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Influence of the method of heating/cooling moulds on the properties of injection moulding parts

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ABSTRACT

Purpose: The main purpose of carry out research was estimate the influence thermal conditions of the mould on properties of injection moulded parts.

Design/methodology/approach: The properties of structure and mechanical properties of injection moulding parts were determined by many factors. One of them is thermal conditions of tool. Injection mould can be heated or cooling during the process and its depend which kind of polymer we produced and what properties we going to obtain. A few different cooling mould systems were presented in the article and disadvantages and advantages of each of them.

Findings: The impact of thermal condition (cooling rate, mould temperature) on the structure and physical properties of injection moulded parts were present.

Research limitations/implications: Research was limited to a few thermoplastics polymers.

Practical implications: Received and presented results are useful from the point of the view of industrial applications and they are able to contribute to improvement parts obtained using injection moulding technology.

Originality/value: Very original microscopic research carry out during cooling stage of polymer and crystallization process.

Keywords: Engineering polymers; Working properties of materials and products; Crystallinity

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The process cycle time in injection moulding process depends greatly on the cooling time of the plastic part, which is facilitated by the cooling channels in the injection mould. Effective cooling channel design in the mould is important because it not only affects cycle time but also the part quality. Traditional cooling channels are normally made of straight drilled holes in the mould, which have limitations in geometric complexity as well as cooling fluid mobility within the injection mould [1-6].

When thermoplastics are processed, sufficient heat has to be removed from the moulding compound for a dimensionally stable state to be achieved (to permit ejection). The time taken to achieve this is known as the cooling time. The quality of the moulded part depends to a decisive extent on a consistent local temperature progression from one cycle to the next. The cost-efficiency of production is largely determined by whether the mould is a good or a poor conductor of heat. If the quality of the moulded part is to be enhanced and production time reduced, it is necessary to understand the laws that govern the exchange of heat in the mould and to apply these on a selective basis [7-24].

2. Methodology and tests

The raw materials manufacturers who supply the thermoplastics generally specify both an optimum processing temperature (or temperature range) and the best mould temperatures for their products. In many cases, the recommended temperatures for the mould are not observed. Processors prefer to work at low temperatures in order to save on cycle time, turning a blind eye to the fact that this can impair the quality of the moulded parts. When thermoplastics are injection moulded, hot molten plastic is periodically injected into a "cold" mould. Assuming there were no heating/cooling system, the mould would heat up on account of the heat content of the molten plastic and would come to settle at an equilibrium temperature level. While it is certain that this specific temperature would develop, it is not really possible to predict its level and the time that would elapse before it set in with any degree of accuracy [1, 2].

How important is it for a specific temperature level to prevail at the cavity moulding surface? This "specific temperature level" is a parameter that can have a particularly decisive influence on the following aspects of moulded part quality: surface appearance, warpage, inherent stresses, uniform structure, dimensional deviations (warpage). To achieve a high level of crystallinity, which extends right through to the surface layers of moulded parts in the case of semi-crystalline moulding compounds, it is necessary to work with high cavity moulding surface temperatures. Excessively rapid cooling (achieved through a lower moulding surface temperature) will hinder crystallization [2,4].

Aims of thermal mould design

- On the basis of the examples that have been given, the following aims can be specified for the mould heating/cooling system:
- The target mean cavity wall moulding surface temperature is to be maintained as precisely as possible.
- The temperature prevailing at the moulding surface should be as uniform as possible at the different points, otherwise inconsistent moulded part properties and warpage may result.
- The cooling time and hence the cycle time must be as short as possible in order to ensure a high cost-efficiency for a given moulded part quality.

Cooling proper commences right at the start of the cavity filling stage, as soon as the polymer enters the mould.

During this cooling phase, however, it is essential that the melt be prevented from freezing, through the "flow heat" that is generated by internal friction (a quasi-isothermal flow process). The chief quantity of heat is exchanged after the filling phase, i.e. up to the point when the mould is opened and the moulding ejected. The exchange of heat between the moulding compound and the coolant takes place by heat conduction through the cavity walls, hence the polymer heats the mould metal, and then the mould metal heats the coolant. The time required for the ejection temperature to be reached (cooling time) could be estimated.

In the same mould we can use different distribution of cooling/heating channels [6]. It depends for many factors eg.: diameter and cross section of channels, pressure drop between inlet and outlet, obtained temperature distribution on the cavity surface, ect. Three different systems of cooling channels distribution were presented on the Fig. 1.

The Figure 1a shows a typical mould half with six cooling channels, which in this case are internally looped, however in many mould shops the same effect is produced by external piping loops. This is generally done to reduce the number of coolant connections that have to be made to the mould when it is installed. This leads to a long coolant flow path with a high

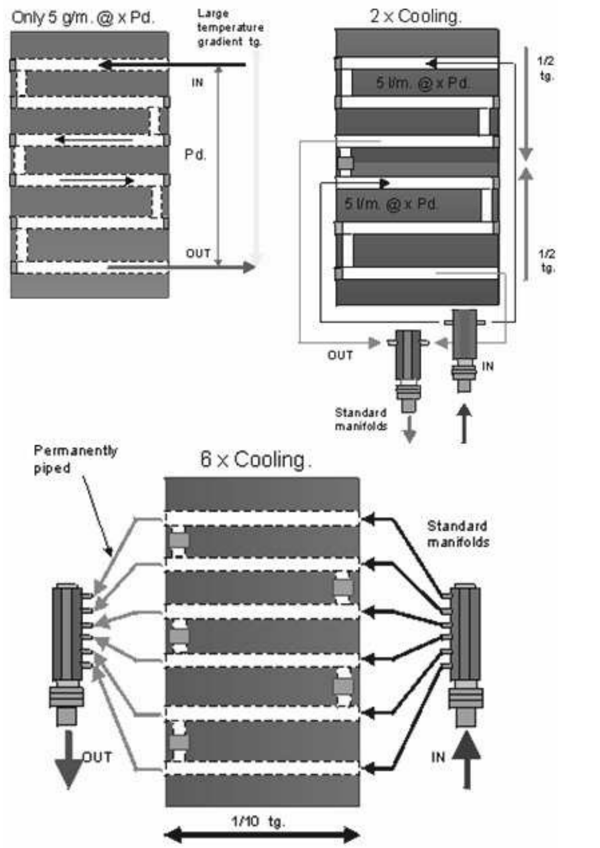

Fig. 1. Three different approaches to cooling channels in the same mould: a) typical joining of cooling channels, b) two-way manifolds, c) two mould mounted manifolds [6]

pressure loss, which will limit the volume of coolant flow through the mould, which in turn limits the amount of heat that can be extracted from the mould metal and therefore the amount of heat the mould metal can extract form the polymer during each moulding cycle, very often limiting how fast the mould can run.

The long flow path has a second effect which can also cause trouble for the moulders, that is, as the coolant flows through the mould its temperature is increased as it removes heat from the mould metal. With this increase in coolant temperature less heat will be removed towards the end of the coolant flow (at the outlets) than is removed at the beginning of coolant flow (at the inlet), so it will produce a temperature gradient across the mould from the inlet to the outlet.

These temperature gradients will affect the plastic parts cooling rate and part size, further slowing cycle time. You have to wait for the hottest parts to cool to their ejection temperature before you can open the mould. Figure 1b shows the simple solution of using two, two-way manifolds to split the cooling channels into two cooling zones. Provided that the manifold and the supply and return pipework are correctly sized this arrangement will have twice the coolant flow volume through the mould, which is now capable of removing more heat from the mould metal and therefore the mould metal can cool the moulded

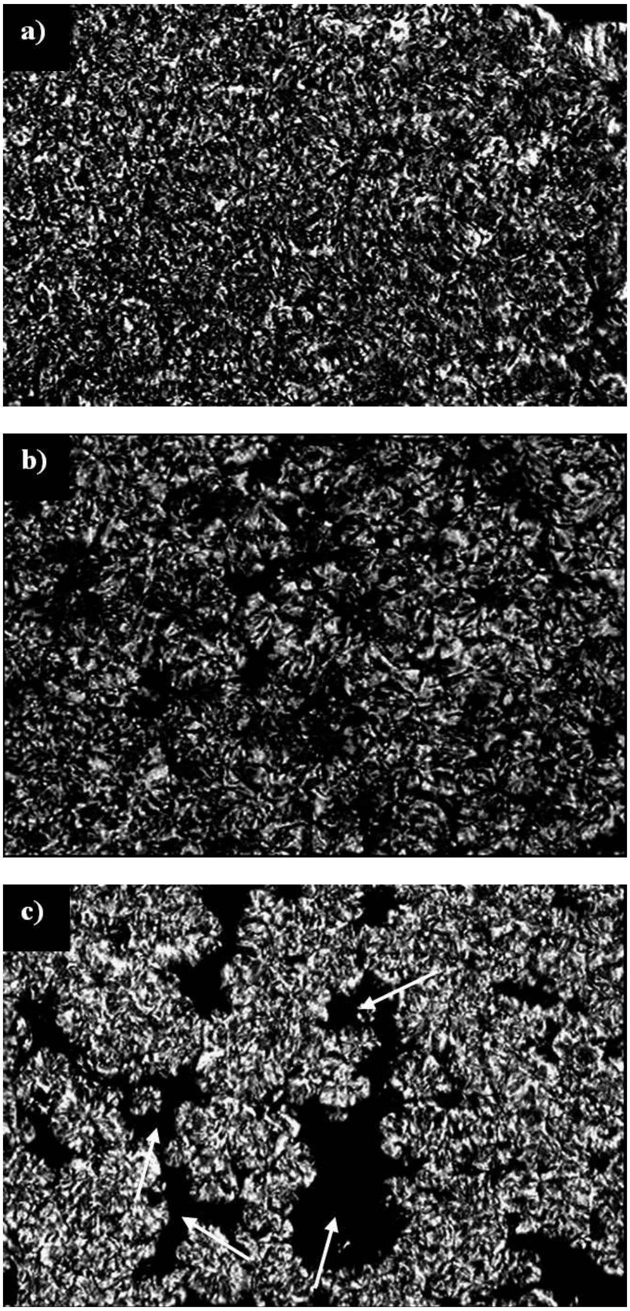

Fig. 2. Morphology of polyoxymethylene (POM) samples in different cooling rates: a) 5^{o}C/min, b) 10^{o}C/min, c) 20^{o}C/min

part more quickly, removing more heat in the same cycle time (eliminating hot-spots) or removing the same heat in a shorter cooling time, leading to shorter cycle times.

Because the coolant channels flow length has been halved, the temperature gradients in the mould will also have been halved leading to a more even moulding surface temperature and therefore a more even part cooling rate, which equals less distortion and less part size variation.

Figure 1c shows the optimum mould cooling configuration for this mould with two mould mounted manifolds each with six ports. There is now no internal or external looping and so the maximum coolant volume can flow through the mould, extracting the maximum heat from the mould metal and therefore allowing maximum heat exchange between the moulded part and the mould for the fastest part cooling rate. The temperature gradients caused by the coolant flow will be reduced to the point where they will no longer affect the moulded part. By using mould mounted manifolds to increase the coolant flow and reduce the temperature gradients we have not increased the number of pipe connections to be made on installation, as the pipework between the mould cooling channels and the manifold stays with the mould.

Each cooling systems, presented in Fig 1 gives different processing conditions during cooling stage, and in effect different structure and mechanical properties of injection moulding parts.

3. Results of the research

Morphology of polyoxymethylene POM samples were presented in the Figure 2a-c. Each of the sample were cooling with different cooling rate. First (Fig. 2a) was cooling with 5^{o}C/min, the second (Fig. 2b) 10^{o}C/min and the last one 20^{o}C/min. We can see three different morphology. Probably the crystallinity degree sample presented in Fig. 2a is higher than sample presented in Fig. 2c. The white arrows presented regions of amorphous phase of polyoxymethylene.

4. Conclusions

Result of investigations proof that the conditions of cooling stage during injection moulding of thermoplastics polymers for e.g. mould temperature and cooling rate influence on structure properties. Presented results shown that the same cooling channels in different configurations can give another thermal condition and in effect different structure [8, 15, 19].

Presented injection moulds that have been soundly designed from the thermal point of view, help to bring down the cost of production whilst ensuring greater reliability. A large number of aids are currently available to design engineers, together with the results of theoretical and practical investigations, which can be used in the thermal design of the mould. In order to attain the specified aims of thermal mould design, i.e:

- precise maintenance of the target mean cavity moulding surface temperature,
- uniform distribution of the cavity temperature,
- short cycle time for a high moulding quality.

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