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A New Method of Polyethylene Pipe Extrusion Using a Specially Constructed Extrusion Head

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Summary. A new method of polyethylene pipe extrusion using a specially constructed extrusion head was presented in this article. A significant feature of the head is that parts of the conical core of the conical nozzle and the nozzle part of the core are on their surfaces spaced by coils in helical path, which are shifted relatively to each other. They form a channel in which the flowing plastic is twisted in a helix. Pipes shaped in this way have a higher mechanical strength.

Key words: extrusion method, pipe, plastic.

INTRODUCTION

A new design of extrusion head for manufacturing of polyethylene pipes was presented in this article. This head allows for the extruding of pipes with increased mechanical strength using standard extrusion processing line. Head design is relatively simple and its implementation and use in technology does not cause problems.

Prerequisites for solving this problem have been plastic processing properties, namely, an increase in strength as a result of elongation of the polymer chain and its rotation [16]. During operation, a pipe for use in gas transmission or waterworks undergoes some stress as a result of internal pressure.

Figure 1 shows the plane state of stress in the pipes during axial tension with longitudinal force Q and the internal pressure p.

In this state of the load pipe, components of principal stresses are specified by dependencies [10, 11]:

$$\sigma_x = \frac{Q}{F} + \frac{pD_{sr}}{4e}, \qquad \sigma_y = \frac{pD_{sr}}{2e}, \qquad \sigma_z = -\frac{p}{2}, \qquad (1)$$

where:
σx, σy, σz – respectively, stress: axial, circumferential and radial,
D – pipe diameter,
e – pipe wall thickness,
F – cross-sectional area of the pipe.

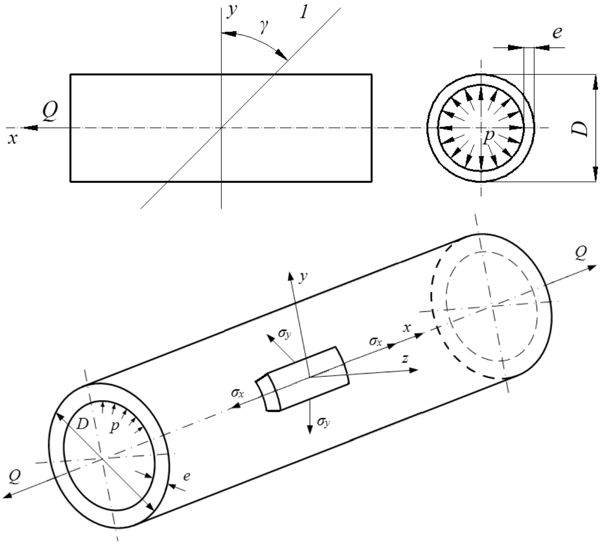

Fig. 1. Schema of plane stress in the pipe at an axial tensile strength of force Q and internal pressure p

If it is assumed that the pipe is only loaded with internal pressure p, and the axial force is zero $Q = 0$, the axial and circumferential stresses are related to the relationship:

$$\sigma_y = k\sigma_x . \qquad (2)$$

The coefficient k is the aspect ratio of stress.

It is assumed that uniform deformation should occur in the pipe wall:

$$\varepsilon_x = \varepsilon_y = \varepsilon . \qquad (3)$$

Dependence of the the aspect ratio of stress (coefficient k) and the γ angle has the form:

$$\cos 2\gamma = \frac{1-k}{1+k}. \tag{4}$$

After the transformation the pattern is obtained, that determines the aspect ratio of the stress (coefficient k) at a certain angle γ.

$$k = \tan^2 \gamma. \tag{5}$$

This means that the quotient of the strain is:

$$\frac{\sigma_y}{\sigma_x} = k = \tan^2 \gamma \cdot \tag{6}$$

The coefficient k is related to the angle γ by the relation (5). The obtained values are: $\tan^2\gamma = 2$ and angle $\gamma = 54^{o}45'$. Thus, by changing the value of the angle γ it is possible to change the proportions of stresses occurring in the wall of the tube. This creates a large pipe design options which meet various criteria, such as maximum strength at minimum weight.

It can therefore be argued that in the extrusion of PE pipes, giving helical movement of plasticized layers of plastic, the mechanical strength of the pipe can be increased, and particularly resistance to internal pressure in the pipe. To meet this requirement, the flow of plastic through the extrusion head nozzle channels should be subjected to circumferential stress. For this purpose, heads with rotating pin or ring are used. In the literature [17, 18] many different designs of heads are described. For design solution, the closest to that shown by the authors should be the solution described in work [9]. Figure 2 shows an example of design solution of straight extrusion head, with a rotating conical core (8) driven by an electric motor through a worm gear and the clutch torque transmission.

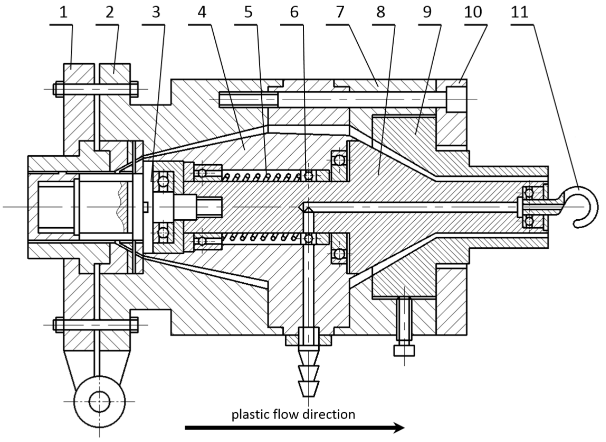

Fig. 2. Extrusion head for pipes manufacturing (longitudinal section): 1 – ring, 2 – housing, 3 – clutch 4 – conical core, 5 – spring, 6 – air-distribution ring, 7 – the nozzle body, 8 – conical rotating core, 9 – Part nozzle, 10 – collar, 11 – hook to attach a rope with stopper

Forming of pipe profile in the head is done by rotation of the conical core (8) relativelly to the nozzle (9). As a result of the friction, plastic moves along the axis of the head by a helicoidal motion. Axial movement of the plasticized material in the head is a result of the pressure difference in the head. It can be assumed that as a result of the axial displacement of the plastic, axial stresses σx, are formed therein and by the rotation of the core σy circumferential stresses arise because the polymeric material works the tension equal to the total sum of:

$$\sigma = \sqrt{\sigma_x{}^2 + \sigma^2{}_y}\ . \tag{7}$$

where:
σx – axial stress
σy – circumferential stresses

Radial stresses generated by different channel diameters can be omitted.

As a result of helical movement, the specific arrangement of the polymer structure occurs, its elongation and twisting, and thus its mechanical strength is increased. Figure 3 shows the change in the mechanical strength of a pipe depending on the rotational speed ωr of the core (8) head [9].

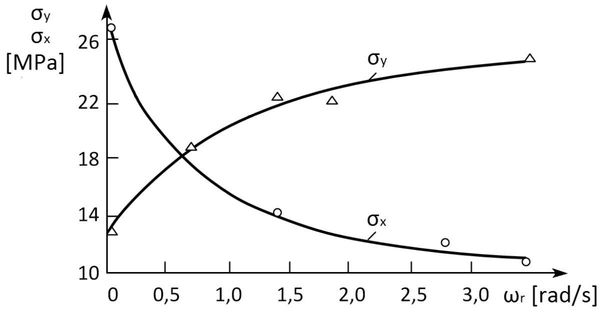

Fig. 3. Relation of strength σx i σy of a pipe on the rotational speed ωr of the core for high-density polyethylene: breaking stress in the circumferential and axial direction [9]

The higher σx component, the greater the increase in strength in the circumferential direction and the smaller one in the axial direction. From Figure 5 it can be seen that with increasing the rotational speed of the core, the strength is greatly increased in the circumferential direction (σy) and decreased in the axial direction (σx). The increase of rotational speed ωr of the core greatly reduces the tensile relative elongation in the direction of extrusion of plastic, and increases it in the tangential direction. This reveals a convergence of dependency between the destructive stress and relative elongation and the rotation of the core head. Presumably, this can be explained by the fact that the axis of the crystallization, which is the chain of the macromolecule is aligned along the axis of the crystallization lattice, which coincides with the direction of the total vector of movement of the plastic. This should contribute to the achievement of greater plastic strength in this direction.

The main disadvantage of the head construction solution shown in Figure 4 is a need for a propulsion in the form of a worm gear and an electric motor for rotating and controlling rotation of the core. Moreover, such a solution necessitates the use of rotating elements in the high temperatures of operation.

The extrusion head for pipe manufacturing from thermoplastic polymers, having a body which is shaped with a central core cooling hole is also known from Polish patent description of the invention [13]. In this solution, shaped core has two outer diameters, from a smooth transition between surfaces forming, and have longitudinal grooves evenly distributed on its circumference, wherein the core forming part of a larger diameter extends beyond the front of the head from a fraction to several diameters. Another solution is an extrusion head [14] consisting of a fixed part and a rotary part, equipped with a tubular element fixed at one end of the body and, at the other end, another one in the shape of a resilient protrusion sliding element embedded in the plastic flow channel.

THE NEW EXTRUSION HEAD DESIGN

The new extrusion head design is shown in Figure 4 which shows the extrusion head in longitudinal section, while Figure 5 shows the helical coils in cross section. The extrusion head has a body (5) ended with the nozzle (7) with the shaped core attached to it (2), whose end, in the shape of a cone, is passing into a cylinder. It is located in the nozzle (7). Between the inner surface of the body, (5) the surface of the nozzle (7), and the outer surface of the core (2) there is a plasticized plastic flow channel. The conical part of the core (2) from the nozzle site (7) and the conical nozzle (7) from the core site (2) have on their surfaces coils arranged along the helical path, to allow uniform flow of the plastic. These coils are offset by half the height of the helix, and their height is ¾ of the channel height. It is necessary to adjust the nozzle body (5) in order to maintain the symmetry of the plastic tube. Plastic extruded at the final stage of the flow is directed through the nozzle (7). Its moves are helical, which is caused by the shape of helical channel.

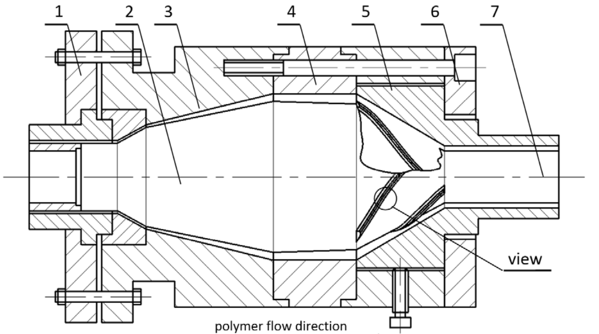

Fig. 4. The extrusion head (longitudinal section): 1 – ring, 2 – conical core with helical line, 3 – body, 4 – connecting ring, 5 – nozzle body, 6 – cover, 7 – part of the nozzle with helical line

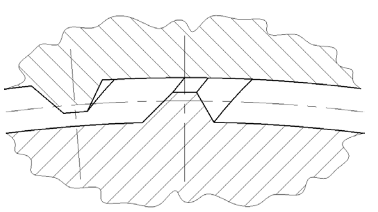

Fig. 5. Cross section of helical channel

The essence of the presented solution is that the conical part of the nozzle core and the conical part of the nozzle of the core are in their coils arranged on the surfaces of the helix which are offset relative to each other. In comparison with known solutions, designed construction of extrusion head allows for helical movement of extruded plastic in the final stage of the flow through the nozzle, which is forced by the stationary portion of the head.

THE EQUATION OF THE HELICAL CHANNEL

Coils are located on the helical core head, on the outside and on the inside of the cone nozzle. The simplest, from a technological point of view, would be a helix of constant pitch. However, it does not provide an even flow of plastic. A better solution according to the authors is the distribution of the helical coils on a fixed length of the thread pitch. Coils positioned in this way provide a uniform plastic flow velocity in the channel formed by the coils. Feasibility of the helical channel on a conical surface is described in work [8].

Generally, space curve is formed by the movement of a point in the sense that it is formed by a set of subsequent positions of the point in space, namely, the point *P* (Fig. 6) will mark a helix of constant length of each pitch of the conical surface if conditions are fulfilled. The point *P* lies on the line *l*, which forms an angle α with the axis *Oz* of Cartesian coordinate system. Straight *l* rotates about axis *Oz* with a constant angular velocity ω. Simultaneously, point *P* moves parallel to the axis *Oz* with advance velocity $\upsilon(t)$. The resultant velocity *w* of point *P* is created by the juxtaposition of speed $\upsilon(t)$ and velocity $\omega \cdot r$ and is constant and the tangent at each point of the curve is delineated. Generally, equations of the curve of fixed length of pitch can be written on the basis of Figure 6. They take the form:

$$\begin{aligned} x &= r\cos\varphi \\ y &= r\sin\varphi\ . \\ z &= \upsilon(t)\cdot t \end{aligned} \tag{8}$$

where:
x, y, z – coordinates of the point *P*,
j – angle of line *l*,
r – radius of the point *P*,
t – duration of the motion of the point *P*.

The radius *r* of a point *P* is defined by the dependence:

$$r = r_o + z\cdot\tan\alpha\,, \tag{9}$$

where:
ro – smaller radius of the base of the cone,
α – half the opening angle of the cone.

Angle of rotation of the cone line *l Oz* axis is defined by the formula:

$$\varphi = \omega\cdot t\,, \tag{10}$$

where:
ω – the angular velocity of the point *P*.

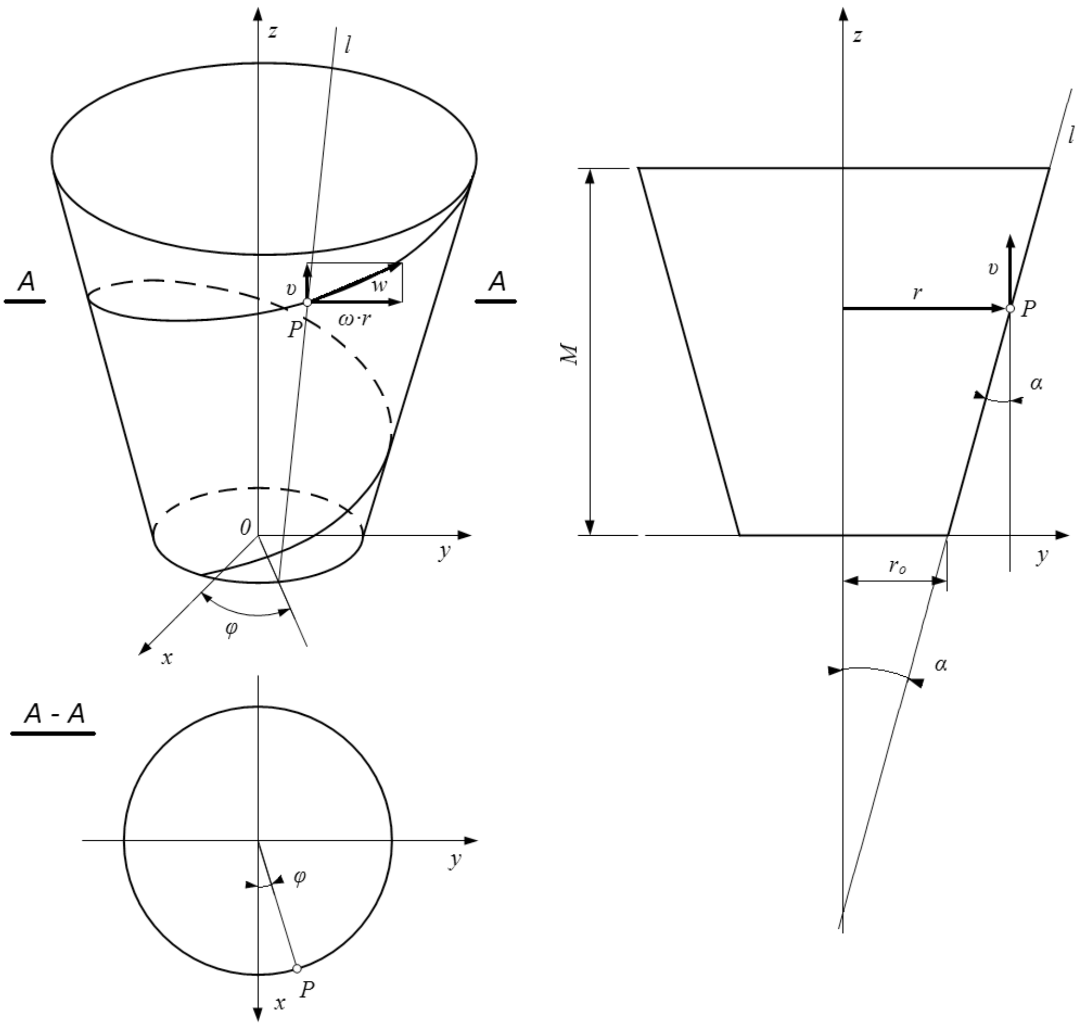

Fig. 6. The formation of a helically fixed length of stroke

The velocity distribution (Fig. 6) shows the following relationship:

$$\upsilon^2 = w^2 - \omega^2 \cdot r^2, \tag{11}$$

after transformation we obtain:

$$\upsilon = \omega \cdot \sqrt{\left(\frac{w}{\omega}\right)^2 - r^2}\,. \tag{12}$$

Using the relationship:

$$w = \frac{s}{t}\,. \tag{13}$$

where:
s – the length of the helix.

Substituting equations (9), (10), (12) into equations (8) by transforming, the equation of the helix is obtained, in which the stroke length s is constant:

$$\begin{aligned} x &= (r_o + z \tan\alpha)\cos\varphi, \\ y &= (r_o + z \tan\alpha)\sin\varphi, \\ z &= \frac{\varphi\sqrt{\dfrac{s^2}{4\pi^2}\left(1+\varphi^2\tan^2\alpha\right) - r_o^2 - \varphi^2 r_o \tan\alpha}}{1+\varphi^2\tan^2\alpha}\,. \end{aligned} \tag{14}$$

CONCLUSIONS

The presented design solution of extrusion head for polyethylene pipes is an innovative solution, that allows for the manufacturing of high-strength pipes made of polyethylene with standard extruder lines. Head design is relatively simple, and creating helical coils on the outer and inner surface of the cone can be implemented on CNC-controlled machine tools, which should not be difficult, either. This solution has been reported to the Polish Patent Office [20]. Modern methods of rapid prototyping [12] allow for easy and inexpensive prototype of nozzle head helix channel which was presented in this work. Stress states appearing in plastic pipes as well as issues related to their strength were discussed in [1-7, 15, 19]. The twisting from the present plastic flow processing through the nozzle channel with helical twist enables the production of plastic pipes which are characterized by an increased resistance to internal pressure at relatively low costs of manufacturing and retrofitting line.

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NOWA METODA WYTŁACZANIA RUR Z POLIETYLENU Z WYKORZYSTANIEM GŁOWICY O SPECJALNEJ KONSTRUKCJI

Streszczenie: W pracy przedstawiono przedstawiono nowe rozwiązanie konstrukcji głowicy wytłaczarskiej do wytwarzania rur z tworzyw sztucznych, zwłaszcza z PE. Cechą charakterystyczną głowicy jest to, że część stożkowa rdzenia od strony dyszy oraz część stożkowa dyszy od strony rdzenia mają na swych powierzchniach zwoje rozmieszczone po linii śrubowej, które są przesunięte względem siebie. Tworzą one kanał, w którym tworzywo przepływające przez niego zostaje skręcone po linii śrubowej. Ukształtowana tym sposobem rura ma większą wytrzymałość mechaniczną.

Słowa kluczowe: metoda wytłaczania, rura, tworzywo sztuczne