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THE FORMABILITY OF SHEET BLANKS IN THE PRODUCT UNDER CONDITIONS OF INTENSE HEAT

When forming products from thermoplastic polymers and compositions on their basis, including sheet blanks, are passing heat and mechanical processes, which require special study: heating and cooling, viscous-plastic flow, sealing and shrinkage, the deformation of viscous stretching, consolidation.

For sheet workpieces made of recycled polypropylene it was determined the kinetics of cooling in two modes: convective heat transfer in air and contact heat exchange in the chilled form. The workpieces sheets for the study were obtained at the extrusion head of the manifold type. When molding product the experiment took place in conditions that are very close to real. Temperature measurement was carried out on the surface and in the center of the workpiece.

To obtain the temperature profile across the thickness of the blank numerical analysis on the basis of the solution of the heat equation for one-dimensional flow was carried out. It is shown that the results of analytical calculation and experiment correlate well.

The derived dependences used to determine the magnitude of the visco-fluid layer by thickness of the workpiece, which ensures the formability of the material in the final product, as well as to identify the optimal temperature and time parameters, while ensuring the adhesion bonds between the two heated molds in the process of forming a composite product.

Key words: recycled polypropylene, recycling, leaf harvesting, shaping products, heat transfer, composite product.

Introduction. One of the areas of development of the plastics molding technology is to find ways to expand the products range by increasing their overall dimensions and improving their appearance. To solve the problems you can use viscous-flow state sheet blanks of a required size from thermoplastic polymers and compositions based on them [1]. This will reduce the influence of the effects associated with the passage of the melt at the forming products stage. In addition, the use of several sheet blanks simultaneously will allow the composite products introduction.

When forming articles from thermoplastic polymers and compositions based on them, including those in the sheet blanks, thermal and mechanical processes that require special investigation proceed: heating and cooling, viscoplastic flow, compaction and shrinkage, viscous stretching deformation, consolidation.

Main part. In the course of material processing during transportation and preparatory operations the blank is exposed to air for some time. During products forming the working surfaces of tooling are cooled to the operational pressing temperature to reduce the cycle time. For most materials, the effective temperature ranges from 40 to 70°C.

To evaluate all stages of the process the cooling kinetics was taken in two modes: the convective heat transfer in air under normal conditions and the contact heat transfer by placing the blank into a cooled up to 60°C tooling.

The research was carried out for recycled polypropylene (PP), which is an agglomerate of polypropylene sack cloth.

The kinetics of cooling for all of the materials tested was determined in the sheet blanks of 5–7 mm thickness. A discharge head of a collector type was used for the manufacture of molten sheet blanks of a required size and quality from recycled thermoplasts [1].

Research data of the recycled polypropylene cooling kinetics are shown in the graphs (Fig. 1–2, points – experimental data, lines –approximation result).

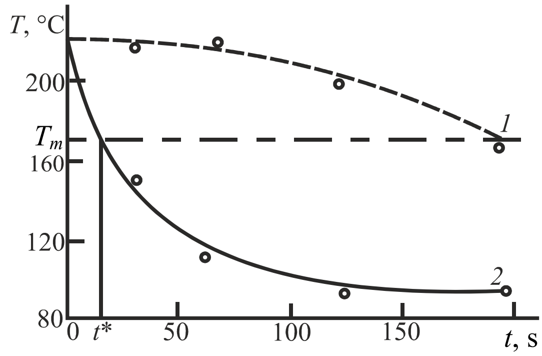

Fig. 1. Temperature distribution of the PP sheet blanks on cooling in air:
1 – temperature change in the blank center;
2 – temperature change on the surface

Due to low thermal conductivity of polymeric materials and low convection coefficient the temperature fall is slow. In the investigated time range

(0 to 180 s) it can be noted that the temperature at the samples center is not lower than the melting temperature of the matrix polymer (Fig. 1).

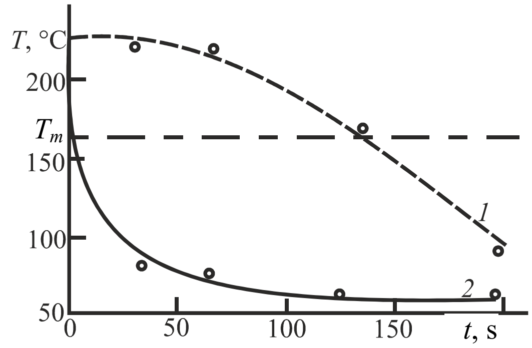

Fig. 2. Temperature distribution of the PP sheet blanks on cooling in tooling: *1* – temperature change in the blank center; *2* – temperature change on the surface

Cooling time t^* of the surface layers up to the melting temperature T_m due to convection in the air is 25–35 s. On the basis of this interval we can determine transportation time of the blank into the tooling with the help of special technique that keeps the sheet shape.

Note, however, that when we place the blank into the tooling there occurs an intense supercooling due to high thermal conductivity coefficient of metal. The temperature falls significantly both in the sample center and on its surface (Fig. 2).

The experiment allows to determine the temperature at only two points (on the surface and in the center), which is insufficient to accurately describe the heat transfer process. To obtain a more complete picture of the distribution of temperature fields analytical methods of calculations were applied, which allowed to determine the temperature at any point of thickness and draw up a temperature profile.

The basis of the analytical methods is the heat conductivity equation for one-dimensional flow. Differential equation was solved by the temperature and heat transfer coefficients in conditions corresponding to the real environment. The determination result of a temperature field through the blank thickness in conditions of its convective cooling in air is shown in Fig. 3.

Due to the thermal inertia of materials temperature conservation is observed in the central zone (the width not less than half the thickness of the sample) in the interval of 30–45 s from the start of cooling.

Comparing experimental PP data (Fig. 1) with the calculated profiles (Fig. 3), we can conclude about the high correlation of results which allows the use of analytical methods for evaluating the cooling kinetics in the process parameters calculations of the products forming from sheet blanks.

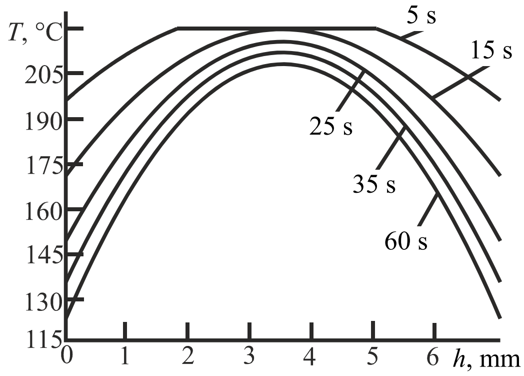

Fig. 3. Temperature field through the PP blank thickness over dwell time in air (solution of heat conductivity equation)

In calculations, analytical dependences have been obtained which are used to determine the quantity of the viscous-flow layer through the blank thickness, which provides the formability of material into the product. Analytical dependences are also used to determine optimal temperature parameters for providing an adhesive bond between two heated blanks.

Temperature field calculated profile through the thickness of one of the blanks in contact is shown in Fig. 4.

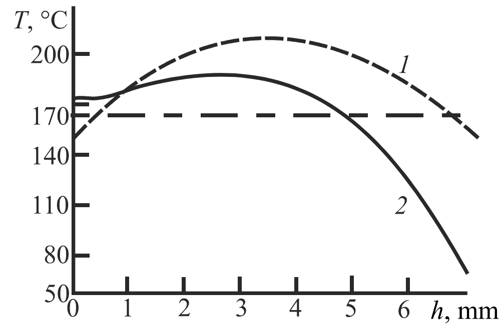

Fig. 4. Temperature distribution in the sample following the contact with the other (calculation): *1* – primary blank temperature field after cooling in air for 30 s; *2* – temperature field in one of the blanks following the tooling contact

The figure shows a single sheet of material. At $h = 0$ there was no heat transfer due to the equality of temperatures of two blanks at the moment of contact. On the other side of the material there was a contact heat transfer with a cooled tooling.

Blanks contact scheme with the forming tooling is shown in Fig. 5.

Thus, for the initial blanks at an initial level of surface temperatures T_1 and at the T_3 center during contact between themselves and with the tooling, a heating between the blank contact surfaces occurs for a short time to a temperature T_4.

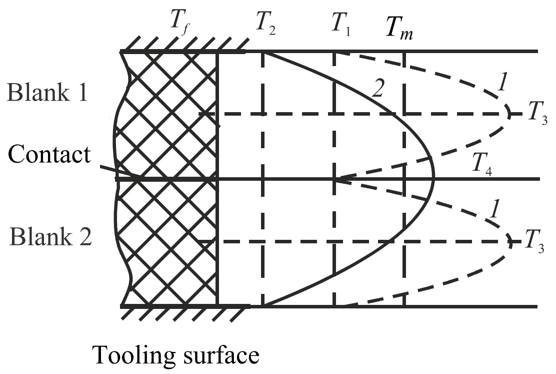

Fig. 5. Distribution scheme of temperature fields in composite products forming:
1 – initial temperature profiles in the blanks;
2 – temperature profile at the time of formation

At the same time there is a decrease of temperature level for the blank as a whole due to the intensive heat exchange with the tooling. In addition, there is virtually instantaneous fall in the surface temperature of the blank to the level of tooling ($T_2 = T_f$).

The optimum condition is when the temperature in the center of the sample in the period of its extreme value on heating will be higher than the matrix polymer melting temperature ($T_4 \geq T_m$) in terms of ensuring a higher degree of material consolidation.

The condition is achieved when $T_4 \geq T_m$ depends on the thermal properties of the material, the initial distribution of temperature fields in the blanks and the forming tool parameters and materials. Thus, the graph 6 shows the dependence between the temperature at the contact surfaces and in the center of the PP blanks despite the fact that the initial residence time in air is different: *1* – 0 s; *2* – 30 s; *3* – >60 s.

As seen from the graph, the time t* to reach the condition, when $T_4 \geq T_m$ increases at lower initial temperatures in the blank and, hence, more exposure time is required to provide the adhesion bond between the blanks. However, under certain conditions, the temperature in the contact area can never reach the melting temperature ($T_4 < T_m$). This leads to the impossibility of establishing adhesion bonds between the blanks.

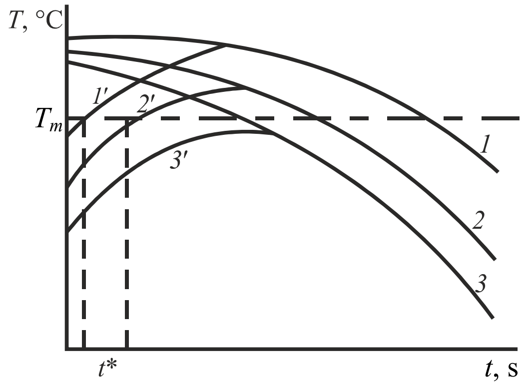

Fig. 6. Dependence of temperature fields on composite product forming conditions (experiment):
1, *2*, *3* – temperature change in the center of blanks;
1', *2'*, *3'* – temperature change on the blank contact surface

Conclusion. Heat transfer between individual blanks of the material during coforming has been studied. Experimental studies to determine the phenomena occurring during the thermal impact between the elements of the composite product have been carried out.

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