Dariusz KWIATKOWSKI, Michał MODŁAWSKI, Tomasz JARUGA*
Department of Polymer Processing, Institute of Mechanical Engineering
Częstochowa University of Technology,
Al. Armii Krajowej 19 C, 42-201 Częstochowa,
* e-mail: jaruga@ipp.pcz.pl

Analysis of flash pocket profile shape in an extrusion blow mould

***Abstract**: The cycle time is a very important issue in manufacturing processes, especially in packaging industry. It depends on the product shape and size, particularly on the wall thickness, but also on tool design and process settings. One of the most important factors influencing the cycle time is cooling system efficiency in the tool. In case of extrusion blow moulding not only the product should be cooled rapidly but also the flash material in the pinch-off zone.*

The results of an PE-HD bottle extrusion blow moulding simulation were presented in this paper. The simulation was done with the use of ANSYS Polyflow software. The cooling efficiency in the pinch-off zone was evaluated for different profiles of the flash pocket by comparison of the temperature distribution after cooling time. It was found that the triangled and semicircular profile is more efficient than trapezoidal and flat shape.

ANALIZA PROFILU PRZEKROJU KIESZENI ODPADOWEJ W FORMIE ROZDMUCHOWEJ

***Streszczenie**: Czas cyklu jest niezwykle istotnym czynnikiem w procesach wytwarzania, szczególnie w przemyśle opakowań. Zależy on od kształtu i wymiarów wyrobu, szczególnie od grubości ścianek, ale także od konstrukcji narzędzia i warunków procesu technologicznego. Jednym z najważniejszych czynników wpływających na czas cyklu jest efektywność chłodzenia wyrobu w narzędziu. W procesie wytłaczania z rozdmuchiwaniem nie tylko należy szybko chłodzić wyrób, ale także odpad w strefie zgniatania.*

W niniejszym artykule zostały zaprezentowane wyniki symulacji procesu wytłaczania z rozdmuchiwaniem butelki z tworzywa PE-HD. Symulację wykonano z wykorzystaniem oprogramowania ANSYS Polyflow. Oszacowano efektywność chłodzenia w strefie zgniatania dla różnych kształtów profilu formy w kieszeni odpadowej poprzez porównanie rozkładu temperatury po czasie chłodzenia. Ustalono, że profile o kształcie trójkątnym oraz półkolistym są bardziej efektywne niż profile płaski oraz trapezoidalny.

1. INTRODUCTION

The extrusion blow moulding process is used to manufacture hollow parts like bottles and other types of containers. In most cases polyolefins are processed by this technology. This process is divided in two stages. First, a parison is extruded and then, in the second stage, it is blown in a mould. The pinching edges in a mould cut off the excessive material which stays in pinch-off sections while the mould is closed. A pinch-off section consists of a pinching edge, a pressure zone and a flash pocket (pinch relief) where the plastic should be intensively cooled. Blow moulds consist of at least several parts. A scheme of an exemplary blow mould is presented in Fig. 1.

Three main zones can be distinguished in a pinch-off section (Fig. 2.): pinching edge just behind the cavity, then pressure zone to compress the material and, finally, flash pocket where most of the flash is held. The design of a pinch-off section should assure the efficient cooling down of the flash – the contact surface

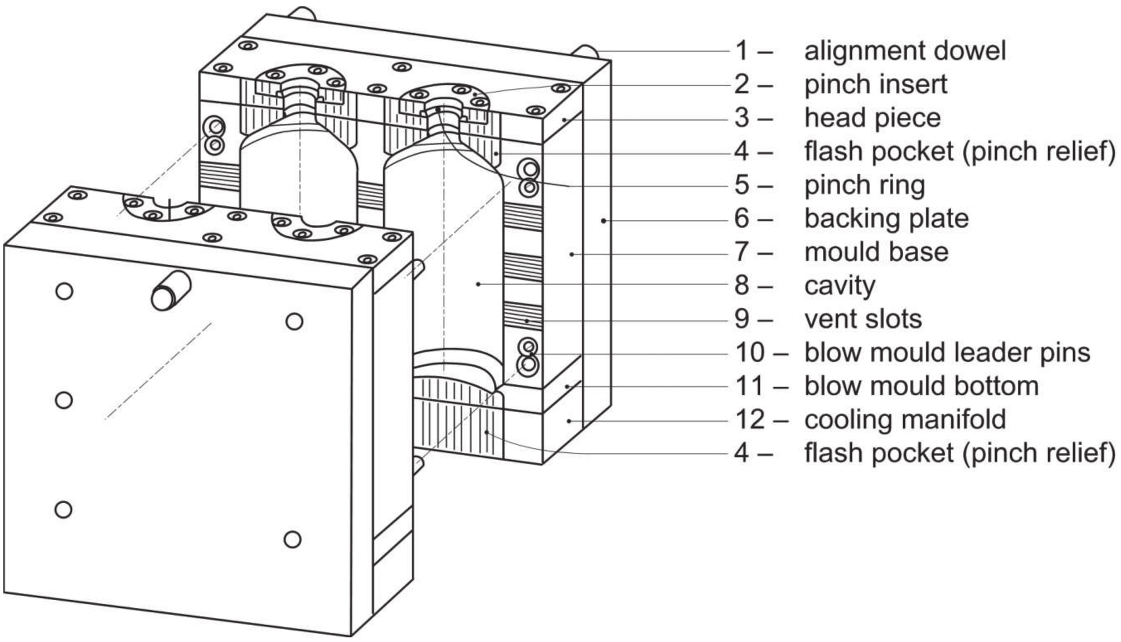

Fig. 1. Scheme of an extrusion blow mould [1, 2]

Rys. 1. Schemat formy do rozdmuchiwania, 1 – elementy ustalające, 2 – wstawka nożowa (odcinająca), 3 – element formujący szyjkę, 4 – strefa zgniatania, 5 – krawędź tnąca, 6 – płyta tylna (mocująca), 7 – element formujący korpus opakowania, 8 – gniazdo formujące, 9 – kanał odpowietrzający, 10 – elementy prowadzące (słupy i tuleje prowadzące, 11 – element formujący dno opakowania, 12 – kolektor układu chłodzącego [1, 2]

between parison and mould should be as large – it can be achieved by manufacturing of a riffled surface. Moreover, the distance between two mould halves in this section is also important. If this distance is too small the flash is compressed with a high pressure and this can result in mould opening because of high force generation. Moreover, the entire pinch-off zone should be large enough to hold all the flash after mould closing. The pinch-off area size and dimensions should be optimized for the particular product, depending on its size and shape, parison dimensions (wall thickness and diameter) machine parameters etc. [1,3]

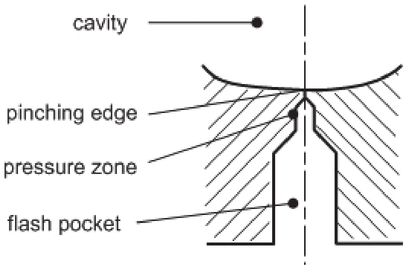

Fig. 2. Geometry of pinch-off section in an extrusion blow mould [1]

Rys. 2. Kształt strefy zgniatania w formie rozdmuchowej [1]

The recommended geometry of a pinch-off section in a blow mould is shown in details in Fig. 3. In this the ribs are designed to increase the cooling area of the flash relief and the angle of a rib is 90°.

A shape of the cavity is determined by an extrusion blow moulded product's shape. The desired product properties can be obtained by the control of processing parameters [5] but the mould design is also an important factor influencing the part quality. For example, the formation of the polymer parison bond inside a mould depends on the pinching edge design [6]. This bond is an area of a high risk of a failure during the part exploitation. The flash pocket and cooling system design have in turn the influence on the process, especially on the cycle time because the flash cooling efficiency can be different.

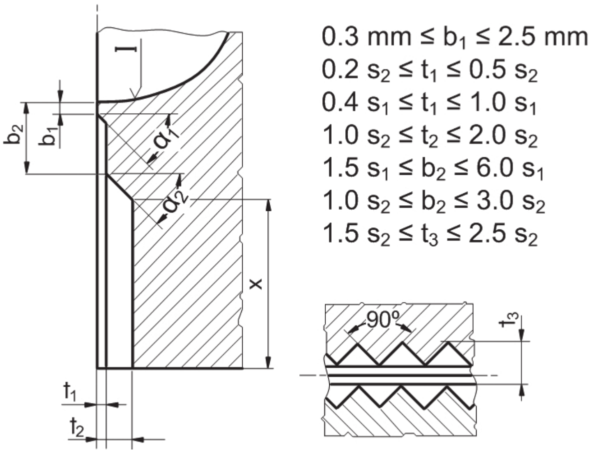

Fig. 3. Section through a pinch-off area; b_1 – width of pinching edge, b_2 – width of pressure zone, t_1 – depth of pressure zone, t_2 – depth of flash pocket, t_3 – distance of ribs, x – ribbed area of flash pocket, I – cavity, α_1, α_2 – transition angles, s_1 – average wall thickness of the product near pinch-off area, s_2 – average parison wall thickness in pinch-off area [1, 4]

Rys. 3. Przekrój strefy zgniatania; b1 – szerokość krawędzi tnącej, b2 – szerokość strefy ściskania, t1 – głębokość strefy ściskania, t2 – głębokość kieszeni odpadowej, t3 – odległość między żebrami, x – użebrowana strefa kieszeni odpadowej, I – gniazdo formujące, α_1, α_2 – kąty przejścia pomiędzy strefami, s1 – średnia grubość ścianki wyrobu w pobliżu strefy zgniatania, s2 – średnia grubość ścianki rękawa w strefie zgniatania [1, 4]

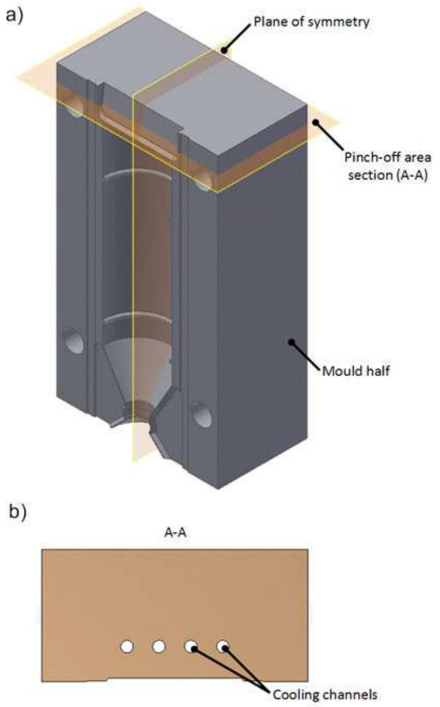

Fig. 4. Half of the analyzed extrusion blow mould, a) the view of the mould, b) the cross-section considered in the computer simulation

Rys. 4. Część analizowanej formy rozdmuchowej, a) widok formy, b) przekrój rozważany w symulacji komputerowej

2. EXPERIMENTAL

The aim of this investigation was to compare the effectiveness of heat transfer in the flash pocket of an extrusion blow mould for different profile shapes in the cross-section of this mould zone, by a mean of computer simulation. ANSYS Polyflow 14.5 software was used for this purpose. Usually, in case of extrusion blow moulding process simulation, this software is used to predict the distribution of product thickness [7] and, for example, to optimize the parison dimensions [8, 9].

2.1. The tool and the product

The extrusion blow moulding process with a mould for manufacturing an axi-symmetrical bottle was analyzed in this investigation. This single-cavity mould is shown in Fig. 4. The bottle dimensions are: 225mm of height and 62mm of diameter. There are more recommendations in the literature concerning the pinch-off zone design in the plane perpendicular to the mould parting plane [1-3] than in the cross-section in the plane marked as A-A in Fig. 4 a. Since the mould surface being in contact with molten polymer should be large, a flash pocket is usually riffled in order to increase the contact area and to cool the polymer better. In this article the results of temperature distribution in A-A cross-section obtained in computer simulation are presented.

Four different shapes in the cross-section of the pinch-off area, in the flash pocket zone were proposed to analyze. They are shown in Fig. 5 and marked with letters A, B, C and D. Shape A is a flat surface and is easy to machine

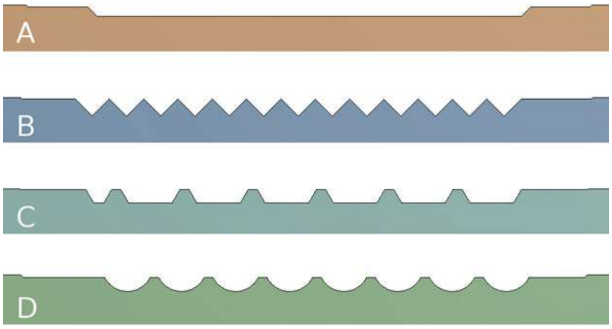

Fig. 5. The analyzed shapes in the cross-section of the mould flash pocket
Rys. 5. Analizowane kształty przekroju kieszeni odpadowej w formie

when the mould is manufactured but it has the smallest contact area with the polymer when a mould is closed. The triangular shape (B) is defined in details in the literature [1]. The semicircular (D) shape is also used in the industry and the trapezoidal shape C is supposed to be a compromise between the complexity of manufacturing and the contact area between polymer and a mould.

The β quotient was used to expressed the complexity of flash pocket surface. It is defined as the heat exchange surface area in the flash pocket related to the area of the projection of this surface onto the mould parting plane. Its value depends on the area of the contact surface between polymer and a mould. The β values for the different flash pocket shapes taken into account in the simulation are listed in Table 1.

Table 1. Values of β quotient

Shape of the pinch-off zone	β value
A – flat	1.00
B – triangled	1.41
C – trapezoidal	1.12
D – semicircular	1.20

The symmetry axis of the mould in the cross-section is coincident with the parison axis. Moreover, in the cases of the ribbed shapes the grooves are located between the teeth of the opposite mould half, as it is shown in Fig. 6 where the cross-section of the closed mould is presented. The flash pocket profile shapes were designed in the way that the mesh nodes in the polymer area would not move during mould closing in the direction perpendicular to the mould movement. The second assumption was that the flash pocket is fully filled with the polymer.

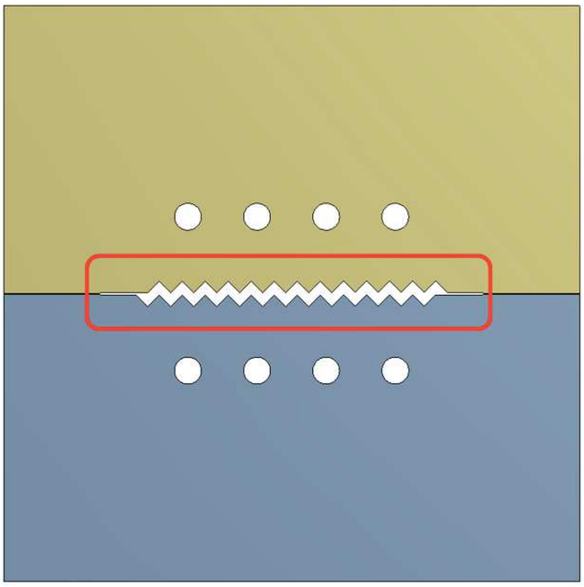

Fig. 6. Cross-section through the pinch-off zone in the flash pocket area after mould closing
Rys. 6. Przekrój przez strefę zgniatania w obszarze kieszeni odpadowej po zamknięciu formy

2.2. Material processed and boundary conditions

The temperature distribution across the polymer in the flash pocket and the mould material was simulated. The temperature depends on the heat transfer between polymeric parison and the cooled metal mould. Two-dimensional (2D) model was used and the simulation was done in a cross-section of the flash pocket. The extruded parison before blowing was modeled first as a tube of 50mm of outer diameter and 2mm of wall thickness (Fig. 7a). However, since it was not possible to define the contact surface between the internal surfaces of the parison,

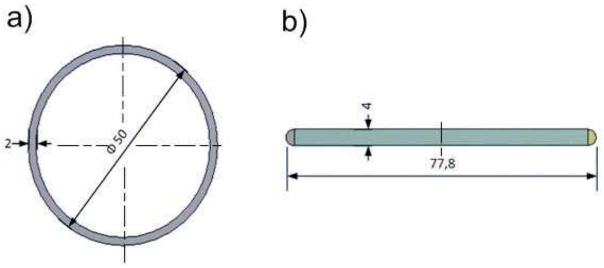

Fig. 7. The shape of the parison before blowing phase: a) real, b) assumed in the simulation
Rys. 7. Kształt rękawa przed rozdmuchem: a) rzeczywisty, b) przyjęty do symulacji

the shape was modified to the form similar to the folded tube – rectangle-like area (Fig. 7b). This kind of shape is obtained just before a mould is closed, when the parison is folded and compressed between two mould halves. The area of the shape from Fig. 7b is equal of polymer surface area in the cross-section of the tubular parison from Fig. 7a. The mould closing phase was not skipped in the simulation but since it was very fast (0.2 s) so the assumption of rectangle-like initial parison cross-section shape was possible.

It was assumed that the parison was extruded first through the extrusion die and then blown in a closed mould and in this time the cooling phase in the flash pocket started. The material the parison is made of is high-density polyethylene (PE-HD) Hostalen ACP 5831D, produced by Lyondellbasell company. The most important properties of the polymer used in the simulation are as follows:

- Viscosity: 37 983 Pa·s
- Melt density: 753 kg/m^3
- Thermal conductivity: 0.3 W/(m·K)
- Heat capacity: 1800 J/(kg·K)

The material of the mould was aluminium of the following properties:

- Density: 2800 kg/m^3
- Thermal conductivity: 58 W/(m·K)
- Heat capacity: 450 J/(kg·K)

The initial conditions for the simulation were as follows: the temperature of the parison after extrusion: 200°C and the initial temperature of the mould was assumed as 12 °C. The boundary conditions of the considered system are defined in Fig. 8. The edge no.1, corresponding with the parison outer surface, was determined as *freesurface* with the *contact condition*. The coefficient of thermal conductivity between the polymer and the mould is 170W/m·K. It was also assumed that the temperature of the coolant is 12 °C and the temperature of the cooling channels walls is constant. The heat transfer between the mould and the air on the surfaces no. 4 exists all the time but in case of surface no. 1 (parison) and no. 2 (pinch-off area) only before the mould is closed. This heat exchange is described by thermal diffusivity coefficient of 20W/(m^2·K) value. The ambient temperature was assumed: 25 °C for surfaces no. 1 and no. 2 and 30 °C for surface no 4. The time of parison cooling (after the mould is closed) is 10s.

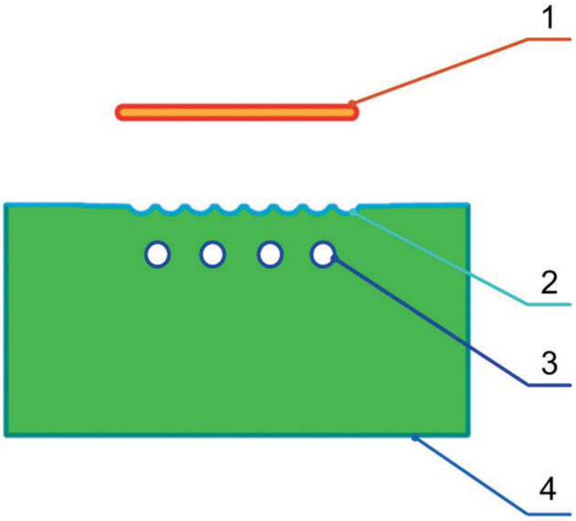

Fig. 8. Boundary conditions assumed in the simulation: 1 – parison (compressed), 2 – flash pocket area surface, 3 – cooling channel, 4 – outer surface of the mould
Rys. 8. Warunki brzegowe założone w symulacji; 1 – rękaw (zgnieciony), 2 – powierzchnia formy w obszarze kieszeni odpadowej, 3 – kanał chłodzenia, 4 – zewnętrzna powierzchnia formy

3. RESULTS AND DISCUSSION

The results of computer simulation were: temperature distribution in the pinch-off zone

– flash pocket area cross-section and the change in the temperature of polymer and mould material during cooling. These quantities obtained for the different shapes of the mould flash pocket were compared.

3.1. Temperature distribution

The temperature distribution of the mould and the compressed parison is shown in Fig. 9 for different shapes: A, B, C and D. The polymer temperature is more uniform in case of the shapes B and D – for the more complex shapes of the flash pocket profile. Moreover, the temperature of the mould in the ribbed areas is higher in these two cases.

3.2. Temperature drop

The change in the average temperature in the compressed parison cross-section area (in the polymer) as well as the change in the average temperature on the parison outer surface during the cooling was simulated and the results are shown in Fig. 10. It was proved that the differences in the heat transfer intensity depend on the shape of the flash pocket area. The most effective flash pocket profile shapes are: triangular (B) and semicircular (D). The smallest cooling effectiveness is observed for the flat surface shape (A), what could be expected because this shape has the smallest value of β coefficient. The difference in the parison outer surface temperature after 10s of cooling was 23°C when comparing the best option triangular shape B and the basic flat shape A. Similar, but even higher temperature differences occured in the case of average temperature in the parison cross-section, but this temperature was generally higher than temperature on the outer surface.

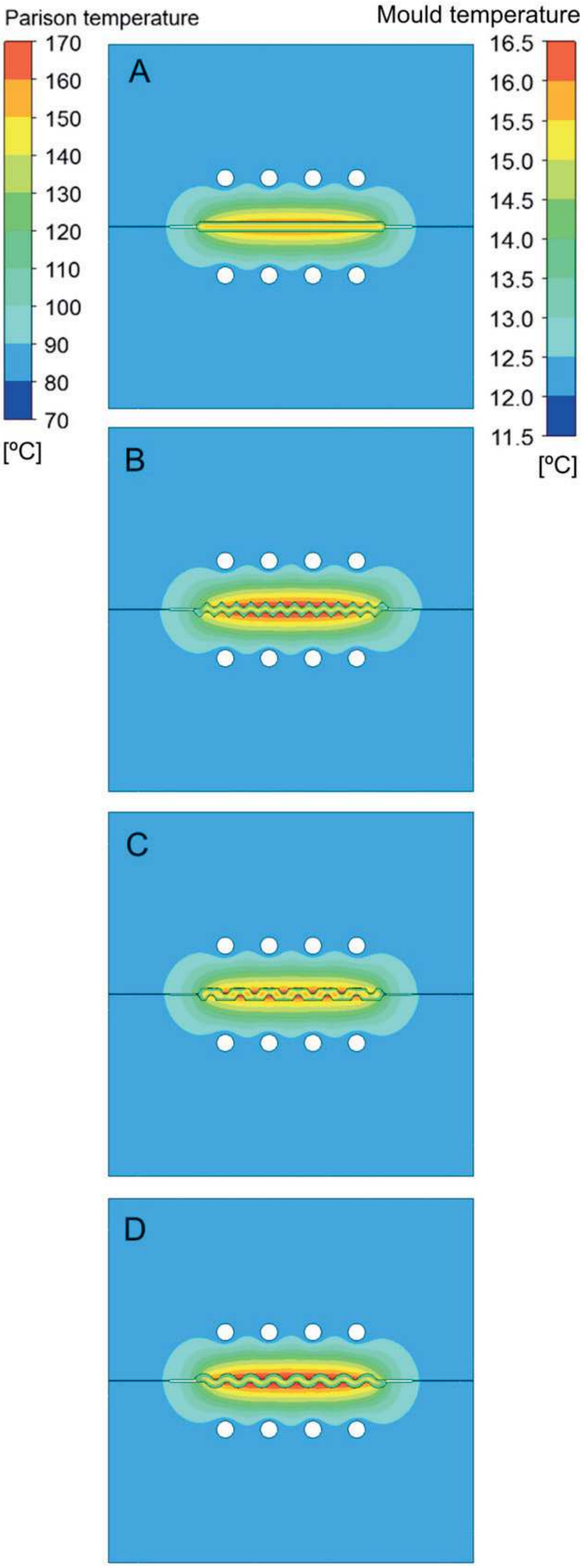

Fig. 9. Temperature distribution in the cross-section of the compressed parison and the mould after 10s of cooling
Rys. 9. Rozkład temperatury w przekroju zgniecionego rękawa i formy po 10 s ochładzania

4. SUMMARY AND CONCLUSIONS

Four different profiles in the flash pocket zone of the pinch-off section in an extrusion blow mould were examined by the computer

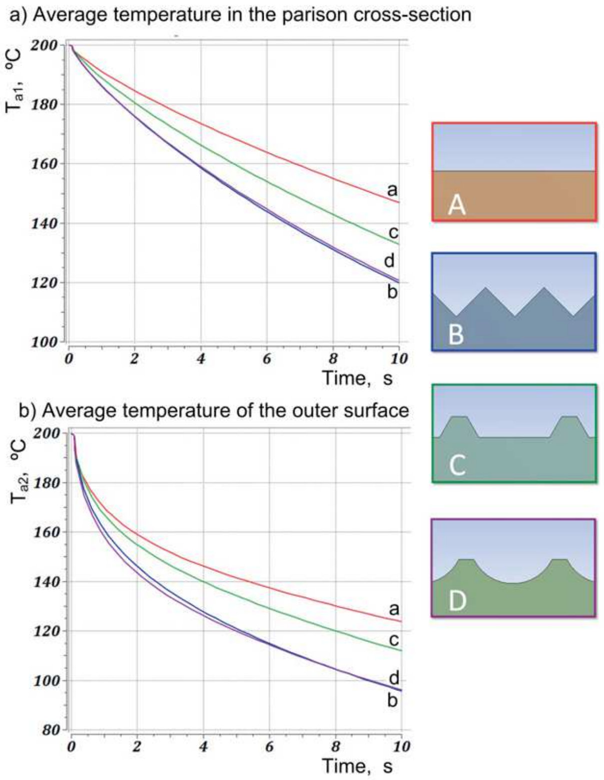

Fig. 10. Change in the average temperature of: a) polymer in the cross-section area of the compressed parison, b) outer surface of the compressed parison, for different flash pocket shapes

Rys. 10. Zmiana średniej temperatury: a) tworzywa w przekroju zgniecionego rękawa, b) zewnętrznej powierzchni zgniecionego rękawa, przy różnych kształtach profilu kieszeni odpadowej

simulation regarding the flash cooling effectiveness. It was found that the speed of the flash cooling is influenced by the shape of a flash pocket surface. The best effectiveness of the heat transfer between the polymeric parison and the mould was obtained for the triangular and semicircular shapes of the ribs while the trapezoidal and flat shapes were not so efficient.

It is important to manufacture extrusion blow moulds with ribbed, efficiently complex surfaces of flash pocket area in order to shorten the cycle time by faster cooling of the flash. However, the ease of manufacturing and flash demoulding should also be considered.

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