CONSIDERATIONS ON EXTRUSION OF THE TUBES MADE OF THERMOPLASTIC MATERIALS

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Abstract:

Due to the special properties that thermoplastic material possess, they can be easily processed by extrusion, achieving tubes with high quality. The surface's quality of the tubes obtained by extrusion largely depends on the thermoplastic material which is used. Thermoplastic materials compete successfully the traditional materials regarding: mechanical resistance, corrosion resistance, elasticity, high: performance/weight, low cost, etc. The form of extruded tube is given by the succession and the final dimension is obtained by simultaneous calibrating and cooling.
One detail that should not be forgotten in the process of extruding a tube of thermoplastic material is the emergence of the phenomenon of "expanding" at the exit of "auger die". This phenomenon has a decisive impact on the quality of extruded semi-manufactured products.

Keywords: extrusion, thermoplastic materials , expand.

1. INTRODUCTION

The thermoplastic materials are materials that do not suffer radical chemical changes under the action of the heat and pressure. The transformations are reversibile. These types of materials are increasingly required on the global/international market because of their indisputable qualities, technical and economical benefits which they present in comparison with traditional materials [2]. In Figure 1 are presented the main categories of plastic materials and in Table 1 the main characteristics of thermoplastic materials [1,7].

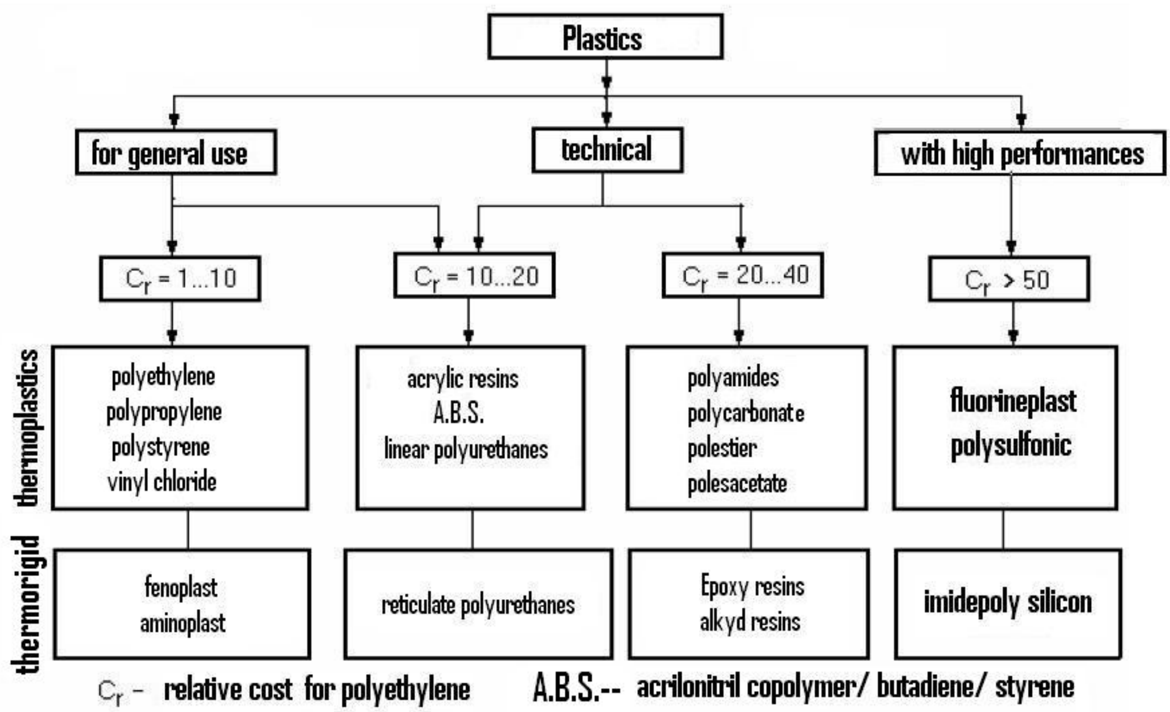

Fig.1 Main categories of plastics

Table 1. The main characteristics of thermoplastic materials

Name of material	Symbol	ρ, kg/m^3	N/mm^2	Tv, °C	Tc, °C	Coefficient of contraction [%]	Observations
Low density polyethylene	LDPE	910...940	5...16	-75	115	1,5-5	crystallized 40 ... 55% elastic, resistant
High density polyethylene	HDPE	950...965	20...40	-75	130	1,5-5	crystallized 40 ... 80% elastic, resistant
Polypropylene	PP	900...910	30...50	-10	170	1-3	crystallized 60 ... 70% more rigid than PE
General purpose Polystyrene	GPPS	1040...1100	20...50	85...100	125	0,2-0,6	amorphous, hard and brittle
Polyvinyl chloride unplasticised	PVCU	1360...1400	40...60	75...105	175... 212	0,1-0,6	amorphous, rigid, sensitive to scratches
Polyvinyl chloride plasticised	PVCP	1150...1250	10...30	-40	150	0,2-5	amorphous vinyl compound, flexible, elastic
Polymethyl methacrylate (plexiglas)	PMMA	1180...1220	60...80	90...105	225	0,2-0,8	amorphous, rigid, tough and resistant to scratches
Polycarbonate	PC	1150...1250	50...70	150	230	0,4-0,8	amorphous, rigid and resistant to shock
Polyamide 6.6	PA 6.6	1120...1180	50...80	55	250	0,6-3	crystallized <60%, tough, durable and rigid
Polyoxymethylene polyacetal	POM	1370...1430	60...70	-50	170	1,8-2,5	crystallized <75%, rigid, elastic, resistant
Polyethylene terephtalate	PETP	1320...1390	40...60	73	255	0,2-3	amorphous or crystallized 30 ... 40%; dimensional stable
Polytetrafluoroethylene	PTFE	2100...2250	20...40	85...125	330	1-2	crystallized <70%; low coefficient of friction
Polyacrylonitrile	PAN	1100...1200	50...60	107	320	0,2 – 0,5	acrylic compound; easily pulled in the fiber
Acrylonitrile butadiene styrene	ABS	1040...1700	20...60	125	-	0.3-1.6	mixture of butadiene-styrene (elastomer) and styrene-acrilonitril (thermoplastic)
Cellulose acetate	CA	1250...1350	25...50	120	-	0,3-1	chemical amending of the cellulose (natural polymer)

Today are known more than 20 technological methods of processing plastic materials, one of the most important of these being the „extrusion".

Extrusion is a continuous processing process of plastic materials from which can be obtained profiles with large length such as: tubes, pipes, sheets, cave bodies, wires, insulation for electrical cables, complex profiles, etc..

Extrusion consists in submitting the material through a thermal-mechanical treatment in the state flow, after which the material is forced to pass through succession with a profile corresponding to the products that had to be made. By this procedure are obtained in a continuous rapid movement, profiles which length is dependent only on the possibilities of storage and transport [4] .

Extrusion include the following operations: determination, homogenization, polishing, cutting, granulation and formation of a product or a profile. The equipments used here are complex and have as a central element an extrusion machine called extruder. In the process of extrusion are obtained different shapes of extruded semi-manufactured products, geometry and quality of these profiles is given by the succession contained by the device extruded. In Figure 2 are presented some examples of profiles which resulted from the extrusion [6].

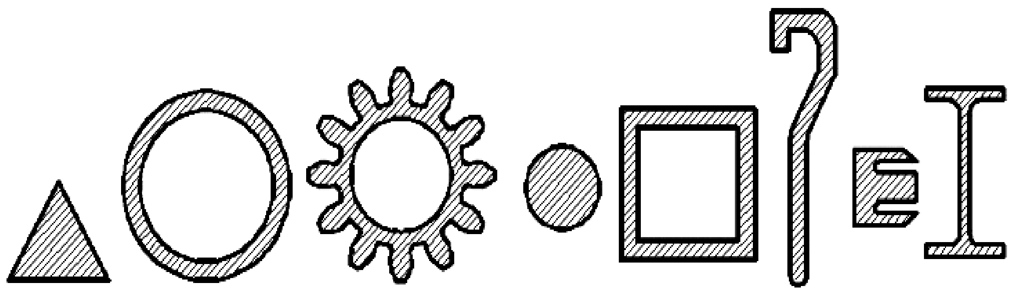

Fig.2 *Semi-manufactured of plastic extruded materials*

2. EXTRUSION MACHINERY AND EQUIPAMENT

Extrusion machine generally consists of the following parts: cylinder, snail, bunker supply, transmission system engine - gear shift mechanism, heating-cooling system etc..

With the extrusion process are produced different products by changing the extrusion device and some of the annex relating to the machine wich polish the product (sizing, cooling, cutting, involuting, printing etc.).

Extrusion of the tubes represents one of the most important application of extrusion. Extruded tube is warm and soft at the exit of auger die, so that the cooling must be effected simultaneously with the calibration.

Calibration is done through several procedures. The most important are:

- the calibration with vacuum;
- the calibration with air pressure [4].

For pipes that have to/must have an inside precise diameter are used mandrels with interior calibration that are fixed by the head of the extruder.

The takeover device is a displacement device of extruded products; those designed for tubes represent the type with roller or caterpillar. The takeover roller device is used the most because it’s easy to operate and maintain. Rolls at the bottom are mechanical trained, and the upper are moving vertically, being pressed with a clenching device. Maximum drawing velocity is 10 m / min, being adjustable according to the speed of the snail. If the pipe is taken over too fast, this causes an attenuation of the pipe’s walls, and if it’s taken too slow, this causes a corrugated surface. The general construction of an extrusion equipment of rigid tubes with large dimensions is represented schematically in Figure 3 [4]:

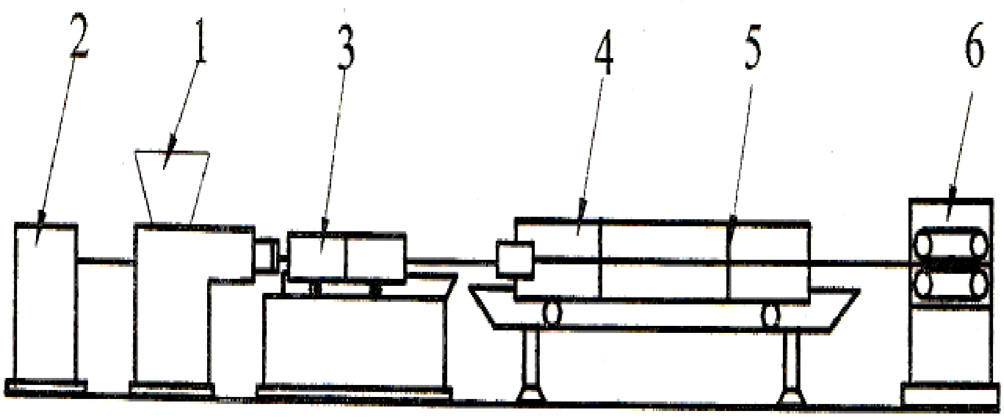

Fig.3 *The equipment for obtaining rigid tubes with large dimensions; 1-extruder, 2- command panel, 3-calibration system with air or vacuum, 4- cooling bath, 5-guides, 6- takeover system*

A more detailed representation of the process of „extrusion a tube of thermoplastic material" is exemplified below, in figure (Fig.4) [3]:

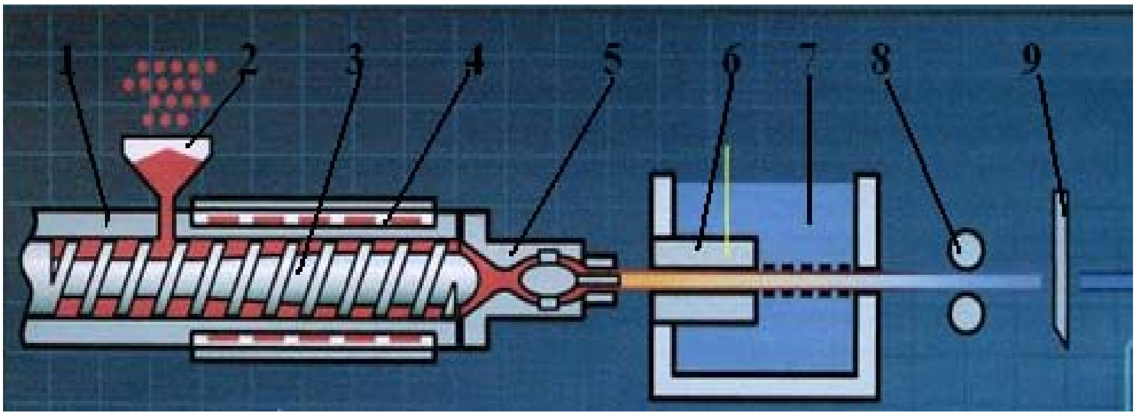

Fig.4 *The equipment used to obtain flexible tubes; 1-cylinder, 2-bunker supply, 3- snail,4-electrical resistors, 5-extrusion device, 6-calibration system, 7- cooling bath, 8- the takeover device, 9-cutting device.*

The plastic material in the form of granules is poured in bunker supply 2 of extruded machine after which the granules are taken by the snail 3 and transported inside the cylinder 1 (the effective length should be at least 24 times greater than its interior diameter) from the supply at output and obliges him to pass through the extrusion head. On the route covered, the plastic granular material is converted into a melt with electrical resistances 4 which have the role of heating cylinder 2 for flowing the plastic material until the temperature required for extrusion is reached. The value of temperature is controlled with thermocouples and continuously adjusted during extrusions. Molten material is forced by snail 3 to enter in the extrusion device 5 mounted at the exit of material from the extrusion cylinder 2 and which contains the succession, that gives the final output form of the extruded tube. After the exit of the auger die, extruded tube is passed through a calibration system 6 and a cooling bath of water 7, thus achieving final dimensions of the extruded tube. Finally, the tube is overtaked with rolls 8, which compose the takeover device of the equipment, and the transport to the cutting device 9 which is to be debited at desired dimensions.

3. QUALITY OF THE EXTRUDED PROFILES

The quality of the extruded profiles is directly influenced by the following elements: the surface's quality of the auger die; auger die dimensions; part material and the technological parameters of the process.

The common tolerances for the plastics products made by extrusion are presented in Table 2 [6].

Table 2

Profile size, [mm]	Tolerance, [mm]	Profile size, [mm]	Tolerance , [mm]
3 - 7	0.15	100-150	0.75
7-12	0.20	150-200	1.00
12-20	0.23	200-250	1.25
20-25	0.25	250-300	1.50
25-40	0.40	300-350	1.80
40-50	0.50	350-400	2.00
50-100	0.65		

3.1 The expand of the thermoplastic materials

Purely viscous liquids, at the exit from a tube with circular cross section have a jet with a descending diameter (fig.5 a). A contrary effect is observed in viscous-elastic fluids, property that thermoplastic materials also have. At the exit of a tube the jet is enlarging his size, is expanding (fig. 5 b) [5].

Numerous researches were made with short tubes or capillaries. The expanding of the jet is increasing substantially if the tube is short. From the Fig.5 c results the mechanism based on what it may be explained the effect of expanding. An element of volume of an fluid in the form 1, during passage through the tube, suffer an elongation in the direction of the flow (form 2). Stored elastic energy is recovered by a pronounced expanding of the jet (form 3). Due to elastic behavior, the form 3 of the element volume is based on form 1, for which has a "memory." The contribution of the elastic component decreases in expanding when the length of the tube increases.

In stationary regime, the expand of the jet is axially symmetric. Power lines at the exit of a long tube, are approaching and dismissing from the central area in the exterior zone. This is due to fluid acceleration at the periphery and deceleration in the middle part.

For theoretical approach of the expanding effect of the jet, inertial, gravitational and surface forces are considered negligible in comparison with the friction forces and gradients pressure. Measurable size in the experimental $\beta = dj / d$ is related to specific parameters of viscous-elastic behavior. Theoretical hypothesis are based on normal stresses or on elastic recovery [8].

At the exit from the tube the pressure is equal to the pressure of the environment. The equilibrium equations with the first and second difference of normal stresses are used to report normal stresses in axial direction at the normal stress in radial direction. Inside of the tube, at the end of exit, normal radial stresses are higher than average axial stress, which explains the expanding of the jet when the walls do not exert pressure.

Elastic recovery is illustrated in Fig. 5 d. An element of volume that flows through the tube without slipping at the wall, under the action of tension shearing will take a form represented by a parallelogram. Due to the elastic component, he stocks a part of energy, which is a unique function of gradient speed of shearing. At the exit of the tube, the shearing forces are removed and the element tends to initial untense form, represented by a rectangle. And as such it takes place the expanding of the jet.

The argument of the elastic recovery has some disadvantages. The volume elements of the central area due to deceleration should expand more on the radial direction, but the elastic deformation is small, because the strain at shearing is reduced. On the other hand, the elements of fluid in the vicinity of the wall have stored the largest quantity of elastic energy, recoverable, but due to the acceleration at the exit of tube, it’s shrinking on radial direction. Certainly, we can say that the expanding appears to fluids that manifest the phenomenon of elastic recovery.

McIntosh believes that the main cause of jet expanding is due to elastic deformation of the fluid during flowing through the tube and elastic recovery in the output area. An element with circular volume and thickness *dr* placed at distance *r*, has a characterized deformation by an angle *α* (d fig.5). After recovery of the deformation, at the exit of tube, the angle *α* is zero, the thickness becomes dr_j and radial position of the element r_j [8].

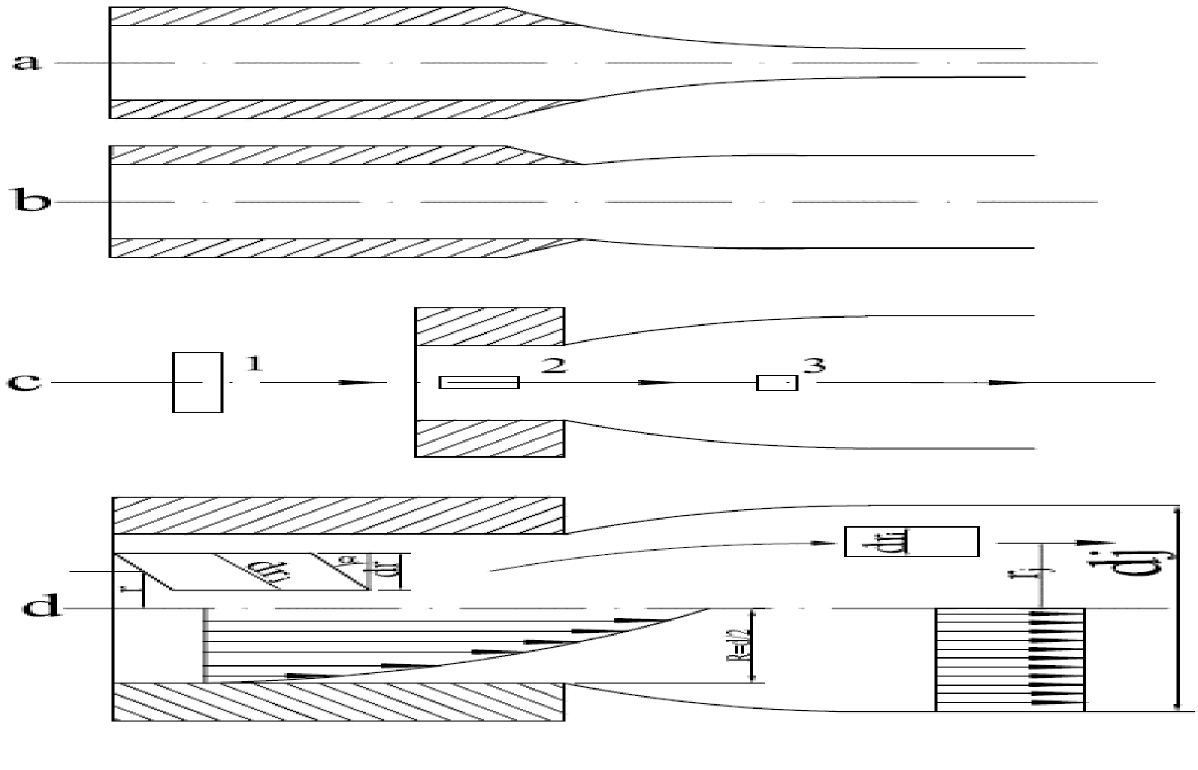

Fig.5 *The changing of the jet diameter*

From the deformed state of parallelogram we can write [8]:

$$\frac{dr_j}{dr} = \sec\alpha = \sqrt{1 + tg^2\alpha} \qquad (3.1)$$

Deformation by shearing is $\gamma = tg\alpha$ and the equation becomes:

$$\frac{dr_j}{dr} = \sqrt{1+\gamma^2\alpha} \quad (3.2)$$

Considering the recovery of deformation as the only cause of expanding of the jet, then:

$$\frac{R_j}{R} = \frac{1}{R}\int_0^{R_j} dr_j = \frac{1}{R}\int_0^{R} \sqrt{1+\gamma^2 dr} \quad (3.3)$$

or, after introduction of the adimensional variable x = r / R:

$$\frac{R_j}{R} = \int_0^1 \sqrt{1+\gamma^2} dx \quad (3.4)$$

The change of velocity profile in the output area contributes to the variation of the jet diameter. From the balance of the average values of the impulses, reported to the unit mass of fluid in the exit and in the jet, results:

$$\bar{v}_j = \frac{1}{\bar{v} \cdot R^2}\int_0^R 2rv^2 dr \quad (3.5)$$

Where $\bar{v}_j$ is the average jet velocity, $\bar{v}$ is the average velocity and v is local velocity in tube. The expression for the local fluid velocity which respect the law power is given by the equation:

$$v = \bar{v}\left(\frac{3n+1}{n+1}\right)\left[1-\left(\frac{r}{R}\right)^{(n+1)/n}\right] \quad (3.6)$$

After the substitution of the local velocity(5.5) and integration, is obtained:

$$\frac{\bar{v}}{\bar{v}_j} = \frac{2n+1}{3n+1} \quad (3.7)$$

For incompressible fluids, volume flow remains constant and the average velocities can be correlated with diameters:

$$\frac{d_j}{d} = \sqrt{\frac{\bar{v}}{\bar{v}_j}}$$

and further:

$$\frac{d_j}{d} = \sqrt{\frac{2n+1}{3n+1}} \quad (3.8)$$

The last equation shows that the jet Newtonian liquids (n = 1) suffer at the exit a contraction of 13% [($d_j$ld) = 0,87]. Pseudoplastic fluids (n <1) presents a profile of velocities that approaches to a flow of piston type, rearranging the output profile being simply and (dj / d)> 0.87. For expansive fluids (n> 1) results (dj / d) <0.87.

Considering the effect of permutation of the velocity and of the elastic recovery like a cumulative permutation, from equations (3.1) and (3.5) results the final degree of expanding [8]:

$$\beta = \frac{d_j}{d} = \sqrt{\frac{2n+1}{3n+1} + \int_0^1 \sqrt{1+\gamma^2}\,dx - 1} \qquad (3.9)$$

The degree of expanding it has to be known for each material in part because according to it the succession and the calibration system of the extrusion will be dimensioned to obtain a desired size for the semi-manufactured product.

4. CONCLUSIONS

The dimensional precision of the extruded profile depends on physical and chemical characteristics of the plastic material and technological parameters of the technological process of extrusion (melt temperature, pressure), by the type of machine extruded, its performance and also by the characteristic properties of the ”expanding phenomenom”.

To achieve an accuracy and a better quality of a semi-manufactured product resulted by extrusion are used extrusion machines with 2 snails that ensures a better plasticizer for the melted material.

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