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IMPROVEMENT OF PRESS-FORMS FOR POLYMERIC ITEMS MOULDING

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ABSTRACT:

Press-forms of the moulding machines were improved and worked out; their constructions enable to produce the items of the advanced reliability

Key words: Moulding machine, press-form for polymeric items moulding, inlet opening, press-form cavity, soldered joints, item reliability

1. INTRODUCTION

The reliability of polymeric items produced by the moulding under pressure depends on physical and mechanical features in the places which bear the highest influence in operational process [1].

The considerable part in the process of the structural building of the moulded polymeric items is done by the element construction of the moulding machines. The most important element of the moulding machine is the press-form where the footwear bottom is formed.

In the modern moulding machines the filling of a press-form is carried out through six inlet openings (Figure 1).

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As the result the soldered joints are created in the meeting places of streams (Figure 1) which have low operational features [10].

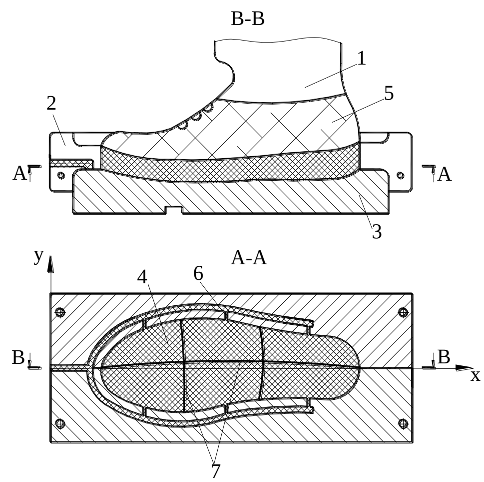

Figure 1 Press-form for footwear bottom moulding: 1 – press last, 2 - a half of matrix, 3 – punch, 4 – completed item (footwear bottom), 5 –footwear top billet, 6 – inlet openings, 7 – soldered joints

As the different item parts in the operational process take the different loads it is necessary that the joints are absent at the places of the most destructive influence or located under the minimum angle to the direction of the destructive influence action (in the work [10] it was determined that the decreasing of the angle between a soldered joint and destructive load action direction increases the item reliability). Thus the actual task and the interest of modern industry is the definition of constructive parameters of the press-form which provide with soldered joints creation in those item places that take the minimum load in the operational process and thereby extend their durability.

2. MATHEMATICAL MODEL OF POLYMERIC MATERIAL FLOWING

In order to research the influence of the press-form parameters on the soldered joints location in the item it is necessary to make a mathematical description of the polymeric smelt flowing. During the composing of the mathematical model for the dynamics of polymeric smelt flowing in the press-form cavity the following suppositions were made: the smelt is uncompressible liquid, gravitational forces are so small that they can be omitted, the smelt is lamellar, dissipation heating was not considered, there is no gliding in the contact place between astringent liquid and the press-form cavity sides.

The mathematical model is based on Navier and Stocks's equation for greatly astringent liquids [5,9]:

$$-\frac{\partial \boldsymbol{\varphi}}{\partial \boldsymbol{x}} + \boldsymbol{\nu} \cdot \left[\frac{\partial^2 \boldsymbol{u}}{\partial \boldsymbol{x}^2} + \frac{\partial^2 \boldsymbol{u}}{\partial \boldsymbol{y}^2} \right] = 0; \quad (1)$$

$$-\frac{\partial \boldsymbol{\varphi}}{\partial \boldsymbol{y}} + \boldsymbol{\nu} \cdot \left[\frac{\partial^2 \boldsymbol{\upsilon}}{\partial \boldsymbol{x}^2} + \frac{\partial^2 \boldsymbol{\upsilon}}{\partial \boldsymbol{y}^2} \right] = 0, \quad (2)$$

u, υ – projections of speed vector to x and y *axes* (Figure 1); φ – ration of pressure to the constant polymer density; ν – cinematic liquid astringency.

The condition of incompressibility was added to the equations [9]:

$$\boldsymbol{D} = \frac{\partial \boldsymbol{u}}{\partial \boldsymbol{x}} + \frac{\partial \boldsymbol{\upsilon}}{\partial \boldsymbol{y}} = 0, \quad (3)$$

D – divergence of speed vector

The Laplace's equation for pressure was received from the equations (1)…(3):

$$\nabla^2 \boldsymbol{\varphi} = \frac{\partial^2 \boldsymbol{\varphi}}{\partial \mathrm{x}^2} + \frac{\partial^2 \boldsymbol{\varphi}}{\partial \boldsymbol{y}^2} = 0. \quad (4)$$

The rheological equation in the form of the degree principle was used for the calculation of the dependence of the astringency on the temperature factors [8]:

$$\mu(\dot{\gamma}, T) = \mu_H(T) \cdot \left[1 + A_1 \cdot \left(\dot{\gamma} \cdot \mu_H(T) \right)^n + A_2 \cdot \left(\dot{\gamma} \cdot \mu_H(T) \right)^{2n} \right]^{-1}, \quad (5)$$

$\boldsymbol{\mu}_{\mathrm{H}}(\boldsymbol{T})$ – Newton's dynamic astringency under the temperature $\boldsymbol{T}$; $\dot{\boldsymbol{\gamma}}$ – deformational speed; n, $\boldsymbol{A_1}, \boldsymbol{A_2}$ – rheological equation coefficients.

The coefficients valuation of pheological equitation for different polymeric materials was chosen from [8]. Newton's astringency with the current temperature was found under the following formula:

$$\boldsymbol{\mu}_{\mathrm{H}}(\boldsymbol{T}) = \boldsymbol{\mu}_{\mathrm{H}}(\boldsymbol{T}_{*}) \cdot \exp\left[\frac{\boldsymbol{E}_{\mathrm{H}}}{\boldsymbol{R}}\left(\frac{1}{\boldsymbol{T}} - \frac{1}{\boldsymbol{T}_{*}}\right)\right] \qquad \textbf{(6)}$$

$\boldsymbol{\mu}_{\mathrm{H}}(\boldsymbol{T}_{*})$ - Newton's dynamic astringency with the temperature of the phase transmission $\boldsymbol{T}_{*}$ (in this case with the temperature of polymeric material aging); $\boldsymbol{E}_{\mathbf{H}}$ – activation energy; $\boldsymbol{R}$ = 8,31 kilojoules/(moth·K) – gas constant; $\boldsymbol{T}$ – absolute temperature of a polymer which was determined from the stationary equation of thermal conductivity.

The mathematical model which is presented by the equation system (1), (2), (3), (4)…(6) combines the polymeric features, press-form parameters and technological parameters of moulding process under pressure from the one side and movement speed of the free surface of the smelt and pressure from the other side.

In order to solve the above mentioned system of differential equations the following boundary conditions were put:

- On the symmetric axis the radical speed $\boldsymbol{\upsilon}$ and tangential pressure $\boldsymbol{\tau}$ were taken as those equal to zero [5];
- At the points, where astringent liquid lies on the firm press-form cavity sides, normal and tangent vector compounds equaled to zero [9], and the temperature was accepted as equal to the temperature of the cavity form side;
- On the boundary of the flowing out the one speed vector constituent was accepted as equal to zero depending on the liquid movement direction, and the value of the other constituent was found from the initial task conditions. The temperature value of the smelt in the press-form entrance was considered as the constant during the whole filling process.

The boundary conditions for the pressure next to the firm sides, on the boundary of the flowing in and on the symmetric axis were found from the equations (1) and (2) by means of substitution of boundary speed in them.

In order to suit the requests of boundary conditions the following acts were conducted: cinematic condition – the speed constituent which is normal to the free surface coincides with transmission speed of the free surface, and dynamic condition – the pressure vector $\boldsymbol{p}$ for platforms tangent to free surface is directed at the normal to these platforms inside and equals to zero [9].

The system of differential equations (1), (2), (4)… (6), was solved by finite-difference method of markers and cells [4, 6] taking into account the boundary conditions. The meaning of it is that all differential quotations and boundary conditions are written down in finite differences on the fixed cellar frame and that covers the flowing area of astringent liquid. The system of markers which are used for the flow visualization is added to the liquid cubage and to its surface.

The liquid configuration was determined by the markers differentiation on the calculated frame which is composed of four types of cellar, namely boundary cellars, in which the conditions next to the firm sides on the boundary of the flowing out and the symmetric axis are conducted, complete cellars which are sharp cut by the other complete cellars and contain the markers, empty cellars which do not contain markers and surface cellars which contain markers but border with the empty cellars.

The liquid motion equation (1), (2) and (4) for the complete cellars in finite-difference form was written down as follows:

$$\left.\begin{aligned} \boldsymbol{u}_{i,j} &= \frac{1}{4}\left[\boldsymbol{u}_{i+1,j} + \boldsymbol{u}_{i-1,j} + \boldsymbol{u}_{i,j+1} + \boldsymbol{u}_{i,j-1} - \frac{\boldsymbol{h}}{\boldsymbol{\nu}_{i,j}}\left(\boldsymbol{\varphi}_{i+1,j} - \boldsymbol{\varphi}_{i,j}\right)\right]; \\ \boldsymbol{\upsilon}_{i,j} &= \frac{1}{4}\left[\boldsymbol{\upsilon}_{i+1,j} + \boldsymbol{\upsilon}_{i-1,j} + \boldsymbol{\upsilon}_{i,j+1} + \boldsymbol{\upsilon}_{i,j-1} - \frac{\boldsymbol{h}}{\boldsymbol{\nu}_{i,j}}\left(\boldsymbol{\varphi}_{i,j+1} - \boldsymbol{\varphi}_{i,j}\right)\right]; \\ \boldsymbol{\varphi}_{i,j} &= \frac{1}{4}\left(\boldsymbol{\varphi}_{i+1,j} + \boldsymbol{\varphi}_{i-1,j} + \boldsymbol{\varphi}_{i,j+1} + \boldsymbol{\varphi}_{i,j-1}\right), \end{aligned}\right\} \quad \textbf{(7)}$$

$\boldsymbol{h}$ – size of a cellar

Cinematic material astringency in the cellar $\boldsymbol{\nu}_{i,j}$ was determined according to the finite-difference equation (5):

$$\nu_{i,j}^{k} = \frac{\mu_H(T_{i,j})}{\rho} \cdot \left[1 + A_1 \cdot \left(H_{i,j}^{k-1} \cdot \mu_H(T_{i,j})\right)^{n} + A_2 \cdot \left(H_{i,j}^{k-1} \cdot \mu_H(T_{i,j})\right)^{2n}\right]^{-1}, \quad \textbf{(8)}$$

k – number of iteration; $\boldsymbol{H}_{i,j}$ – intensity of the deformation speed in cellar ($\boldsymbol{x_i}, \boldsymbol{y_j}$).
Newton's dynamic astringency under the temperature $\boldsymbol{T}_{i,j}$ was determined from the equation:

$$\mu_{\mathrm{H}}(\boldsymbol{T}_{i,j}) = \mu_{\mathrm{H}}(\boldsymbol{T}_{*}) \cdot \exp\left[\frac{\boldsymbol{E}_{\mathrm{H}}}{\boldsymbol{R}}\left(\frac{1}{\boldsymbol{T}_{i,j}} - \frac{1}{\boldsymbol{T}_{*}}\right)\right], \quad \textbf{(9)}$$

Absolute temperature of material in cellar was found from finite-deference equation of heat conduction:

$$T_{i,j} = \frac{1}{4} \cdot \left(T_{i+1,j} + T_{i-1,j} + T_{i,j+1} + T_{i,j-1} \right). \qquad \textbf{(10)}$$

The speed, pressure and smelt cinematic astringency of the polymeric material for the boundary and surface type of cellars was determined by the substation of boundary conditions in the formula (7)…(9).

Thus the complete system of linear algebraic equations for the determination of all unknowns in different types of cellars - boundary, complete and surface – was received. For the solving of this system the Libman's integration method was used with the conduction of the consecutive top relaxation.

The location of the free surface polymeric smelt was determined by the position data of each marker. The data were calculated according to the received speed field of numerical integrating [7]:

$$x_m^{n} = x_m^{n-1} + u_m \cdot \Delta t, \qquad y_m^{n} = y_m^{n-1} + \upsilon_m \cdot \Delta t, \qquad (11)$$

x_m^{n-1}, y_m^{n-1} – marker location in the previous moment of time; Δt – time pitch; u_m, υ_m – horizontal and vertical marker speed vector compounds which were determined by the linear interpellation method [5].

According to the method of astringent liquid flowing calculation described above the complex of calculating programs was created. That enables to visualize the process of filling a press-form with a polymeric material.

2. METHOD OF PRESS-FORM CAVITY DESIGNING

The mathematical model and program package created for its realization were the basis of the engineering method of press-form designating of moudeling machines.

The method of press-form designing includes several stages.

At the first stage the geometrical form press-form cavity, size and quantity of inlet openings and the places of their locations were determined with the help of the known methods of pres-form designing [11] or according to the results of experimental research (Figure 2).

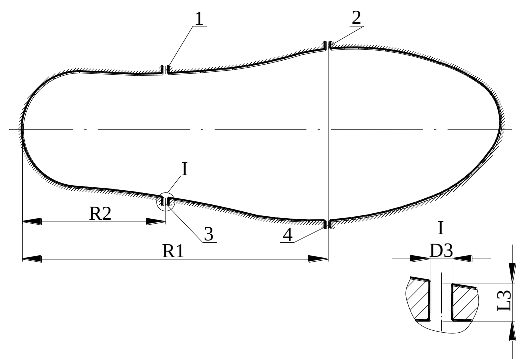

Figure 2 Geometrical scheme of press-form cavity: 1,2,3,4 – inlet openings; R1 – distance to the inlet openings 2 and 4; R2 – distance to inlet openings 1 and 3; D3, L3 – diameter and length of inlet opening 3

At the second stage the quadratic cellar frame is applied to the geometric drawing of press-form cavity. Then curvilinear boundaries are substituted by the boundaries which coincide with the lines of calculating frame (Figure 3).

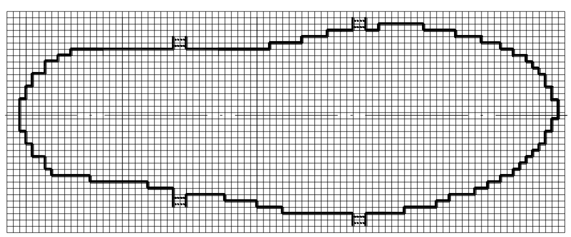

Figure 3 Calculating scheme of press-form cavity

At the third stage the initial position of marker parts and speed profile on the entrance to the press-form cavity is specified. For that it is necessary to know the cubic expenses of polymeric material. The cubic expense in the calculations is taken as that which responses the real conditions of footwear production.

At the fourth stage the process of press-form cavity filling with the polymeric material is visualized with the help of the developed programs. This makes it possible to define the places of soldered joints creation in the finished item (Figure 4). If there were such soldered joints location received with which the item reliability was decreasing then the press-form constructive parameters would be changed and all stages would be passed again.

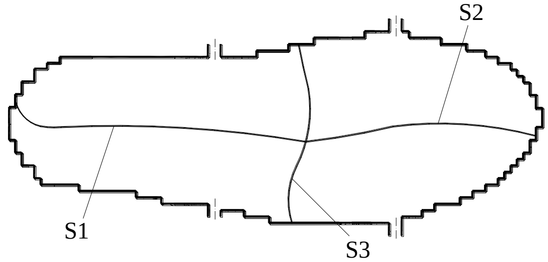

Figure 4 Soldered joints location in the finished item
S1, S2, S3 – soldered joint lines

This would be repeated until the certain press-form parameters are not defined. These parameters ensure with soldered joints location in the least loaded places during the operational process or in the minimum angle to the destructive influence direction.

With the help of this method it was determined that the bottoms of footwear which is produced on the moulding machines has low operational characteristics because the soldered joint **S** was located in the most loaded footwear bottom place during the operational process, i.e. in the bunch zone (Figure 5).

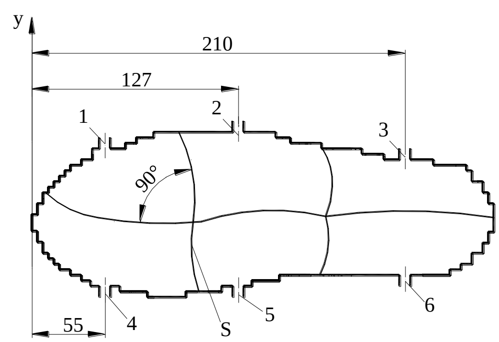

Figure 5 Soldered joints location in the finished item received with the usage of the existing press-form: 1…6 – inlet openings

As the result of the research of soldered joints creation process with the different inlet openings location the press-form is proposed in which the inlet opening **2** is done on the distance of 0,104 m and the inlet opening **5** is done on the distance of 0,158 m from the axis **y** (Figure 6).

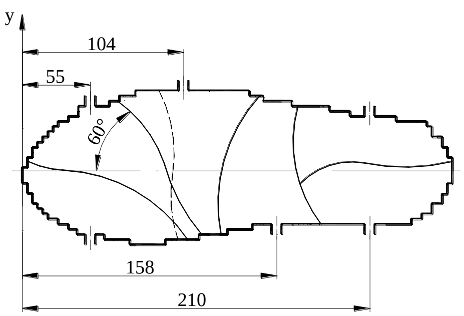

Figure 6 Soldered joints location in the finished item received with the usage of the proposed press-form:
——— Location of the soldered joint *S* before the inlet orientation change
– – – – Location of the soldered joint *S* after the inlet orientation change

Such inlet openings location enables to reduce the angle between the line of soldered joint **S** and the destructive influence direction to 60 ^{0}. That increases the footwear bottom reliability.

4. CONSTRUCTION OF MOULDING MACHINE PRESS-FORM FOR THE OBTAINING OF JOINT FREE ITEMS.

As it is known from [3] that the press-form cavity filling is conducted in two modes.

In first mode the moulding pressure increases in the process of press-form filling and the cubic speed in the cavity entrance is constant. The press-form filling in this mode ensures the stability of item material stability and operational characteristics [2].

The second mode starts when the moulding pressure reaches its boundary valuation and become constant, and the cubic speed in the cavity entrance become dependent on the location of free surface of polymeric material smelt. During the press-form filling in the second mode the process of cubic speed oscillation is run in the entrance, thus the filling time. As the result the quality of the moulded item is low [2].

During the moulding under pressure of big polymeric items at first the filing of press-form cavity is conducted in the first mode which is substituted by the second afterwards. This leads to the decrease of operational features of the finished items. Therefore for the obtaining of footwear bottoms by the moulding under pressure the polymeric material smelt is delivered in to the cavity through several inlet openings. This ensures the press-form filling in the first mode. As the result of this the footwear bottom details contain the soldered joints which reduce their operational features.

With the help of the developed program package we have researched the process of press-form filling with the polymeric material through the one inlet opening with the different cavity sides temperature (cubic expense is constant).

The research was conducted for the press-form with the cavity height H = 0,005 m; 0,01 m; 0,018 m.

As the result the graphics of the dependence flowing depth of polymeric smelt **L** in the press-form cavity on the temperature of its sides **Tf** were received (Figure 7).

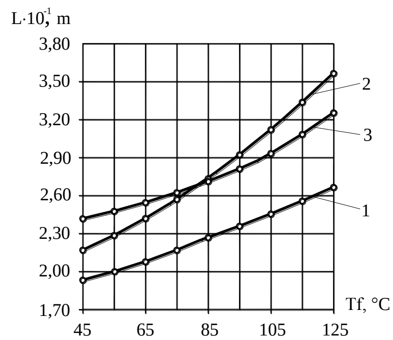

Figure 7 Graphics of the dependence of polymeric smelt flowing depth on the press-form sides temperature under the constant cubic expense for the cavity height H: 1 – 0,005 м; 2 – 0,01 м; 3 – 0,018 м

From these graphics it is evident that during the moulding of footwear bottoms with the thickness from 0,01 m to 0,018 m for the ensuring of the full press-form filling, before the injection of the polymeric smelt it is necessary to warm up the sides of the forming cavity to the temperature of 75 ÷ 105 ^{0} C depending on the item size (Figure 5). And during the moulding of footwear bottoms with the thickness of 0,005 m it is necessary to warm up to the temperature of 100 ÷ 120 ^{0} C.

On the basis of this we have proposed the new construction of the moulding machine press-form for footwear bottoms obtaining. The given press-form includes the soldered joints creation and thus enables to obtain the items of advanced reliability (Figure 8).

As the result of the conducted research the special press-form for footwear bottom was designed (Figure 6). This press-form includes the creation of the soldered joints allowing them to receive the items with the advanced operational features.

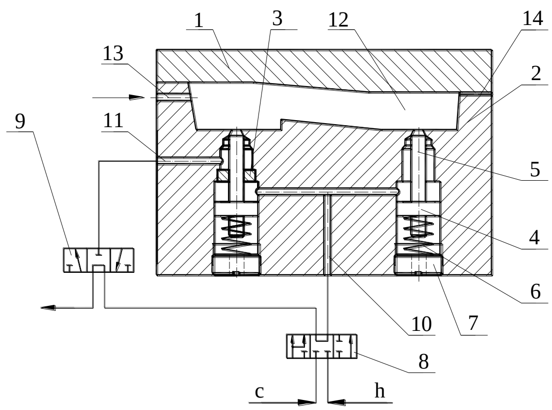

Figure 6. Press-form for footwear bottom production: c – pipeline of cold compressed air; h – pipeline of hot compressed air

The press-form works in the following way: punch 1 and matrix 2 unite creating the forming cavity 12. Pneumospreader 8 plugs in the channel 10 to the pipeline of the hot compressed air. This leads to the displacement of the pistons 4 with styluses 5 down. As the result the hot air penetrates into the forming cavity 12 and comes out through the channel 11 into the atmosphere. The sides of the forming cavity 12 are heated. Then the pneumospreader 8 switches off the channel 10 from the pipeline of the hot compressed air and pneumospreader 9 connects that channel 10 with atmosphere. As the result the pistons 4 with the styluses 5 move up. Then the polymeric material fills the forming cavity 12 through the funnel channel 13. After the fastening of the polymeric material the punch 1 and matrix 2 are disconnected and pneumospreaders 8 and 9 connect the channels 10 and 11 to the pipeline of the cold compressed air. As the result of this the pistons 4 with the styluses 5 move down and the air pushes out the ready footwear bottom from the press-form.

The condition of the pistons 4 sinking with the styluses 5 is secured by the regulating of the previous compression of the springs 6 by means of turn of corks 7.

5. CONCLUSIONS

(1) The mathematical model of polymeric material dynamics was worked out. It differs form the previous models by the including of non-isothermility of the process and possibility of its more detailed description.

(2) On the basis of the developed mathematical model the engineering method of designing of moudeling machine press-forms was proposed. It enables to define the press-form constructive parameters which ensure the soldered joints location in the least loaded item places during the operational process.

(3) The press-form for footwear bottom moulding and footwear top storing up. It enables to reduce the angle between the soldered joint and destructive load direction improving the operational features of the item.

(4) The new construction of the moulding machine press-form was worked out for the footwear bottom obtaining of the advanced reliability due to the soldered joints exclusion.

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UDOSKONALENIE PRES-FORM DLA ODLEWU POLIMEROWEGO

SUMMARY

Cel projektu: opracowanie inżynierskiej metody projektowania **pres-form** dla odlewu podeszw.
Niezawodność wyrobów z tworzyw polimerowych, wytwarzanych ciśnieniowo, zależy od fizyko-mechanicznych właściwości miejsc, które są poddane największym obciążeniem eksploatacyjnym. Ma na nie istotny wpływ konstrukcja elementów maszyn ciśnieniowych. W maszynach ciśnieniowych wypełnienie **pres-form** odbywa się poprzez kilka dysz wtryskowych**.** W wyniku tego, w miejscach styku strumieni tworzywa tworzą się spoiny, które mają niskie właściwości eksploatacyjne. W celu przeprowadzenia badań nad wpływem parametrów **pres-form** na miejsca rozmieszczenia spoin w podeszwie opracowano matematyczny model ich wypełniania tworzywem polimerowym. Stanowił on podstawę inżynierskiej metody projektowania **pres-form,** dzięki której spoiny znajdą się w najmniej obciążonych eksploatacyjnie miejscach podeszwy

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