Prototype modular inserts to boost the cooling of mold cavities in polymer processing *(Rapid Communication)*

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Abstract: Design features and configuration of modular turbulent inserts (MTI) that boost the cooling of cavities for polymer processing (blow molds and injection molds) in straight-line cooling channels were proposed. The MTI inserts were made with the fused deposition modelling (FDM) technology for rapid prototyping in order to experimentally verify their efficiency at the designed test stand. Selected configurations of MTI inserts in tubular cooling channels were evaluated. The desired effect of cooling time reduction was achieved in each of the analyzed cases.

Keywords: modular polymer inserts, rapid prototyping, cooling, injection molding, blow molding.

Prototypowe wkładki modułowe intensyfikujące chłodzenie wnęk form w procesach przetwórstwa polimerów

Streszczenie: Zaprojektowano cechy konstrukcyjne i wzajemną konfigurację modułowych wkładek turbulentnych (MTI) intensyfikujących chłodzenie gniazd narzędzi do przetwórstwa polimerów (form rozdmuchowych i wtryskowych) w liniowych kanałach chłodzących. Metodą szybkiego prototypowania FDM (z ang. *fused deposition modelling*) wykonano wkładki MTI w celu doświadczalnego zweryfikowania ich efektywności w zaprojektowanym stanowisku badawczym. Dokonano oceny wybranych układów konfiguracji wkładek MTI w rurowych kanałach chłodzących. W każdym z analizowanych przypadków osiągnięto pożądany efekt skrócenia czasu chłodzenia.

Słowa kluczowe: polimerowe wkładki modułowe, szybkie prototypowanie, chłodzenie, wtryskiwanie, rozdmuchiwanie.

Injection molding and extrusion blow molding belong to the most popular methods of manufacturing of polymer products. It is true not only for packaging industry, but also for many others, because it is characterized by high efficiency of producing complex shapes at relatively low costs [1, 2]. European data on the processing industry [3] show that the polymer processing plays a significant role from the point of view of economic growth thanks to the innovations in many sectors of the European industry, such as automotive, electrical, electronic construction industry *etc*. The mass of processed polymer materials is constantly rising (on average — 5 % yearly). Poland shows the tendencies for even quicker than European increase in the use of polymer materials (7.1 %). In 2014, the demand for such materials in Poland amounted to *ca.* 3.11 million tons (for the entire Europe the value was 46 million tons) [4].

There is a visible tendency among manufacturers in the market to try to reduce the time of production processes. One possibility is to shorten the cycle time of cooling of production mold cavities, using various available technologies and innovations. Some of the manufacturers use conformal cooling in reasonable cases [5], while others use conventional straight-line or modified straight-line cooling systems, *e.g.* spiral or helical inserts [2]. Also not in every case of mold construction there is justification for conformal cooling, particularly for molds of large size or polymer parts of a simple geometry, where there is a possibility of applying linear channels. Those who use straight-line cooling are still looking for various ways to improve the efficiency of heat exchange between polymer and the mold, and between mold and a liquid in the cooling channel, mainly in order to improve the heat exchange and reduce the cycle time simultaneously, especially in medium and large molds [1, 2].

As a result of these activities, there is a stronger and stronger pressure on manufacturers of injection and blow molds, to produce tools, while at the same time minimizing their production costs, as well as to use these tools more effectively for manufacturing purposes.

Usually, the highest factor that determines the injection molding cycle time is the cooling cycle time in the mold cavity. This time takes account of a cooling both, the products manufactured by the blow molding and the

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waste that are produced during the process (it takes between 40 and 70 % of the manufacturing process cycle) [2, 6, 7]. It clearly shows that energy and time efficiency in the processing largely depends on cooling efficiency [1, 8].

Thus, there are grounds to perform a research in this area. One of the ways to boost cooling and heat exchange in shell and tube heat exchangers is to use barriers. Based on available publications [9, 10], the design was proposed for barrier inserts, with initially assumed geometrical features of repetitive segments that allow various configurations.

In this paper we suggest design solutions for modular turbulent inserts (MTI) that allow variable configuration, various mutual arrangements and lengths, depending on the assumed intensity of the cooling of the mold cavities with straight-line cooling channels. Also the base of conducted research could in the future help to modify the conformal channel geometry by use of modified MTI geometry.

The aim of the test was to verify the accepted design assumptions on the manufacture of tools that use straight-line cooling channels with increased parameters of heat exchange between the coolant and the mold cavity through the application of MTI segments in polymer processing tools.

EXPERIMENTAL PART

Modular test inserts accepted for verification

The geometrical shape of the modular test insert for the tested straight-line tubular channel with inner diameter of $D = 12$ mm is shown in Fig. 1. The insert was designed in such a way as to allow the pin-sleeve inter-connection of particular segments in configurations of a given length. The inserts were made of acrylonitrile-butadiene-styrene copolymer (ABS) with a Stratasys Dimension Elite machine that employs fused deposition modelling (FDM) technology.

The proposed CAD 3D model of MTI insert made it possible to create a set of segments to be used during the
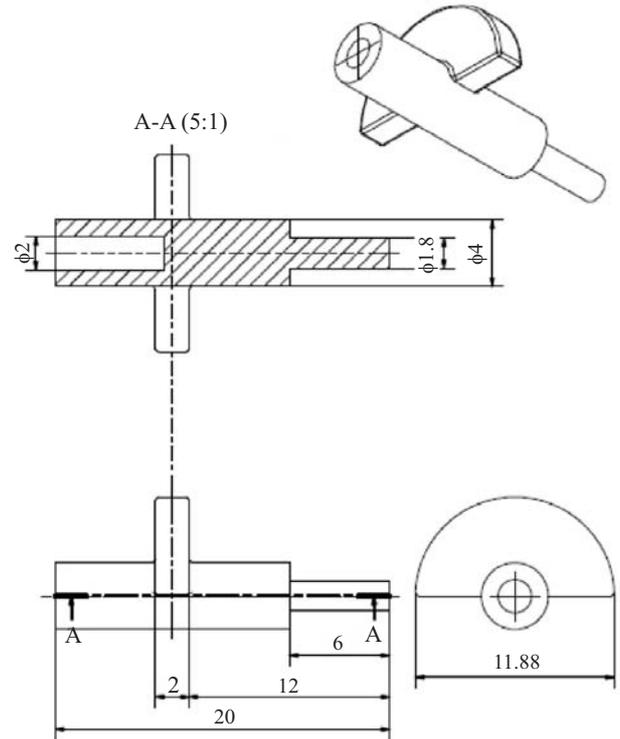

Fig. 1. Geometrical features of a single MTI insert for a straight-line cooling channel with the inner diameter of $D = 12$ mm

T a b l e 1. Analysed MTI configurations of the given segment types

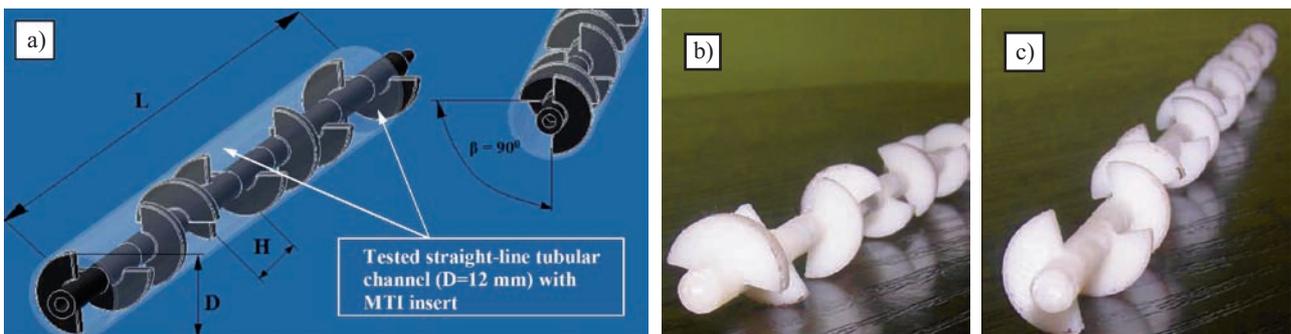| Symbol of segment type (β-H/D-H)	β, °	H/D	H, mm
45-1-12	45	1	12
45-2-24	45	2	24
45-3-36	45	3	36
90-1-12	90	1	12
90-2-24	90	2	24
90-3-36	90	3	36
180-1-12	180	1	12
180-2-24	180	2	24
180-3-36	180	3	36

Fig. 2. Basic geometrical features of the arrangements based on the selected MTI insert with: a) $H/D = 1$, $L/H = 17$, $\beta = 90$ ° (type 90-1-12), b) $H/D = 1$, $L/H = 17$, $\beta = 45$ ° (type 45-1-12), c) $H/D = 1$, $L/H = 17$, $\beta = 180$ ° (type 180-1-12)

tests. The basic features of the analyzed arrangements, which are presented in Fig. 2, include: a ratio of the spacing between the barriers to the channel diameter (H/D), measure of β angle of barriers configurations and ratio of the length (L) of the arrangement to the distance between H barriers. The analyzed arrangements are described in Table 1. Particular types of proposed segments are denoted by symbols (β-H/D-H) where: β = 45, 90 or 180 °, H/D = 1, 2 or 3 and H = 12, 24 or 36 mm.

The testing method

Tests of particular segments were carried out at specially prepared test stand. The model and the photograph of the test stand are presented in Fig. 3. The test stand was used to simulate the process of discharging heat from the plasticized material in the mold. A cylindrical heat exchanger with outer diameter of 35 mm wrapped with a coil heater serves as the model element of a mold at the test stand. The model heat exchanger was heated to the temperature of 60 °C with a heater. When the heat exchanger reached the required temperature, the coolant (water) was supplied to the cooling channel, using a chiller. When the surface temperature of the heat exchanger dropped to 23 °C, the cooling time measurement was stopped and the experiment was repeated. The heat exchanger's surface temperature measurement was carried out with infrared thermal imaging camera of type Flir E40 [11, 12]. Flow parameters of the coolant at the output of the chiller were as follows: Q = 0.7 dm³/s, p = 0.3 MPa, T = 16 °C, where Q stands for the efficiency of the pump of the coolant, p stands for the dynamic pressure, and T stands for the coolant temperature.

RESULTS AND DISCUSSION

The physical tests of the heat exchanger cooling efficiency with the use of MTI inserts were completed. The experiment results are presented in Fig. 4. Based on the completed tests, as a result of the application of modified tools, the desired effect of the cooling time reduction in a straight-line cooling channel was achieved in each of the analyzed cases. It was observed that three analyzed cases (type 90-1-12, 45-2-24, 45-1-12) showed higher reduction of the cooling time then other ones. When it comes to the conventional straight-line cooling channel, the segment of type 90-1-12 was characterized by a barrier configuration with the highest cooling efficiency — the cooling time was reduced by 29 %. It can be assumed that it is associated with the formation the particular turbulent flows and turbulence locally to ensure the intensifi-
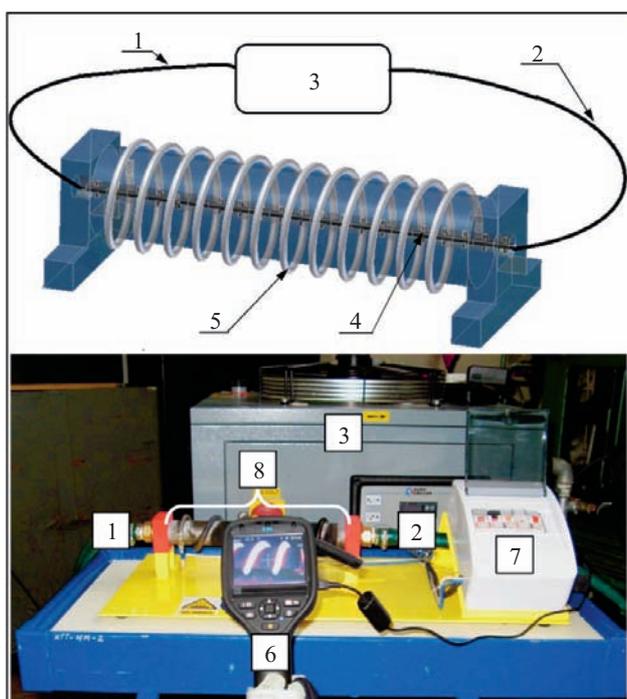

Fig. 4. Cylindrical heat exchanger cooling time from 60 °C to 23 °C, using given types of segmental inserts

Fig. 3. Model and photograph of the test stand: 1, 2 — flexible input and output tube, 3 — coolant pump, 4 — MTI insert in tested straight-line tubular channel, 5 — heater, 6 — thermal imaging camera, 7 — test stand control system, 8 — test heat exchanger
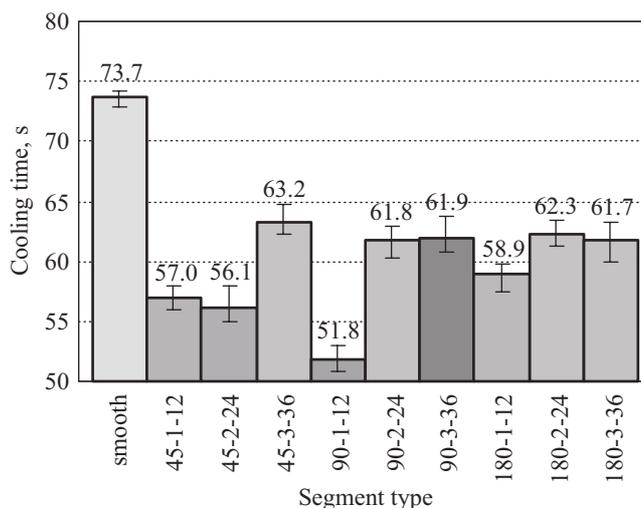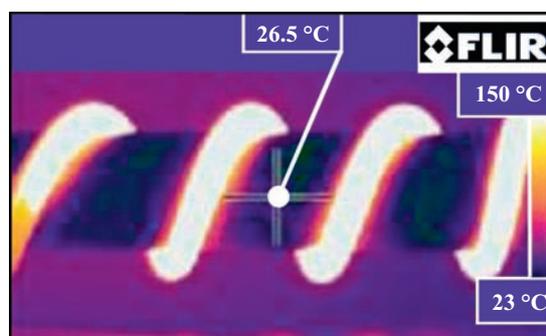

Fig. 5. Photograph from thermal imaging camera during measurements using segment 90-1-12 (26.5 °C — temperature at indicated point, 23—150 °C — the range of temperature at the measured area)

cation of heat exchange in the considered system. In other cases described in Table 1, the cooling time reduction ranged from 14 to 20 %. The tests may lead to an assumption that additional improvement of heat exchange in processing tools (increased energy efficiency of the process) should occur especially in places where there is high accumulation of heat (*e.g.* extrusion blow molding pinch-off section). The example of an image from thermal imaging camera during the measurements is presented in Fig. 5.

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