction. The quotation directions mentioned are related to the origin of the elementary cell.

b) *Tests made on the surface* – where four samples from *Al 99.5 %* and *CuE* (electrolytic cupper) where investigated after a partial extrusion, with ratios $R = A_0/A$ = 3,52 and 6,25, with an angle of the active die of $\alpha = 60^o$.

The following parameters of the crystalline network were measured:

- the width of the diffraction line B_{220} (in mrad) – whose size is directly proportional to the second order internal stresses, which according to Hook’s law are correlated to the second order internal deformations. It is known that second order internal stresses are considered stresses appeared at the grain size;

- the width of the diffraction line B_{110} (in mrad) – a parameter whose size is inverse proportional to the grains medium dimension considered after the crystallographic direction *[110]*. It is correlated to the size of the material yielding point according to relation (2), [1], where: σ_o is the yielding point of the crystal; k – a standard coefficient; D_{med} – the medium dimension of the grains.

$$\sigma_c = \sigma_o + \frac{k}{\sqrt{D_{med}}} \qquad (2)$$

- the parameter $(I_{fond}/I_{max})_{220}$ – whose value is directly proportional to the dislocation density (edge and screw dislocations) from the material crystalline network.

On the basis of the measured values of these parameters in Figs. 7, 8 and 9 are presented these variations.

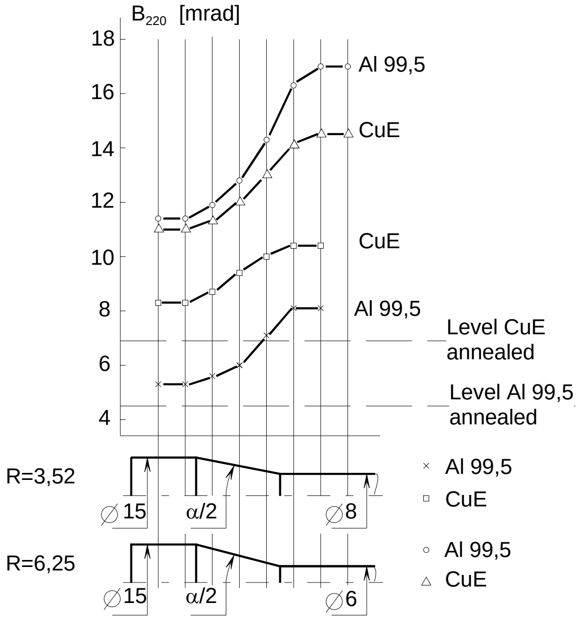

Fig. 7. Variation of the diffraction line B_{220}

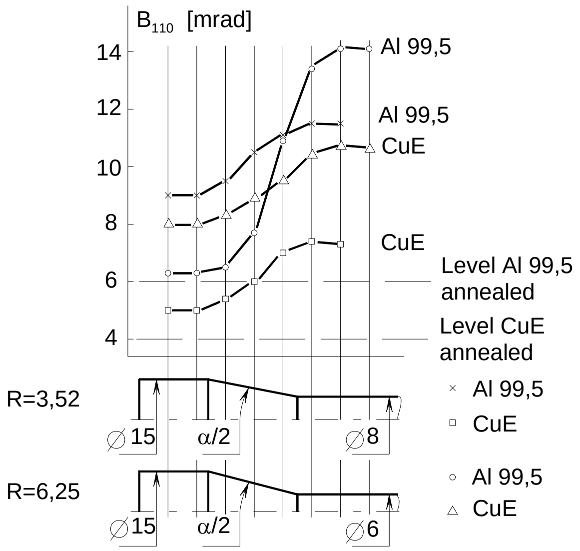

Fig. 8. Variation of the diffraction line B_{110}

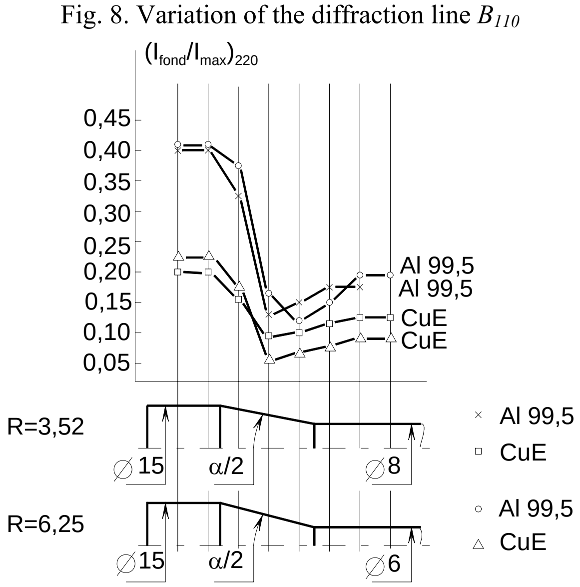

Fig. 9. Variation of the parameter $(I_{fond}/I_{max})_{220}$

5. CONCLUSIONS

In the *A* and *B* areas, the same type of texture modifications are produced, Fig. 5. The most powerful texturing is produced after the plan *[311]* for all areas. The transfer from *A* to *B* produces an increase in the number of the sliding planes of the type.

- Compared to the initial state, due to the influence of the hydrostatic pressure there appears a rise of the internal stresses even in the material left un-extruded. These stresses proportional to the second order internal deformation increase toward the more intensely deformed area. In the initial state there is a great density of the dislocations, generated probably by the action of the hydrostatic pressure, that favours the plastic micro flowing process after the plan *[311]*, Fig. 7.

- Compared to the initial state the medium dimension of the grains is diminished even in the areas in which there was no extrusion (outside the proper deformation focus). It decreases as the material penetrates into the conic area of the die. The increase of the extrusion ratio has as a result the breaking up of the grains (for higher values of the extrusion ratio the structures are finer). The influence of the extrusion ratio *R* (degree of deformation) toward the mean dimension of the grains is more pronounced to *Al 99.5 %* than to *CuE.*

- As deformation takes place, the dislocation density decreases, leading to the diminishing of the deformation properties and implicitly to the increase of hardening (Fig. 9). As a result the internal deformation energy increases due to the fragmentation of the grains (see relation 2) and to the increase of the second order internal micro deformations, while dislocations have a more reduced role in this hardening mechanism. The very powerful hardening after the deformation is due to both fragmentation of the grains, Fig. 8, and increase of the second order internal stresses (from the grain size, Fig. 7). The effect is more intense to *Al 99.5 %* then to *CuE.*

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