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A New Bending Method for Producing Polymer Sections

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The extrusion process for producing sections made of mixtures of plastics enables the manufacture of products with properties different from those of individual components of the mixture. Due to the use of the mixture of materials, produced sections acquire new characteristics, which in turn will broaden the range of their applications as well as reduce production costs. The paper presents a new method for bending sections extruded from a mixture of thermoplastics. An analysis of the process is performed using data obtained during the bending of sections made of a mixture of high density polyethylene (HDPE) and olefinic thermoplastic elastomer (TPO), each in a content of 50% by weight. The new bending method is based on the idea of new devices for bending sections described in the patent applications P. 413407 and P. 413408. In the study, the distribution of forces and bending moments occurring in the bending process are determined using the designed bending devices.

Keywords: bending sections, thermoplastics, bendability.

1. Introduction

Nowadays polymer sections, tubes and bars are extruded from various kinds of plastics depending on their application (e.g. supply of water, gas or loose materials). These products are mainly made of low– and high–density polyethylene (LDPE, HDPE) as well as poly(vinyl chloride) (PVC) [1, 2, 3]. Given the need to change certain characteristics to obtain and higher mechanical properties (including bendability) as well as requirements for such products, it is necessary to look for new materials or new bending methods. Owing to the use of polymer mixtures, it is possible to produce parts which have higher stiffness and barrier properties as well as increased strength and higher aesthetic quality than previously manufactured polymer products [4, 5, 6].

Elastic light–transmitting thermoplastic sections with different shapes of cross section are also applied in the advertising industry as single–layer shields made of poly(vinyl chloride) (PVC) for LED-diode tapes (mounted with external aluminium strengtheners) [7]. Single–layer sections can also be made of low density polyethylene (LDPE). Given their specified mechanical strength, the wall density of these sections is considerably high, which at the same time has a negative effect on their forming during bending [8]. Moreover, due to higher rigidity in the longitudinal direction, the forming of such parts requires the application of a high force during bending. This problem can be solved by the application of sections which are made of suitable plastics (e.g. by co–extrusion) or mixtures of different plastics (e.g. HDPE with TPO) [2, 3, 9].

The extruded sections for the advertising industry are manufactured in compliance with requirements of a client, which means that certain advertising signs must be subjected to bending at small bending angles (Fig. 1).

The bending of sections requires the use of special devices (section bending machine) or heating a selected region of the section directly prior to bending [10]. The application of special bending techniques increases the costs of a ready product (i.e. a complete advertising installation). The innovative solutions, including new designs of bending machines, will produce effects such as higher deformability of the section, the same of higher mechanical properties, and optical advertising installations.

The aim of this study is to present the design of devices for bending sections along with a description of the proposed bending method, as well as to determine the distribution of forces acting on the workpiece made of a mixture of two polymers.

2. Description of the bending devices

The bending of sections with a considerable length made of polymers can be done using, among others, two types of devices described in the patent applications, "A device for bending sections with a considerable length" nos. P. 413407 and P. 413408.

Figure 1 Example of an illuminated advertisement made of a polymer section [5]

A general view of the bending device is shown in Fig. 2. The device (bending machine) consists of a plate of a body 1, to which a die 2 is rotationally fixed by a mandrel 3. To the body 1 below the die 2, on a mandrel 3, the end of an arm 4 is fixed. In the central part of the arm, a bending roll 5 and a heating roll 6 are fixed rotationally. The arm is also articulatedly joined with one end of a connecting arm 8, which in turn is connected in a rotary way with a cooling roll 7. The other end of the connecting arm 8 is linked by a spring 9 with the central part of the arm 4 to ensure constant pressure of the cooling roll 7 on the workpiece. In the die 2, heating roll 5 and bending roll 6 there are heating systems to heat the workpiece to the melting point; in the cooling roll 7 there are channels for supplying liquid (cooling medium). Moreover, in the body there is a groove 10, in which a support roll 11 is mounted such that its location can be adjusted.

As for the first bending machine (shown in Fig. 3), in the a 2 and a heating roll 5 there are channels 5a which supply the heating medium (hot air) to the surface of the workpiece in order to heat it to the melting point at the place of bending. In a cooling roll 7 there are channels 7a which supply the cooling medium (cold air or liquid) to the surface of the workpiece to cool it down to the temperature that ensures fixing of the produced bend.

The heating and cooling system of the other device consists of a die 2 and a heating roll 5 heated using Patron heaters, while a cooling roll 7 is cooled by a liquid flowing in the there located channels (7a). A schematic design of the cross section of the roll and the die is shown in Fig. 4.

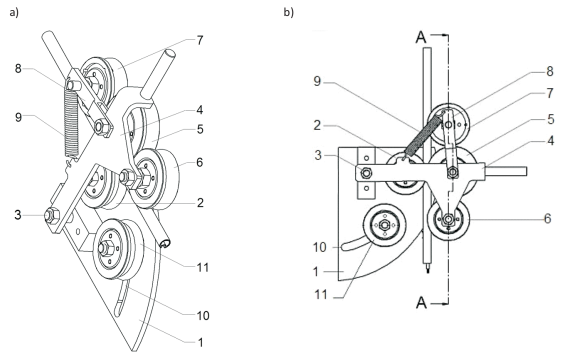

Figure 2 Schematic design of the device for bending sections described in patent applications P. 413407 and P. 413408, 1 – body, 2 – die, 3 – spindle, 4 – arm, 5 – heating roll, 6 – bending roll, 7 – cooling roll, 8 – connecting arm, 9 – spring, 10 – guiding groove, 11 – support roll

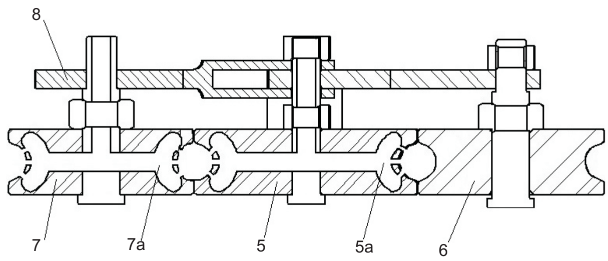

Figure 3 Cross-section of the device for bending sections according to the patent application P. 4134075 - heating roll, 6 - bending roll, 7 - cooling roll, 8 - connecting arm, 5a, 7a – channels supplying thermal factor

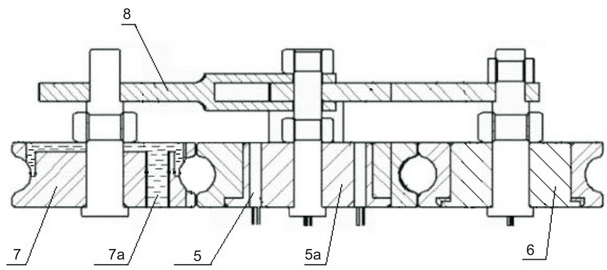

Figure 4 Cross–section of the device for bending sections according to the patent application P. 4134045 – heating roll, 6 – bending roll, 7 – cooling roll, 8 – connecting arm, 5a – heater, 7a – cooling channel

3. Description of the bending process

The desired bending angle of the polymer section with a ring–shaped section used for making advertising signs can be obtained by heating the section in the bending area. The bending process using the described devices consists in feeding the section in between a die 2, a heating roll 5, a bending roll 6 and a cooling roll 7, and its end is fixed in the chuck located behind the cooling roll 7 (not shown in the figure). Next, the section is subjected to heating between the die and the heating roll 5. Due to an increase in the temperature at the points of contact between the section and the rolls, the polymer undergoes plasticization, which leads to a decrease in the force that is necessary for bending a section on the die with a radius that is smaller than the acceptable bending radius at ambient temperature. Following the bending of the section, the point of contact between the workpiece and the cooling roll is subjected to cooling by the cooling roll moving towards the chuck.

Figure 5 shows a schematic design of loading the bending device's arm by the force F and a selection of values of the bending angle of the section.

All the above factors can be used in analysis of the variations in the force F applied to the end of the bending device's arm, determined in a function of a bendability coefficient depending on the temperature and the deflection angle of the bending device's arm.

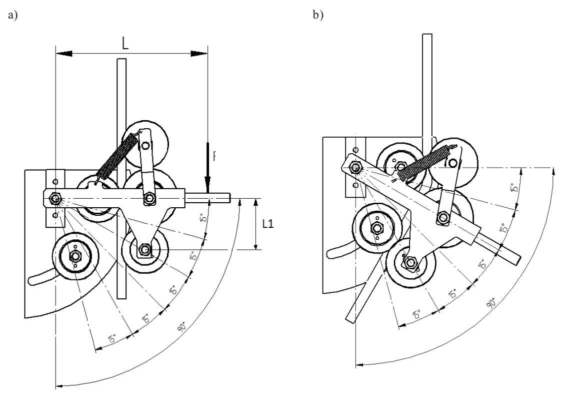

Figure 5 Schematic design of loading the bending machine's arm and the determined deflection angles a) 0° b) 30°

4. Theoretical calculations

The investigated kinematic and strength problem concerns the bending of a section with a ring–shaped cross section (tube) made by mixing two polymers: thermoplastic elastomer and high–density polyethylene, each in a quantity of 50% wt.

Given the design of the device for bending sections, the computations rested on the following assumptions [11, 12]:

1. the heating roll and the cooling roll exert a negligible load on the workpiece, and their location is determined by the range of decreased mechanical properties caused by a higher temperature,
2. the bending roll has impact on the workpiece as a concentrated force perpendicular to its longitudinal axis, the rolls rotate without slipping or friction,
3. the shearing stresses in the section's cross section are negligibly small compared to the bending stresses,
4. the material is ideally elastic–plastic, and the computations are conducted for the longitudinal axis of the section (the ratio of height of the cross section to radius of the die does not exceed 0.2).

The section with a length l is fixed at one end and supported by two slidable props, while the other end is free (Fig. 6). The loading of the beam is generated by defining the displacements of contact point with the bending roll in the direction y. Based on the equation of bending moments relative to the axis of rotation of the device, the determination of reactive force at point D enables determination of the force acting as load of the chuck.

Table 1 Dimensions of the bending device and parameters of the investigated process

Dimension	Value
x_{0B}	50 mm
α	15^o
x_{AC}	15 mm
x_{cb} $(\varphi = 0)$	0 mm
φ	$0 - 90^o$
$E_1(23^oC)$ $E_2(70^oC)$	230 MPa 103 MPa
$\sigma_{gMax1}(23^o)$C $\sigma_{gMax2}(70^oC)$	9.04 MPa 4.68 MPa
L	200mm
Φ	40 mm
Φ	34 mm

The system shown in the above figure describes a twice statically indeterminate beam. In the elastic range it will be solved by the force method where the canon equation has the form:

$$\begin{cases} \delta_{DD}X_D+\delta_{BD}X_B=y_D \\ \delta_{DB}X_D+\delta_{BB}X_B=0 \end{cases} \tag{1}$$

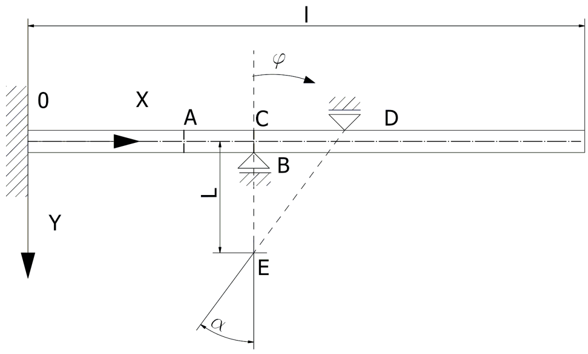

Figure 6 Diagram showing the deflection of the active part of the bending device's chuck which is rotated relative to point (E) and bending roll (D), as well as location of the region with reduced mechanical properties (A-C)

where:

δ_{DD}, δ_{BD}, δ_{DB}, δ_{BB} – are the characteristic coefficients of equation,

X_D, X_B – are the generalized forces,

y_D – is deflection of the section at point D.

The characteristic coefficients of equation are mainly calculated by the graphic integration method, but, in this case, it is necessary to employ analytical integration due to elevated temperatures along the axis of the workpiece. With increasing the temperature of the section, its mechanical properties (E and σ_g) decrease. On defining the kinematic nodes in a function of deflection of the chuck by the angle Φ, we obtained translation of the support D in the directions y and x:

$$\Delta D_y(\varphi) = (L + \frac{\Phi}{2}) - [(L + \frac{\Phi}{2}) \tan[\alpha] \sin[-\varphi] + (L + \frac{\Phi}{2}) \cos[-\varphi]] \tag{2}$$

$$\Delta D_x(\varphi) = (L + \frac{\Phi}{2}) \tan[\alpha] - (L + \frac{\Phi}{2}) \tan[\alpha] \cos[-\varphi] - (L + \frac{\Phi}{2}) \sin[-\varphi] \tag{3}$$

The deflection and the torsional angle of the section loaded with the generalized force X_d in the direction y are described by the below dependencies. Based on their values, we determined the characteristic coefficients δ_{DD}, δ_{BD}, δ_{DB}.

$$y'' = \frac{M(x)}{E_1(x)\ J} \tag{4}$$

$$M(x) = X_D(l_{0D} - x) \tag{5}$$

$$\begin{array}{l|l|l|l}
y'' = \frac{\mathrm{X}(l_{0D}-x)}{E_1(x)J} & +\frac{\mathrm{X}(l_{0D}-x)}{\mathrm{E}_2(\mathrm{x})\mathrm{J}} & \frac{\mathrm{X}(l_{0D}-x)}{\mathrm{E}_2(\mathrm{x})\mathrm{J}} & +\frac{\mathrm{X}(l_{0D}-x)}{\mathrm{E}_1(\mathrm{x})\mathrm{J}} \\
y' = \frac{-\mathrm{X}\left(\mathrm{x}l_{0D}-\frac{x^2}{2}\right)}{E_1 J} & +\frac{-\mathrm{X}\left(\mathrm{x}l_{0D}-\frac{x^2}{2}\right)}{E_2 J} & +\frac{-\mathrm{X}\left(\mathrm{x}l_{0D}-\frac{x^2}{2}\right)}{E_2 J} & +\frac{-\mathrm{X}\left(\mathrm{x}l_{0D}-\frac{x^2}{2}\right)}{E_1 J} \\
y'(0) = 0 \to C_1 = 0 & & & \\
y = \frac{-\mathrm{X}\left(\frac{x^2}{2}l_{0D}-\frac{x^3}{6}\right)}{E_2 J}+\mathrm{C}_2 & +\frac{-\mathrm{X}\left(\frac{x^2}{2}l_{0D}-\frac{x^3}{6}\right)}{E_2 J} & +\frac{-\mathrm{X}\left(\frac{x^2}{2}l_{0D}-\frac{x^3}{6}\right)}{E_2 J} & +\frac{-\mathrm{X}\left(\frac{x^2}{2}l_{0D}-\frac{x^3}{6}\right)}{E_1 J} \\
y(0) = 0 \to C_2 = 0 & & & \\
0 \le x_1 \le l_{0A} & & & \\
\hline
l_{0A} \le x_2 \le l_{0B} & & & \\
\hline
l_{0B} \le x_3 \le l_{0C} & & & \\
\hline
l_{0C} \le 4 \le l_{0D} & & &
\end{array} \tag{6}$$

The coefficient δ_{BB} was determined analogically from the dependence:

$$\begin{array}{l|l}
y = \frac{\mathrm{X}\left(\frac{x^2}{2}l_{0B}-\frac{x^3}{6}\right)}{E_1 J} & +\frac{\mathrm{X}\left(\frac{x^2}{2}l_{0B}-\frac{x^3}{6}\right)}{E_2 J} \\
0 \le x_1 \le l_{0A} & \\
\hline
l_{0A} \le x_2 \le l_{0B} &
\end{array} \tag{7}$$

Since the force method is only effective in elastic range, the boundary value of the stresses σ_{gMax2} at point B was set to 4.68 MPa. The force necessary for the critical angle describing material plasticization is $\Phi_{gr} = 1.8^o$. At higher angles of deflection, a plastic articulated joint is produced in the area region where the highest stresses occur (Fig. 7).

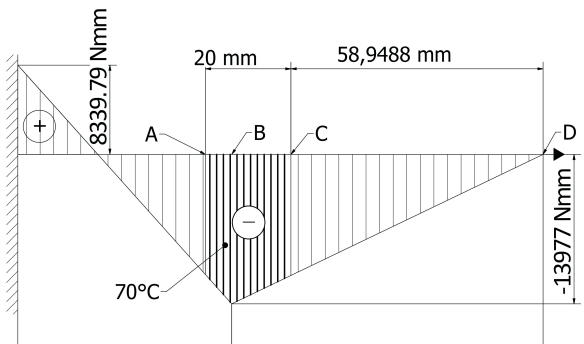

Figure 7 Diagram illustrating the bending moments and temperatures in the section versus load at the critical angle of 1.8^o

The force necessary for chuck deflection generates stresses σ_{gMax2} at point C, which enables die forming of the heated section:

$$F\left(\varphi \ge 2\varphi_{gr}\right) = \frac{\sigma_{gMax2C}\, Wz}{l_{CD}} \frac{l_{CD}}{L_f} \tag{8}$$

The developed model of the bending process for a tubular section enabled preliminary determination of the force in a function of the angle of deflection both for the heated section and for the section subjected to cold bending (Fig. 8).

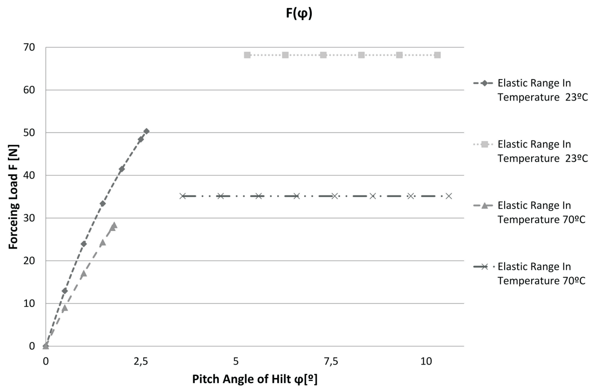

Figure 8 Force-deflection angle characteristics of the section subjected to cold bending and heated to 70^0C

5. Conclusions

The new bending method for sections made of polymers ensures that the bending process is more economical and accurate. Due to the application of die heating systems and a heating roll in the presented bending devices, the forces necessary for producing the desired result get decreased. In turn, the application of the cooling roll leads to immediate cooling of the material subjected to bending, which will make it stiff and prevent undesired defects.

The results of the analysis for determining a value of the force required for section bending by a specific angle based on the stresses in the section, demonstrate that such products can be made of a mixture of plastics, and the results of the bending process run at 23^oC and at 70^oC are satisfactory. The findings demonstrate that the extent of elastic strains decreases with increasing the temperature. In addition to that, the force F, which is necessary for bending sections, decreased by almost two times (from 68 N at 23^oC to 35 N at 70^oC).

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