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POSSIBILITIES TO INCREASE THE DURABILITY OF THE ACTIVE PLATES OF THE EXTRUSION DIES

Cristian – Ioan INOAN, Radu – Nicolae CORCHEȘ, Gheorghe **ACHIMAȘ**

Abstract: Extrusion is the operation of deformation in volume, through which parts with simple or complex configurations are executed, based on the plastic flow of the material in the space between the punch and the extrusion plate or through the hole of the extrusion plate.

Active plates for extrusion from molds must ensure the geometry and dimensional accuracy of the parts and be resistant to high stresses in the process of deformation of the material. The problems that arise in the design of active plates from extrusion dies are: determining the pressure, respectively the tensions;

- establishing the configuration of the assembly and the geometry of the active area.

An increase in the strength of the active plate from the extrusion mold can be obtained by means of shrinkage. It consists of a radial compression of the tube loaded by an internal pressure, through which the maximum normal circumferential tension is reduced. Shrinkage is done by inserting tubes, one into the other, concentric with tightening. Shrinkage can be achieved by the following methods: hot shrinkage; cold shrinkage and shrinkage under cryogenic conditions.

***Key words*:** Extrusion, active plate, extrusion die, shrinkage, seraje, pressed assemblies.

1. INTRODUCTION

The most important advantage of the cold extrusion, compared to other metal processing procedures, is the material and energy savings.

The most important advantage of cold extrusion compared to other metalworking processes is the saving of material and energy. Compared to metal cutting, this saving is 25 – 60%, and in special cases, is up to 75% (fig. 1).

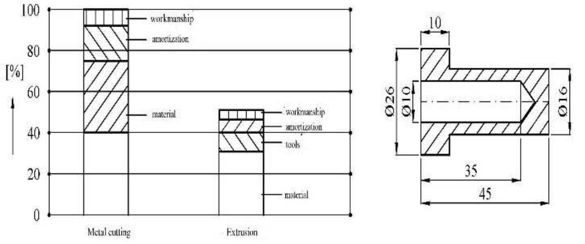

Fig. 1. Comparison between the factory cost of a part achieved by metal cutting and by extrusion [11]

In the industrial practice, three extrusion modes are currently used: direct, reverse and combined extrusion. Figure 2 shows the three ways of extruding semi-finished products obtained by cutting, as follows:

- for solid parts (Fig. 2b), the direct extrusion;
- for cylindrical, glass type parts (Fig. 2a), reversed extrusion;

for parts with special shape (Fig. 2c), combined extrusion.

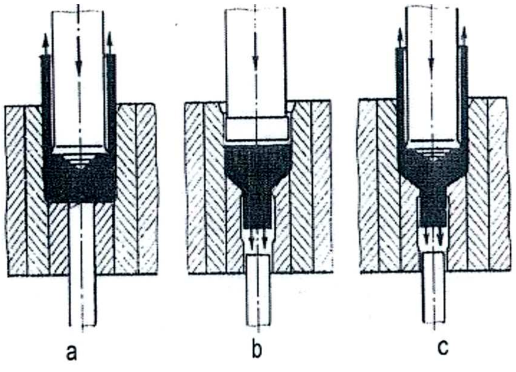

Fig. 2. Extrusion modes of some half finished products: a – reverse; b – direct; c – combined

In direct extrusion, the active extrusion plate is highly stressed, so that the section transitions from diameter “D” to “D_1” must be made with a suitable taper and the connections with radii as large as possible (Fig. 3).

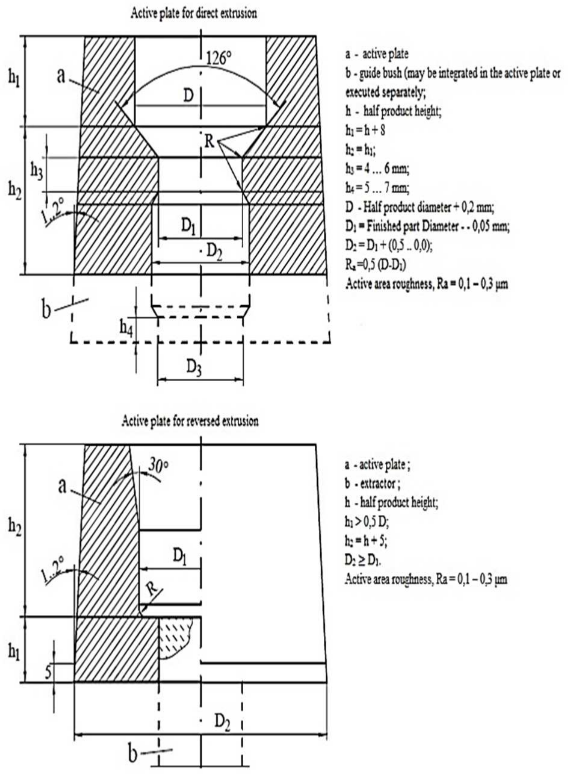

Fig. 3. Geometry of the active plates used for cold extrusion

During the deformation of the semi-finished product, a pressure “p” arises in the pocket of the active plate which acts on the entire inner surface.

This generates a radial compression stress “σ_r” and a tangential tensile stress “σ_t”; both stresses have maximum value on the internal walls of the active plate (Fig. 4), and outwards their value decreases.

These two stresses overlap in their action, building a resultant stress σ_v which applies to the body of the active plates stresses at different points, as a tensile stress.

The calculation of stresses is based on the laws of elasticity theory, valid for empty bodies with thick walls, subjected to pressure.

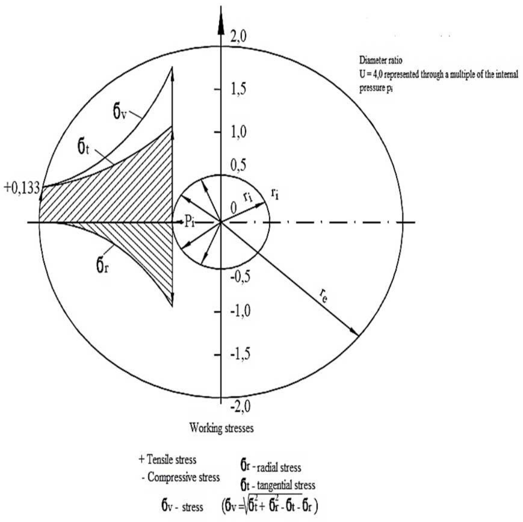

Fig. 4. Distribution of internal stresses at simple active plate for extrusion (in one piece)

The values of s and s can be determined with the relations:

$$\sigma_r = p * \frac{1}{a^2-1}\left(1 - \frac{r_e^2}{r_i^2}\right), \tag{1}$$

$$\sigma_t = p * \frac{1}{a^2-1}\left(1 + \frac{r_e^2}{r_i^2}\right), \tag{2}$$

where: “a” represents the ratio $a = x_e/x_i$ (Fig. 4).

The value of the resultant stress “σ_v” is determined from the following relation, based on the hypothesis of the mechanical deformation work []:

$$\sigma_v = \sqrt{\sigma_r^2 + \sigma_t^2 - \sigma_r * \sigma_t}\ . \tag{3}$$

From figure 4, results that the variation of the stress “σ_v” is maximum on the internal surface of the active plate, having a value of 1, 85 greater than the internal pressure. If the pressure “p” in the surface of the pocket of the active plate reaches the value of 100 daN/mm^2, then the material of the active plate is stressed with $\sigma_v = 185$ daN/mm^2.

The reduction of the maximum tension on the surface of the active area of the extrusion plate can be achieved, only by applying a tangential compression pre-stress, achievable by shrinking a thick outer mantle over the active plate, so that the pre-stress acts in the opposite direction to the tangential tension created by the extrusion pressure.

2. CONSTRUCTIVE TYPE FOR SHRINKED ACTIVE PLATES

2.1 General aspects

If the stresses that appear in the allowable range are greater than the flow limit of the active plate material, then the expansion or contraction is done according to Hooke's law and the deformation can be calculated with the relation [11]:

$$\varepsilon = \frac{\Delta d}{d} = \frac{\sigma}{E}, \tag{4}$$

whence it results:

$$\Delta d = \frac{\sigma}{E} * d \tag{5}$$

According to the expansion respectively, contraction hypothesis, the relation (5) becomes:

$$\Delta d = \frac{d}{E} * \left(\sigma_T - \frac{1}{m} * \sigma_r\right), [mm] \tag{6}$$

where: E is the coefficient of elasticity, in daN/mm^2;

σ_t – tangential tensile strength (relation 2), in daN/mm^2;

σ_r - radial compression stress (relation 1), in daN/mm^2;

d – diameter of the pocket from the active plate, in mm;

m – coefficient of increase of the compression stress (m ~ 0,3).

2.2 Classification of self-tightening assemblies (tightening)

Assemblies with self-tightening (elastic) are made by tightening caused by the elastic deformation of the joined parts. The classification of self-tightening assemblies can be:

a) According to the constructive form of the assembly, they can be:
  - assemblies without intermediate clamping elements;
  - assemblies with intermediate clamping elements.

b) According to the mounting technology:
  - compressed assemblies, executed at the environment temperature;
  - shrunk fit assemblies.

Shrinkage can be done by the following methods:

a) Hot shrinkage. Heating the ring to a temperature that must not exceed the annealing temperature of the material and not produce a thermal deformation of the bore greater than 10% of the initial bore.

Hot shrinkage requires that the steel from which the rings are made, does not lose its hardness at the temperature at which it is heated, therefore the temperature will not exceed 450^{o}C.

However, the assembly of the extrusion plates by hot friction also has some disadvantages:

- high energy consumption;
- not observing the specified shrinking temperature may lead to reducing the hardness of the material;
- the interchangeability of the component elements is not ensured.

b) Cold shrinkage (20^{o}C). This procedure is recommended to be used due to the following advantages, i.e.:

- the hardness of each pre-tensioning ring is preserved;
- the extraction and replacement of the active plates from the extrusion die is relatively easy to perform, and the pre-tensioning rings can be standardized.

The pressing size is calculated based on the total change of the diameters of an *armor* and based on the angle of inclination.

The calculation method for cold pressed conical adjustment is laborious. In practice it has been replaced by an empirical method, by using a pre-tightening of 0.1 mm, for every 20 ... 25 mm of the diameter of the active plate or the ring, the taper being 0.5 .... 1^o.

c) Shrinkage in cryogenic conditions. In this case, the extrusion plate will be cooled in liquid nitrogen, following the pressing of the plate in the outer ring to a simple reinforcement, or the intermediate ring cooled in liquid nitrogen followed by pressing in the outer ring and then the plate (cooled in liquid nitrogen) in the assembly outer ring – intermediate ring.

This shrinking procedure is a very economical process (reduced energy consumption), it also eliminates residual austenite and stabilizes martensite and does not reduce the hardness of active plates and shrink rings.

An increase of the resistance of the active plate can be obtained, with the help of shrinking. It consists of a radial compression of the active plate subject to an internal pressure, by which the normal maximum tension is decreased. Shrinking is usually done by using tubes inserted into each other, concentrically with tightening, as in Figure 5.

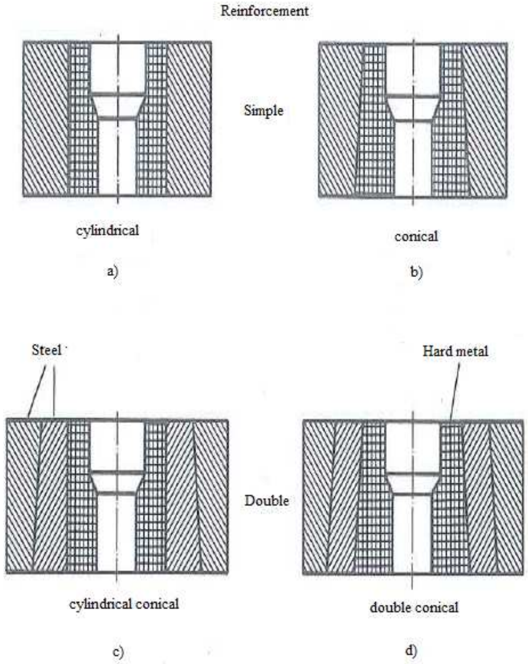

Fig. 5. Shrinking-on active plates for extrusion: a) shrink ring with cylindrical adjustment b) one shrink ring with conical adjustment; c) two shrink rings, one cylindrical adjustment and one conical adjustment; d) two shrink rings with conical adjustments

Shrinking can also be produced by winding a spiral cable, under tension, on the external surface of the active plate.

The reduction of the maximum tension in the extrusion plate can also be achieved by reinforcing the extrusion plate with the help of a high-strength steel strip wound in a spiral shape (fig. 6).

In the case of cold extrusion, the active plate and the punch have one of the most important roles. On their good design, as well as their accurate execution depends the number of executed pieces

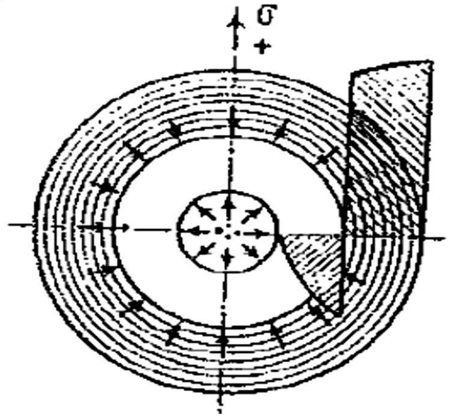

Fig. 6. Pre-tensioning of an active plate with a steel strip wound in a spiral shape

2.3 Constructive types of shrink active plates

The problems that arise in the construction of active plates for extrusion are establishing the geometry of the active area, determining the stresses and choosing the appropriate material.

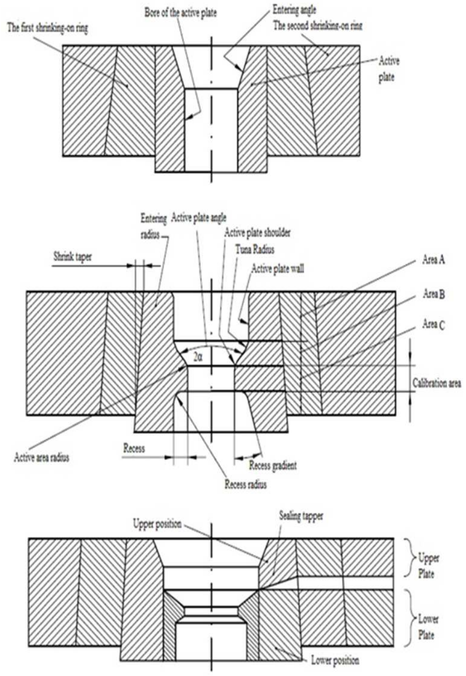

Fig. 7. Types and constructive elements for shrinking-on active plates from the extrusion dies

Figure 7 shows the types and the name of the constructive elements for shrinking-on active plates from the extrusion dies.

The reduction of the maximum tension on the surface of the active area, can only be achieved by applying a tangential compression pre-stress of opposite sense to the tangential stress created by the pressure "p". This can be achieved by shrinking-on one or two shrinking rings.

Distribution of the σ_r, σ_t, and σ_v stresses and of the pre-tensions in case of a simple reinforced active plate is presented in Figure 8.

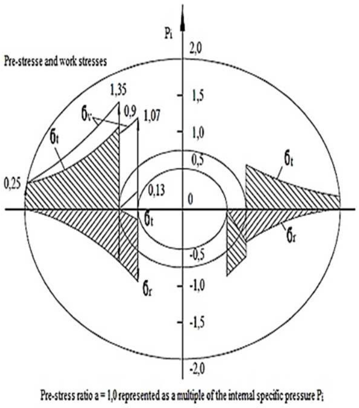

Fig. 8. Distribution of stresses in an active plate with one shrink ring

The right part of figure 8 shows the stress ratios of the reinforced active plate in the unloaded state, i.e. before the application of the deformation pressure; on the left side, is represented the way in which the pre-stresses and the working stresses overlap when applying the entire deformation pressure. It is observed that the tangential stresses in the plate disappear almost completely; they moved in the ring of the active plate.

By this, the real stress of the plate is reduced in the wall of the pocket from the value of 1.87 p to the value of 1.07 p.

Instead, in this situation the active plate ring must take on a higher load; it is loaded at the contact surface between the plate and the outer ring with a value of 1.35 p.

If this peak load of the shrink ring will be higher than the yield strength σ_c, then the ring may break or increase its size beyond the elastic limit; in this case, the active plate will be overloaded and it will crack.

To eliminate this shortcoming, two shrink rings are used (fig. 9), in this case achieving a more uniform distribution of the load.

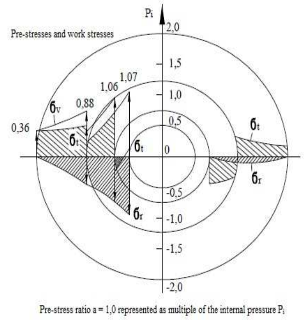

Fig. 9. Distribution of stresses in an active plate with two shrink rings

As it results from figure 9, the double reinforcement considerably reduces the maximum load for the active plate and thus the load can be distributed more evenly over the entire cross section of the plate.

Based on some practical data (11), certain values of the diameters of the shrink rings and of the outer diameter compared to the inner diameter of the active plate D were established. Between these, it is indicated to have the ratios:

$$D * n : d * n^2 : D * n^3 \tag{7}$$

where: D is the internal diameter of the plate;

n = 1.6 …. 1.7 – for easy extrudable capacity steels

n = 2 – for alloyed steel and hard extrudable steel.

The active plates have relatively small heights, which are subject to internal pressure only in a certain region – pressure areas. Only these pressure areas can explain the causes of the cross cracks and fractures.

Figure 10 shows an active plate having H = 2d and with a pressure area equal as height with the internal diameter, placed asymmetrical to the plate height.

The influence of the unsolicited regions δ and δ' leads to a tangential stress "σ_t", that varies in the longitudinal direction as seen in the diagram to the right of figure 10.

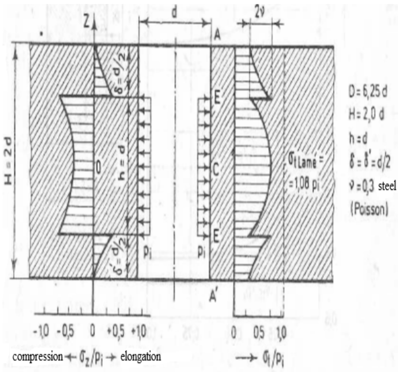

Fig. 10. Actual stress in an active plate for extrusion

In the center of the pressure area "c", the tangential tensile stress has the value $\sigma_t = 0,72 \cdot p$, decreasing to the edge to $0,2 \cdot p$, and in the vicinity of this point, the tangential effort suddenly increases to $0,8 \cdot p$, to then decrease continuously to the value of $0,1 \cdot p$.

For the so stressed plates, the maximum tangential force is at the "E" point, and the diagram on the left of Figure 10 shows the variation of the axial force "σ_t".

The pressure area is stressed by the axial compressive stress, but in the points E and "E" it changes its sense, becoming tensile stress with a maximum value of ca. $0,4 \cdot p$.

Figure 11 shows the reverse extrusion plate which allows a pressure of p = 160 … 200 daN/mm^2, the improved plate consists of four parts.

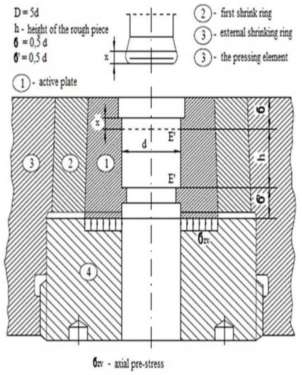

Fig. 11. Active plate for extrusion with axial and radial pre-tightening

The actual plate (1) – with the unsolicited sections δ and δ' – is shrunk into two rings, (2) and (3). The pressure pad (4) has a fine pitch thread that produces an axial force of your pre-tightening "σ_{zv}" in the plate (1). This avoids both longitudinal cracking as well as cross cracking at fatigue, which occurs frequently at points E and E' in active plates of this kind.

For large deformations, which occur in active plates with a large angle "2 α" and small nose radii R, in which the inner plate is in one piece as in the right part of Figure 12, the danger of cross cracks is high.

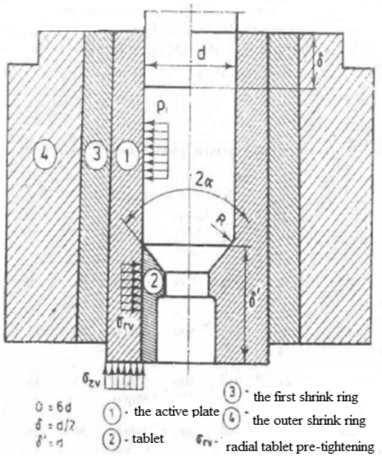

Fig. 12. Active plate for extrusion, longitudinally divided

The construction presented in the right side of the Figure 12, removes this disadvantage by the fact that the active plate is divided in two parts, at which the part (2) is shrinking-on with a great pre-tightening.

In this way the radial compressive stress, achieved by pre-tightening, compensates the pressure during the deformation, forming an area "δ'" without stress and, according to the above, the danger of cracks in this area is diminished.

For the mass production and for alloyed steel extrusion, active plates with metallic carbides are used.

The required conclusion is that in order to obtain a high productivity, the load of the active plate must remain in the range of 100 ... 120 daN /mm.

3. 3. TENSIONS IN ACTIVE EXTRUSION PLATES

4.

3.1 Active plate subject only to internal pressure

In case of active extrusion plates subject to only internal pressure (Fig. 13), the stresses are obtained thus [5], [9]:

$$\sigma_r = \frac{p_i R_i^2}{R_e^2 - R_i^2} - \frac{1}{r^2} * \frac{p_i R_i^2 R_e^2}{R_e^2 - R_i^2} = \frac{p_i R_i^2}{R_e^2 - R_i^2}\left(1 - \frac{R_e^2}{r^2}\right), \quad (8)$$

$$\sigma_t = \frac{p_i R_i^2}{R_e^2 - R_i^2} + \frac{1}{r^2} * \frac{p_i R_i^2 R_e^2}{R_e^2 - R_i^2} = \frac{p_i R_i^2}{R_e^2 - R_i^2}\left(1 + \frac{R_e^2}{r^2}\right). \quad (9)$$

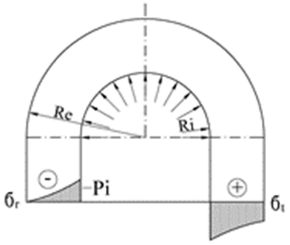

Fig. 13. Active plate

Stresses on the internal surface of active plate are obtained for r = R_i, as follows:

$$\sigma_r = -p_i, \quad (10)$$

$$\sigma_t = \frac{p_i(R_i^2 + R_e^2)}{R_e^2 - R_i^2}. \quad (11)$$

The stresses for the outer surface are obtained for r = R_e, as follows:

$$\sigma_r = 0\,, \quad (12)$$

$$\sigma_t = \frac{2 p_i R_i^2}{R_e^2 - R_i^2}. \quad (13)$$

Figure 13 shows that the maximum stresses are on the inner surface, as shown by the stress variation diagram.

Since the inner diameter of the active plate is known, the outer diameter or thickness of the active plate walls must be determined. Expressing "R_e" from relation (11), results:

$$R_e = R_i \sqrt{\frac{\sigma_a + p_i}{\sigma_a - p_i}}. \quad (14)$$

The relation (14) is also known as Lame formula.

3.2. Active shrinking-on plate

In order to increase the internal pressure (Fig. 13) at which the active extrusion plates can be subject an external pressure is generated which has as effect diminishing the stresses "σ_t". Basically this pressure can be created by inserting a ring over the active plate.

It is considered the case of a shrunk tube, consisting of two tubes, inserted into each other with tightening.

It is considered the case of a shrunk tube, consisting of two tubes, inserted into each other with tightening. It is assumed that the two tubes are at the same temperature. The difference between the outer radius of the inner tube and the inner radius of the outer tube in the not assembled state is called *seraj* [5]:

$$\Delta = b_1 - b_2 \quad (15)$$

In assembled state between the two tubes is developed a shrinking-on pressure "p_f". So, through shrinking the external radius of the internal tube decreased with the measure "u_1", and the internal radius of the external tube increased with "u_2" and they have reached the common radius "b" of the contact cylinder (Fig. 14):

$$b = b_1 - u_1 = b_2 + u_2, \quad (16)$$

From the relation (16), results:

$$\Delta = u_1 + u_2 \quad (17)$$

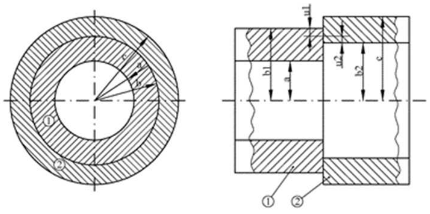

Fig. 14. The principle of shrinkage

If we note with R_1, R_2 and R_3 the radii of the both shrunk tubes (Fig. 15), the radial displacement of the external face of the internal tube, for which the shrinking-on pressure "p_f" is an external pressure (r=R_2):

$$u_1 = -\frac{1}{E} * \frac{p_f R_2^2}{R_2^2 - R_1^2}\left[(1-\mu)R_2 + (1+\mu) * \frac{R_1^2}{R_2^2}\right] = \frac{1}{E} * p_f R_2 \left(\frac{R_2^2 + R_1^2}{R_2^2 - R_1^2} - \mu\right). \quad (18)$$

where: μ is the friction coefficient

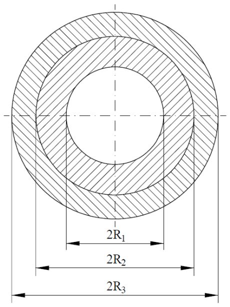

Fig. 15. Active plate with one shrinking-on ring

$$u_2 = \frac{1}{E} * \frac{p_f R_2^2}{R_3^2 - R_2^2}\left[(1-\mu)R_2 + (1+\mu)\frac{R_3^2}{R_2^2}\right] = \frac{1}{E} * p_f R_2\left(\frac{R_2^2+R_3^2}{R_3^2-R_2^2} + \mu\right). \tag{19}$$

$$\Delta = \frac{p_f R_2}{E} * \left(\frac{R_2^2+R_1^2}{R_2^2-R_1^2} + \frac{R_2^2+R_3^2}{R_3^2-R_2^2}\right). \tag{20}$$

From the relation (20), results:

$$p_f = \frac{E*\Delta(R_2^2-R_1^2)(R_3^2-R_2^2)}{2R_2^3(R_3^2-R_1^2)}. \tag{21}$$

The pressure produced by the shrinking pressure in the internal tube are for r = R_1:

$$\sigma_r = 0\,;\ \sigma_t = -\frac{2p_f R_1^2}{R_2^2-R_1^2}, \tag{22}$$

and for r = R_2 we obtain:

$$\sigma_r = -p_f\,;\ \sigma_t = -p_f\frac{R_1^2+R_2^2}{R_2^2-R_1^2}. \tag{23}$$

The stresses produced by the shrinkage pressure in the external tube are, for r = R_2:

$$\sigma_r = -p_f\,;\ \sigma_t = \frac{p_f(R_2^2+R_3^2)}{R_3^2-R_2^2}. \tag{24}$$

and for r = R_3, we obtain:

$$\sigma_r = 0\,;\ \sigma_t = \frac{2p_f R_2^2}{R_3^2-R_2^2}. \tag{25}$$

The effect of the internal pressure "p" is manifested on the entire thickness of the tube so that the stresses produced by this pressure are for r = R_1, according to the relations (10) and (11), we obtain:

$$\sigma_r = -p_i\,;\ \sigma_t = p_i\frac{R_1^2+R_3^2}{R_3^2-R_1^2}, \tag{26}$$

and for r = R_2, results:

$$\sigma_r = \frac{p_i R_1^2}{R_3^2-R_1^2}\left(1-\frac{R_3^2}{R_2^2}\right) = -\frac{p_i R_1^2(R_3^2-R_2^2)}{R_2^2(R_3^2-R_1^2)}. \tag{27}$$

$$\sigma_t = \frac{p_i R_1^2}{R_3^2-R_1^2}\left(1+\frac{R_3^2}{R_2^2}\right) = \frac{p_i R_1^2(R_3^2+R_2^2)}{R_2^2(R_3^2-R_1^2)}. \tag{28}$$

For r = R_3 we obtain:

$$\sigma_r = 0\,;\ \sigma_t = \frac{2p_i R_1^2}{R_3^2-R_1^2}. \tag{29}$$

By overlapping the effects, can be determined the variation of the stresses for r = R_1:

$$\sigma_r = 0\,;\ \sigma_t = p_i\frac{R_1^2+R_3^2}{R_3^2-R_1^2} - p_f\frac{2R_2^2}{R_2^2-R_1^2}. \tag{30}$$

and for r = R_2, in the internal tube is obtained:

$$\sigma_r = -p_i\frac{R_1^2(R_3^2-R_2^2)}{R_2^2(R_3^2-R_1^2)} - p_f. \tag{31}$$

$$\sigma_t = p_i\frac{R_1^2(R_3^2+R_2^2)}{R_2^2(R_3^2-R_1^2)} - p_f\frac{R_1^2+R_2^2}{R_2^2-R_1^2}. \tag{32}$$

In the external tube we have:

$$\sigma_r = -p_i\frac{R_1^2(R_3^2-R_2^2)}{R_2^2(R_3^2-R_1^2)} - p_f. \tag{33}$$

$$\sigma_t = p_i\frac{R_1^2(R_3^2+R_2^2)}{R_2^2(R_3^2-R_1^2)} + p_f\frac{R_3^2+R_2^2}{R_3^2-R_2^2}. \tag{34}$$

and for r = R_3 , we obtain:

$$\sigma_r = 0\,;\ \sigma_t = \frac{2p_i R_1^2}{R_3^2-R_1^2} + \frac{2p_f R_2^2}{R_3^2-R_2^2}. \tag{35}$$

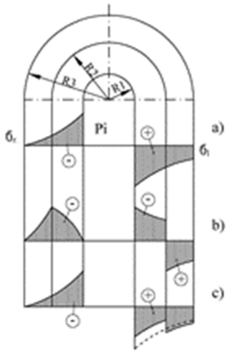

Fig. 16. The diagram of variation of the stresses produced by the internal pressure "p_i" in an active plate for shrinkage

Figure 16 shows the diagrams of variation of the stresses produced by the internal pressure "p_i" (Fig. 16 a), by the shrinking pressure "p_f" (Fig. 16, b), and the resulting diagram (Fig. 16, c). The stresses produced by the internal pressure are represented with an interrupted line in order to see the effect of the shrinkage. It is observed that the shrinkage pressure does not change the maximum value of the tension “σ_r” inside the tube, but it decreases the maximum tension “σ_t”, which was exactly pursued by the shrinkage. It is achieved, also a more uniform distribution of stresses on the thickness of the friction ring.

4. WEAR OF THE ACTIVE PLATE OF COLD EXTRUSION DIES

The main forms of wear that appear on the active plates of the extrusion dies are: adhesion, abrasion, due to fatigue, superficial and impact wear.

Adhesion wear is caused by welding and breaking of the welding points between contact micro-areas. Welding occurs due to high pressures, which occur in case of phosphating or improper lubrication or due to too low hardness of the active elements, when the tangential stress due to friction on the contact surface between the tool and the material becomes higher than the maximum characteristic stress of the deformed material.

Abrasion wear is caused by the presence of hard particles between the contact surfaces and occurs according in the direction of flow of the material.

Wear due to surface fatigue occurs as pinching or spalling. Pinching is a form of fatigue wear, due to tearing by local adhesions caused by high pressures and variations in stresses on contact surfaces. Spalling is manifested by the detachment from the friction surfaces of some particles in the form of scales, as a result of the fatigue of the surface layer in contact.

Impact wear occurs in punches due to repeated collisions with the surface of the semi-finished product, forming on the front surface of the punch a series of craters of different shapes and sizes.

In addition to defects due to wear to the active elements of the extrusion molds, there can also occur cracks, deformations or ruptures.

Cracks are due to overloading or material defects. In active plates they appear in areas with large variations in tensions.

Plastic deformation is due to improper material.

Breakage occurs due to incorrect sizing or accidental stresses.

5. CONCLUSIONS

Modern concept of economic growth, sustainable development defined as a process of transformation in which the use of resources, investment orientation, selection of processing methods and international changes take place harmoniously, in correlation with the natural environment.

The implementation of the principles of sustainable development in the machine building industry, at this stage when the national economy is looking for solutions to be stronger, is not only necessary but also timely.

The deformation pressure "p_i" acting on the surface of the active plate, gives rise to a tangential compression stress “σ_r" and a tangential tensile stress “σ_t", both having maximum values on the inner walls of the active plate.

The reduction of the tension on the surface of the active area of the extrusion plate can be achieved by applying a tangential pre-tension of compression, opposite to the tangential stresses created by the pressure "p_i". This is done by shrinking one or two outer rings.

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POSIBILITĂŢI DE CREŞTERE A DURABILITĂŢII PLĂCILOR ACTIVE LA MATRIŢELE DE EXTRUDARE

Rezumat: Reducerea tensiunii maxime pe suprafaţa zonei active din placa de extrudare se poate realiza prin aplicarea unei pretensiuni tangenţiale de comprimare, realizabilă prin fretarea unui inel peste placa activă, astfel că pretensiunea acţioneaza în sens contrar tensiunii tangenţiale de intindere create de presiunea de extrudare.

Fretarea se poate realiza prin următoarele metode: fretare la cald, fretare la rece, fretare în condiţii criogenice.

Principalele forme de uzare ce apar la placa activă de extrudare sunt: de adeziune, de abraziune, datorită oboselii, superficiale şi de impact.

Problemele care se pun la construcţia plăcilor active sunt: stabilirea geometriei zonei active, determinarea tensiunilor şi alegerea materialului corespunzător.

Cristian-Ioan **INOAN,** PhD Student, Eng.: Technical University of Cluj – Napoca, Department of Manufacturing Engineering, 103 – 105 Muncii Blvd. 400641 Cluj – Napoca, E-mail: cristi.inoan@gmail.com, Phone: 0040-745 128 412.
Radu-Nicolae **CORCHEŞ,** PhD Student, Eng.: Technical University of Cluj – Napoca, Department of Manufacturing Engineering, 103 – 105 Muncii Blvd. 400641 Cluj – Napoca, E-mail: radu.corches@delgaz-grid.ro, Phone: 0040-744 644 515.
Gheorghe **ACHIMAŞ**, Prof. PhD, Eng.: Technical University of Cluj – Napoca, Department of Manufacturing Engineering, 103 – 105 Muncii Blvd. 400641 Cluj – Napoca, E-mail: Gheorghe.Achimaş@tcm.utcluj.ro, Phone: 0040-264 401 731.