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MANUFACTURING METAL TUBES BY EXTRUSION METHODS

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Abstract: Extrusion is the technological method of machining metals through plastic deformation in volume, which is used in making parts of simple or complex configuration, hollow or solid, with a section transversally smaller than that of the semi-finished part, due to the material flowing in the space between the punch and the active plate or through the hole in the active plate. The extrusion methods entail large reductions in the cross sectional area of the semi-finished product, reductions which can reach up to 90% or more in a single operation. Metal extrusion technologies have a wide range of applications, i.e.: Fine Mechanics, Electrotechnics, Electronics, consumer goods industry etc.

Key words: Extrusion, plastic deformation, tubular parts.

1. INTRODUCTION

The obtaining of extrusion manufactured products with no interior or exterior defects and with imposed mechanical properties requires good knowledge of the properties which characterize metal deformability, respectively their plasticity and resistance to deformation, as well as their modes of variation.

Metal deformability through extrusion is influenced by: the mechanical characteristics of the extruded metal, the chemical composition, structure, deformation conditions, temperature, material deformation speed and ratio, state of stress and deformation scheme. The method of machining tubular parts through extrusion is of real interest due to the fact it considerably reduces metal consumption and labor. The technological process of reverse – cold or hot – extrusion of steel or non-ferrous alloys is applied with maximum economic efficiency for small and medium sized tubular parts only in mass production or process production.

The metal extrusion technology is currently in full progress and the research is extensive, with the purpose of improving

industrial applications both economically and technically, with focus on part geometry and size. In our country metal extrusion technologies have started to be applied relatively recently and are considered, here and worldwide, a technological process with great prospects.

2. EXTRUSION METHODS

Extrusion is classified by taking into account the following criteria (Fig.1): • the temperature where the semi-finished part gets deformed, • the nature of the deformation energy, • the direction of the force and of the material flow. The technological methods of extrusion can be: direct, reverse, combined (mixed) and lateral [6],[5].

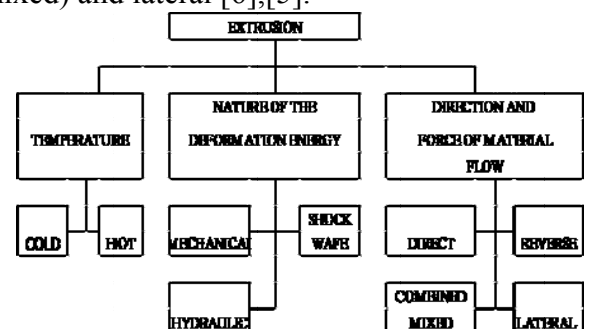


Fig.1. Classification of extrusion methods [6]

Direct extrusion is the technological method through which the deformed material flow direction is the same with the direction of travel of the punch. According to the nature of the deformation energy, direct extrusion can be: mechanic, hydrostatic and by shock. We thus obtain solid parts and hollow parts.

Reverse extrusion is the technological method where the deformed material flows in the opposite direction of the punch travel. We thus obtain solid parts or hollow parts.

Combined extrusion (mixed) is the technological method where the material of the semi-finished part travels both in the direction of travel of the punch and opposite. Through this method we make parts with complex shapes.

Lateral extrusion is the technological method where the direction of travel of the punch and the material flow form an offset angle of $0...180^{\circ}$. Through this method we make parts with complex shapes.

Besides these technological methods which have become classic, some new variants have been experimented successfully, such as: extrusion in mobile dies, extrusion between rolls etc.

3. TECHNOLOGICAL ELEMENTS OF METAL EXTRUSION

Theoretically, all metals and alloys can be machined through extrusion, but in practice the use of various metals and alloys is conditioned by their deformability. The specific pressure needed for extrusion must not be over $200-250 \text{ daN/mm}^2$, this value ensuring good durability for active elements and stress on the machine within acceptable limits. The extrusion method, the deformation stages and the original dimensions of the semi-finished part are to be chosen according to the shape and dimension of the part.

The wall thickness of extruded parts can range from $0,5...15 \text{ mm}$ for steel and from

Based on the drawing of the part we can determine the technological elements needed for making a technological process of extrusion, namely:

$0,05...5 \text{ mm}$ for non-ferrous alloys. The ratio between the diameter and height of the extruded parts varies within the limits $h/d=3...8$ [5].

The precision of dimension and geometrical shape obtained in the case of machining by extrusion is comparable to that obtained through grinding. Specialized literature [6], [5], presents the following performance for pieces resulted through extrusion, as follows:

- deviations in the obtained diameter: $\pm 0,03...0,05 \text{ mm}$,
- deviations in the wall thickness: $\pm 0,02...0,04 \text{ mm}$.

The smoothness of surfaces resulted after extrusion are within the limits $0,1...3,5 \mu\text{m}$, being comparable to that obtained after grinding. Both axially symmetrical and asymmetrical parts can be obtained by extrusion. The most widely made are parts with symmetrical shape.

The economic advantages of extrusion as compared to other types of machining are extended. They can be best highlighted in relation to metal cutting. Compared to turning (fig.2), extrusion ensures a metal saving of about $25...60\%$, and the labor costs are $40...50\%$ lower [6].

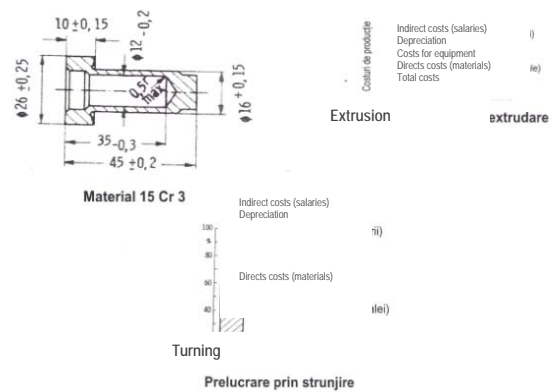


Fig.2. Comparing production costs for machining a piece by turning and by extrusion [6]

- the volume of the semi-finished part,
- the shape and dimensions of the original semi-finished part,
- the number of deformation operations,

- the sequence of operations,

The number of operations is established by considering the maximum admissible deformation ratio. In a single operation a limited maximum deformation can be reached and its size depends mainly on the mechanical characteristics of the extruded material (tab.1) and on the available machine.

Table 1

Maximum limits of deformation in cold extrusion in a single operation [6]

Material	Deformation maximum limit	
	Conventional specific deformation	Main real deformation ϕg
Al 99,5 AlMgSi (tempered)	For section $\varepsilon A = \frac{A_0 - A_1}{A_0} =$ 95 ... 99%	$\phi A = \ln \frac{A_0}{A_1} =$ 250 ... 460%
	For wall thickness $\varepsilon S = \frac{S_0 - S_1}{S_0} =$ 95 ... 99%	$\phi S = \ln \frac{S_0}{S_1} =$ 230 ... 300%
AlCuMg AlMnCu Steel $C < 0,10 \%$	$\varepsilon A = 90 \dots 95\%$ $\varepsilon S = 80 \dots 90\%$	$\phi A = 230 \dots 300\%$ $\phi S = 160 \dots 230\%$
Am 63 Steel $C \leq 0,80 \%$	$\varepsilon A = 75 \dots 80\%$ $\varepsilon S = 70 \dots 75\%$	$\phi A = 140 \dots 190\%$ $\phi S = 120 \dots 140\%$

4. METAL EXTRUSION TECHNOLOGICAL PROCESS

The technological process for manufacturing parts by extrusion mainly comprises the following operations:

- cutting the semi-finished part;
- heat treatment;
- preparing the surface;
- lubrication;
- extrusion;
- final machining of extruded parts.

The creation of a technological process of extrusion is made according to the drawing

of the finite part and to the mechanical characteristics of the material.

4.1. CUTTING

The cutting operation needs to ensure:

- low roughness of the separated surface;
- high precision of the volume or of the length;
- high precision of the deviations from the geometrical shape;
- the preserving of the initial material characteristics in the area of separation.

For extrusion, the semi-finished parts need to observe the following conditions (fig.3) [6]:

- volume deviation, $\eta = \frac{\Delta v}{v} = 0.02$;
- flattening, $c = \frac{c}{d} = 0$;
- smoothness deviation, $b_0 = \frac{b}{d} = 0$;
- perpendicularity deviation, $\alpha = 1^0$.

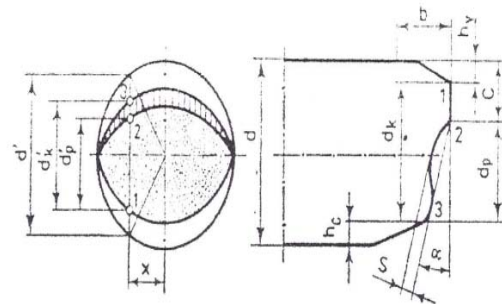


Fig.3. Geometrical elements of parts obtained by precision cutting

The most used technological methods for obtaining semi-finished parts for extrusion are cutting and shearing (precision cutting).

4.2. HEAT TREATMENT OF SEMI-FINISHED PRODUCTS

The material needs to have good deformability and a homogenous structure for the extrusion of semi-finished parts. These requirements can be achieved through the proper heat treatment of the semi-finished parts. For steel parts initial or intermediary heat

treatment is applied, such as: normalizing, soft and recrystallization annealing.

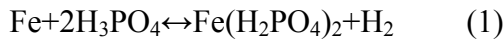
For the extrusion of metals and non-ferrous alloys, the heat treatment is prescribed with the purpose of obtaining minimum hardness, maximum plasticity and a homogenous structure, preferably monophasic, with no hard compounds.

4.3. PREPARING THE SEMI-FINISHED PRODUCTS SURFACE

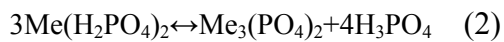
The existence of high pressure in the range of 250-300 daN/mm², places the friction processes taking place during extrusion in the area of limit friction.

In order to reduce the extrusion pressure and implicitly the energy needed for extrusion, the coefficient of friction needs to be lowered. The operations which allow the reduction of friction during extrusion are bonderizing and lubrication.

The bonderizing operation is based on the interaction of phosphoric acid and the superficial layer of the semi-finished part, according to the reaction:



which takes place simultaneously with the reaction:



in which: Me=Zn, Mn, Fe.

Thus, a porous greyish layer is obtained, the main component of which is Zn₃(PO₄)₂.

The thickness of the phosphate layer is recommended to be between 5-15 μm, or otherwise said 30-45 milligrams/dm² semi-finished parts surface. The layer is also recommended to be uniform, smooth and adherent.

4.4. LUBRICATION

In extrusion processes the lubrication has the following functions:

- to reduce the friction between the active elements of the die and the material subject to deformation;
- to increase the durability of the die's active elements;

- to improve the part surface quality.

The lubrication can be done with:

- oils with Cl, S, P based additives;
- aqueous solutions of monovalent metal based soaps;
- lubricating substances in suspension state, such as MoS₂, WS₂, graphite, di and polyvalent soaps.

Molybdenum disulphide and graphite based lubricants are used for extruding parts with complex geometrical shapes, or materials with reduced plasticity.

5. CASE STUDY: EXTRUSION OF A TUBULAR PART

The technological process of extrusion mainly comprises three operations:

- the preparing of the semi-finished part;
- the extrusion itself;
- the post-extrusion machining of the parts obtained;

Among these operations, we have analyzed and described some technological aspects regarding the preparation of the semi-finished part and the extrusion itself for the manufacturing by reverse extrusion of the tubular part with the shape and dimensions shown in figure 4.

To obtain the tubular part shown in figure 4, cold or hot laminated, aluminum killed low carbon round steel was used.

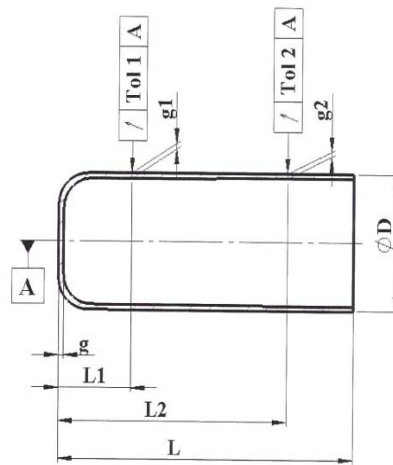


Fig.4. The tubular part

Before the material is entered in production, it has to be accepted. The chemical analysis is made, the mechanical characteristics are checked together with the material structure and the bar dimension.

The steel's technological characteristics will be checked through "the cold upsetting test", according to STAS 2233-80, at an upsetting ratio of 66%. The test consists of compression deforming a cylindrical sample between two flat surfaces, with the purpose of studying the aspect of the lateral surface of the sample (the appearance of the first crack).

The relative upsetting ratio obtained in the end is expressed by the equation:

$$X = \frac{h_0 - h}{h_0} \cdot 10 \quad [\%] \quad (3)$$

where: h_0 - initial sample height;

h - final height.

The steel macrostructure is checked on samples cut transversally from the end of the bar, after being pickled with metallographic reagents. The steel must not show defects which could affect the steel's homogeneity and compactness, such as: sulphides, stratifications, fissures, cracks and other defects visible to the naked eye. Porosity shall not surpass the maximum of 2 points according to STAS 11961-83.

The microstructure of steel in state of delivery must be made of ferrite and perlite distributed as evenly as possible in the ferrite mass.

The admissible score for the size of the real grain must be within the limits 6...9, determined according to STAS 5490-80 scale 2.4.2.3.

A ferrite perlite structure in strings scoring 3; 4 and 5 according to the standards scale in Annex 1 of STAS 5490-80 is not allowed.

The admissible average score of metallic inclusions (STAS 5949-80) can go maximum to:

- sulphides=3;
- oxides=3;
- silicates=3.

No decarburized layer is allowed.

The shape of hot laminated peeled bars must comply with the provisions of STAS 6433-80, point 2.5.2 and point 2.5.3.

The shape and dimensions of the part "Tube" shown in figure 4 made of steel or brass requires the manufacturing by reverse extrusion, the principle of which is presented in figure 5.

The volume equalization method is used for the calculation of the initial semi-finished part dimensions. Strictly speaking there is a condition that the volume of material in the semi-finished part should be the same for the finished parts. Since the height of the upper wall of the extruded product is formed freely, the volume of the finished part was supplemented with an addition which shall be removed through trimming.

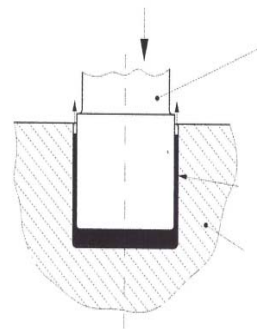


Fig.5. Manufacturing the part "Tube" by reverse extrusion

The condition of maintaining the volumes of material is expressed through the equality:

$$V_{sf} = V_{pf} + V_{addition} \quad (4)$$

Where: V_{sf} is the volume of the semi-finished part

V_{pf} is the volume of the finished parts

$V_{addition}$ is the volume of the addition

The value of V_{pf} was determined by direct measuring on the 3D model of the part, made with the SolidWorks design software.

Taking into account figure 4, the equation for calculating the volume is:

$$V_{sf} = \frac{\pi \cdot D^2}{2} \cdot (H - h) + \frac{\pi \cdot h}{3} \cdot \left[\frac{x^2}{4} + \frac{D}{2} \cdot \frac{D - 2h}{2} + \frac{(D - 2h)^2}{4} \right] \quad (5)$$

Where: *H* is the height of the semi-finished part;

h – height of the bevel;

D – diameter of the semi-finished part.

According to equation (4) and equation (5) the height of the semi-finished part can be calculated:

$$H = h + \frac{4 \cdot (V_{pf} + V_{adaus})}{\pi \cdot D^2} - \frac{h}{3 \cdot D^2} \cdot \left[D^2 + D \cdot (D - 2h) + (D - 2h)^2 \right] \quad (6)$$

Based on these calculations we can obtain the dimensions of the initial semi-finished part, which in this case is made of steel (fig.6).

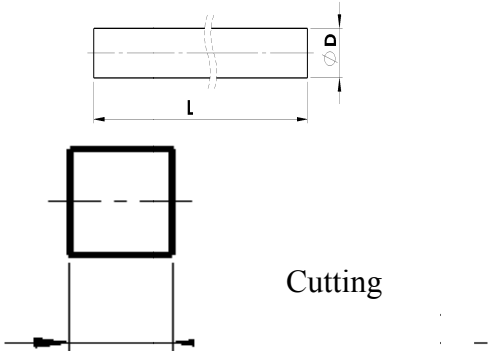


Fig.6. Dimensions of the semi-finished part used at the extrusion of the steel “Tube”.

Based on the aspects analyzed above, the following technological itinerary for the part steel extruded “Tube” (fig.4) was created.

1. Cutting the semi-finished part (fig.6)

Machine: Vertical press -type PAI 63

Tool: High precision shearing device

Material: Steel

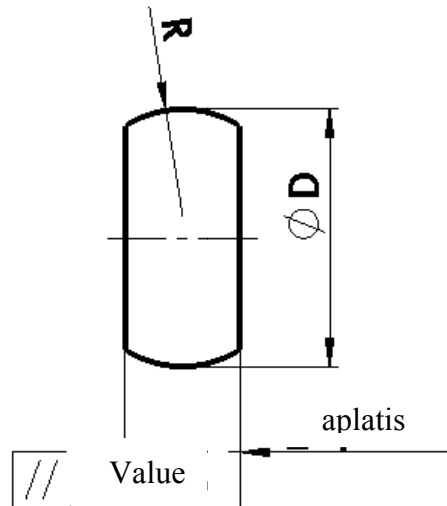


Fig.7. Flattening the semi-finished part

2. Flattening the semi-finished part (fig.7)

Machine: Hydraulic press

Tool: Flattening plates

The workpiece material is hardened and its structure is uneven and elongated with grains, after the flattening operation, which is not appropriate with the extrusion operation.

3. Annealing the semi-finished part (fig.7)

Machine: Electric furnace

Control parameters: 145 HB or 200HV0,1

A homogeneous and fine-grained structure is obtained after annealing. This makes the extrusion material to be produced in optimal conditions.

4. Greasing the parts during cupping is an essential factor.

By greasing the part during cupping, a gliding layer between the tool and the part is ensured and this prevents the contact between these elements and reduces the frictional resistance of the respective surfaces which would otherwise lead to extensive tool wearing.

Through greasing, the effort needed for extrusion is considerably reduced.

The lubricants used for cupping need to have the following characteristics:

- To form a thin, uniform, adherent and pressure resistant layer;
- To be easily removed for the parts surface;

- To not damage the parts surface mechanically or chemically;

The surface of the semi-finished part is treated as follows: a layer of zinc phosphate tetrahydrate is formed $Zn_3(PO_4)_2 \cdot 4H_2O$ after the crystalline phosphate treatment; zinc phosphate is used as lubricant.

Phosphate treatment consists in dipping parts before extrusion in a phosphate solution, heated at a temperature of 60-80°C

5. Extrusion (fig.8)

The stages of the extrusion operation:

- Feeding the machine with semi-finished parts
- The semi-finished parts move in front of the extrusion die;
- The extrusion of parts: the back releaser is aligned to side A of the extrusion die in such a way as to avoid the part overlapping. The punch moves forward, inputs the semi-finished part in the die and carries out the extrusion operation.
- Extracting the extruded parts: the extrusion punch moves back and the part is extracted from the punch with the help of releaser 1. Meanwhile, the back releaser moves forward, extracting the part from the extrusion die, afterwards moving back to position "A".

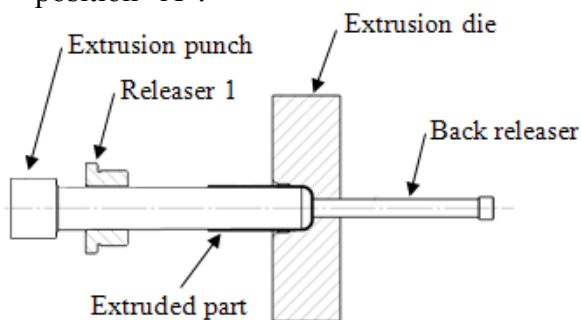


Fig.8. Extrusion of a tubular part

Machine: Horizontal press

Semi-finished part: Phosphate treated semi-finished part (fig.7)

6. Washing and drying

Machine: Aggregate for washing-drying,

7. Control (fig.9 and fig.10)

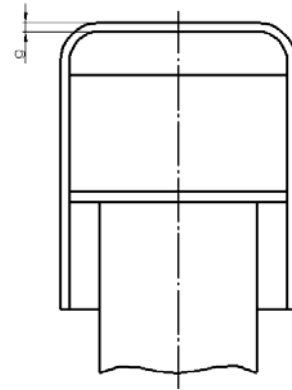


Fig.9. Controlling the part root thickness "g"

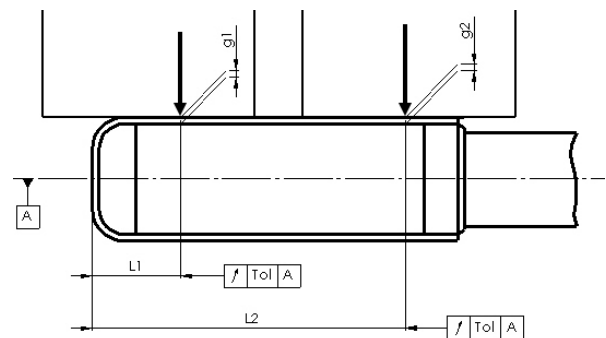


Fig.10. Controlling the thickness of walls "g₁" and "g₂", and also the runout

The following shall be checked:

- the part root thickness "g" (fig.9)
- the thickness of walls "g₁" and "g₂" and also the runout (fig.10)

8. Reception of extruded tubes

Steel extruded tubes are subject to aspect and dimension checking according to the defect category and the acceptable quality level.

6. CONCLUSIONS

Research made up to now regarding steel tube extrusion allows us to formulate some conclusions, such as:

- metallic tube extrusion processing ensures high productivity, a high degree of metal use and reduction of workload ,
- surface roughness 0,1-0,4 μm
- extruded parts are in the precision range 10-11 according to STAS 8101-8

7. REFERENCES

- [1] Bejinariu C. *Indirect Cold Extrusion of Steel*, Tehnopress Publishing House, Iasi, 2008
- [2] Comăa, D.S. *Finite Elements Method*. UTPress Publishing House Cluj-Napoca, 2007
- [3] Cristea, C. *Production System Management*. Todesco Publishing House, Cluj-Napoca, 2013
- [4] Gligor, Gh. *Extrusion of Non-ferrous Metals*. UT Press Publishing House, Cluj-Napoca, 2004
- [5] Socaciu, T. *Cold Reverse Extrusion of Metals*. "Petru Maior" University Publishing House Targu Mures, 1998
- [6] Tăpălagă, I, a.o. *Cold Extrusion of Metals*. Dacia Publishing House, Cluj-Napoca, 1986
- [7] *** *Precision Extrusion of Tubular Parts*. In: Engineering materials and design, vol.21, 1977, P.39-44

EXECUTAREA TUBURILOR METALICE PRIN TEHNOLOGII DE EXTRUDARE

Rezumat: Extrudarea este procedeul tehnologic de prelucrare a materialelor metalice prin deformare plastică în volum, prin care se pot executa piese de configurație simplă sau complexă, cave sau pline cu secțiunea transversală mai mică decât a semifabricatului, ca urmare a curgerii materialului prin spațiul dintre poanson și placa activă, sau prin orificiul din placa activă. Procedeul de extrudare implică reduceri mari din aria secțiunii transversale a semifabricatului, reduceri care pot ajunge până la 90% și chiar mai mult într-o singură operație. Tehnologiile de extrudare a metalelor au un domeniu larg de aplicare și anume: industria constructoare de mașini; mecanica fină; electrotehnica; electronica; industria bunurilor de larg consum etc.

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