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PROCESS OF COOLING INJECTION MOULD AND QUALITY OF INJECTION PARTS

Abstract:
Injection mould cooling to an important way influences both technology and economy of production cycle. Main requirement given onto cooling system of injection moulds is quick and homogenous heat removal from injection part. Because of these reasons are in engineering practice quite often used methods which support commonly active cooling device, i.e. circulating medium in cooling ducts. The aim of this paper is refer to possibilities of hest removal from shape part of mould by heat pipe or by using highly thermal conductive materials (for production of shape inserts of mould) and namely with regard to properties and quality of injection part.

Keywords:
Cooling system, Heat-pipe, Ampcoloy, Polypropylene

INTRODUCTION

Quality and properties of injection parts are to a great extent given by chemical and molecular structure of polymer and by additives elements. Very important is however also supramolecular structure (morphology of polymer) which is created during processing of plastic melt into final injection part namely during its cooling and solidification. Morphology of polymeric injection part is so given not only by structure possibilities but also by its processors: i.e. cooling conditions for injection part – it means injection mould temperate, cooling time and used cooling medium – or more precisely cooling system of mould.

Size of morphological shapes influences final properties of injection part and depends on running (temperature) of cooling and are created during solidification of parts from melt [1]. Conditions of solidification are not however same for all areas of injection part and from the structure point of view is created non-homogenous, anisotropic material with specific structure which differs in core of part and onto its surface (so-called skin-core structure, see fig. 1). This is because in consequence of shear and temperature gradient in mould cavity which differs along cross-section and length of flow line of polymer´s melt [2]. Individual layers of injection part structure: surface layers, shear and center one differ from the flow intake their thickness, shape, morphology also crystallinity and influence also final properties of injection part.

From the technological point of view is clear that for cooling system of injection mould (which must enables quick and homogenous heat removal from shape part of mould) have to be given not only side-attention because it is not only connected with heat removal from mould (economical point of view) but also to a great extent influences processing process (melt flow properties) [3] and injection part quality – i.e. for example surface quality, physical-mechanical properties, size of shrinkage [4], anisotropy of properties [5], residual stress [6] etc.

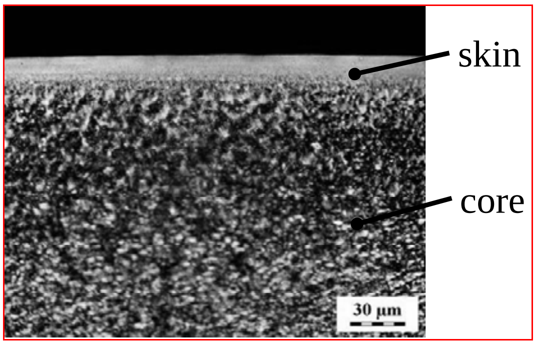

Fig. 1 Characteristic micro-structural elements of injection part thickness cross-section

Cooling Systems Of Injection Moulds

Conception of cooling system in mould is given by design of injection mould, shape solution of part and requirements pose onto cooling itself. Common and in engineering practice mostly using cooling system consists of cooling and control section, couplers and cooling ducts in injection mould in which circulates cooling medium (most often water or oil). Frequently is however this active cooling system (which is heat source directly in mould) added or entirely replaced by passive cooling devices which contribute to increase heat removal intensity from shape part of mould, namely in areas of injection part where is difficult to design common cooling system, e.g. by using of heat pipe, application of highly thermal conductive material etc.

Heat pipe

Heat pipe is device which works as an excellent heat conductor enables very intensive heat transfer from the area with higher temperature to the area with lower temperature namely on the base of cooling medium phase conversion inside pipe. Principle of heat pipe is closely described e.g. in [7]. Advantages of heat pipes are their small diameters that is why are in the branch of polymers injection using namely for injection of thin and often also rugged shape parts which would other required difficult cooling ducts. Accordingly they have found application for cooling of long punches where is not possible to ensure circulation of water towards to its peak.

Heat pipe is device which with proper conception enables highly intensive heat removal from shape parts of moulds, but is necessary to take into account that in dependence on cooling course there can be change of injection part morphology and thus also its utility properties. On the base of experimental measurements carried out during cooling of injection parts from polypropylene by heat pipe capillaries (which replace cooling of core by so-called partition system with circulating water – see fig. 2), which is placed in drilled part of core and its wetting part flows into main cooling ducts with circulation water (see fig. 3), was identified that by application of heat pipe is possible not only to make heat removal from mould quicker, but also can influences microstructure of injection part (see table 1) and thus also can change of mechanical properties (see table 2).

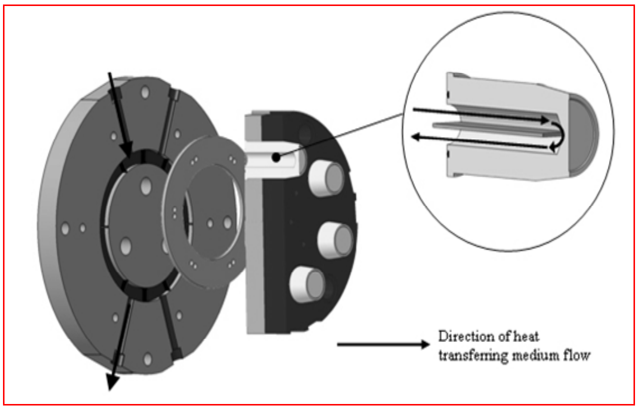

Fig. 2 Scheme of moveable mould parts and cooling of punch by partition system with circulation water

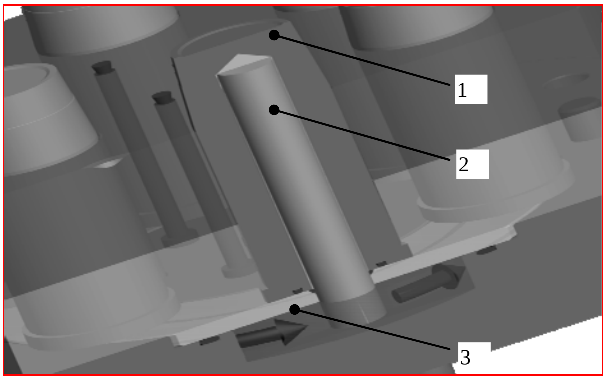

Fig. 3 Cooling of core by heat pipe.
1- core; 2 – heat pipe;
3 – main cooling duct with water

Influence of cooling medium onto so-called skin-core structure is in table 1 shown by change of whole surface layer thickness which was measured onto microtome samples of injection parts under polarized light, including shear layer (transition layer). From obtained experimental results is possible to further state that degree of crystallinity depends only on mould temperature (with higher mould temperature also increases degree of crystallinity and thus also e.g. flexure modulus of injection part) and not on used cooling medium (table 3).

Table 1 Surface layer of micro-structure polypropylene parts

Skin layer thickness [μm]			
Cooling system	Temperature of moulds		
	30 °C	45 °C	60 °C
Circulating Water under canal of core	92 μm	61 μm	45 μm
Heat pipe	80 μm	45 μm	52μm

Table 2 Mechanical properties of polypropylene injection parts in dependence on cooling system

Tensile and Flexure properties [MPa]			
Cooling system	Temperature of moulds		
	30 °C	45 °C	60 °C
Circulating Water under canal of core			
Tensile strength	34,3±0,3	34,7±0,8	34,5±0,4
Flexure strength	62,8±2,4	68,9±2,2	72,8±1,7
Flexure modulus	1549,2±48,3	1617,1±43,7	1632,9±86,5
Heat-pipe			
Tensile strength	34,5±0,2	34,7±0,2	34,9±0,4
Flexure strength	64,7±0,8	65,8±1,6	73,5±0,4
Flexure modulus	1615,8±70,2	1649,6±49,8	1749,2±69,1

From table 2 is clear that the same flexure modulus which was achieved for injection parts cooled by water under mould temperature 45 °C, resp. 60 °C, is with application of heat pipe possible to achieve already under mould temperature 30 °C resp. 45 °C. This enables reduction of injection part cooling time and thus reduction of process cycle time.

By using heat pipe was for polypropylene injection parts and mould temperature 30 °C and 45 °C observed thickness reduction of whole surface layer of injection part and increase of flexure modulus. Under mould temperature 60 °C there was however increase in surface layer thickness which is because by different behavior of heat pipe in different temperature intervals, resp. lower time delay in start of working (continuous heat removal) heat pipe under mould temperature 60 °C.

Table 3 Degree of crystallinity of polypropylene injection parts determined by diffusion method of X-radiation in dependence on cooling system

Degree of crystallinity [%]			
Cooling system	Temperature of moulds		
	30 °C	45 °C	60 °C
Circulating Water under canal of core	42 %	44 %	47 %
Heat pipe	41 %	43 %	46 %

USING OF HIGHLY HEAT CONDUCTIVE MATERIALS

Highly heat conductive materials are not real cooling medium, however in design of injection mould are using e.g. for shape inserts to heat removal from such areas of injection part which are difficult for cooling [8]. Heat is thus transferred to areas where is possible to ensure further heat removal by common ways – most often with help of cooling ducts with circulation of water.

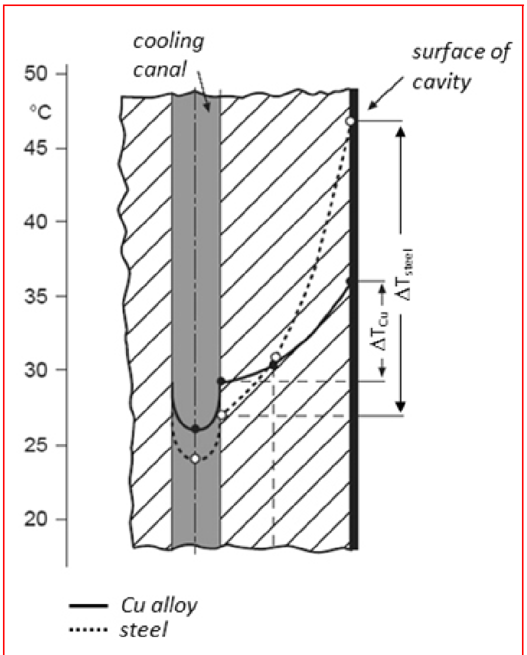

Fig. 4 Temperature outline in cross-section of mould during injection part cooling

Highly heat conductive materials – copper alloys (e.g. Ampco, Ampcoloy, Moldmax etc.) ensure not only highly intensive heat removal (see fig. 4 and fig. 5) but also prohibit non-homogenous *heat loading of mould and injection part (see fig. 5) with all of its consequences (e.g. non-homogenous properties, high eigenstress etc.). Disadvantages coming from using of such alloys are namely their low hardness which however can be solved by newly patented technology Mecobond [9].*

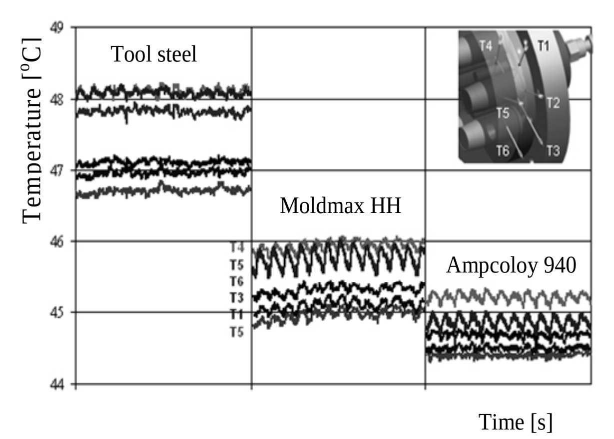

Fig. 5 Field of temperature in injection mould in the area of shape core in dependence on core´s material under cooling by circulation of water in ducts

Table 4 Surface layer of micro-structure polypropylene parts

Skin layer thickness [μm]			
Material of core	Temperature of moulds		
	30 °C	45 °C	60 °C
STEEL	92 μm	61 μm	45 μm
AMPCOLOY 940	94 μm	75 μm	51μm

Table 5 Mechanical properties of polypropylene injection parts in dependence on material of injection mould core

Tensile and Flexure properties [MPa]			
Material of core	Temperature of moulds		
	30 °C	45 °C	60 °C
STEEL			
Tensile strenght	34,3±0,3	34,7±0,8	34,5±0,4
Flexure strenght	62,8±2,4	68,9±2,2	72,8±1,7
Flexure modulus	1549,2±48,3	1617,1±43,7	1632,9±86,5
AMPCOLOY 940			
Tensile strenght	33,6±0,4	33,7±0,4	34,2±0,3
Flexure strenght	65,9±0,7	68,5±0,9	68,7±0,9
Flexure modulus	1663,8±157	1578,5±185	1751,2±78

Table 6 Degree of crystallinity of polypropylene injection parts determined by diffusion method of X-radiation in dependence on cooling system

Degree of crystallinity [%]			
Material of core	Temperature of moulds		
	30 °C	45 °C	60 °C
STEEL	42 %	44 %	47 %
AMPCOLOY 940	41 %	44 %	46 %

From results of experimental measurement with using copper alloy Ampcoloy 940 for production of injection mould shape core (cooled by water, partition system – see fig. 1 and replacing steel core) is possible to state that there is increase of whole surface thickness in injection part structure (see table 4) as a consequence of rapid heat removal and cooling of injection part surface. From measured mechanical properties is not possible with regard to measured values variance make any clear conclusions about surface layer influence onto such properties. Concerning influence of copper alloys onto measured polypropylene injection parts degree of crystallinity (under different mould temperature) is from results possible to state that by using copper alloys there is influence only surface layer of injection part structure and there is not influence of final degree of crystallinity of injection part (see table 6) which is influenced only by mould temperature.

CONFORMAL COOLING OF INJECTION MOULDS

Increase intensity of heat removal from injection part is possible to ensure not only by application of heat pipe and highly heat conductive materials in design of injection mould but also by alternative methods for production of shape cores of mould and its cooling systems – i.e. for example "conformal cooling". This is method which uses standard methods of circulation water in cooling ducts but however contrary of common cooling method follows shape circumflex of mould cavity (see fig. 6). Shape insert with cooling ducts is produced very quickly and effective layer by layers with the help of method Direct Metal Laser Sintering (DMLS, see fig. 7), whereas with regard to achieve maximal cooling effect is possible to optimize size, shape and cross-section by the help of simulation programs [10], [11].

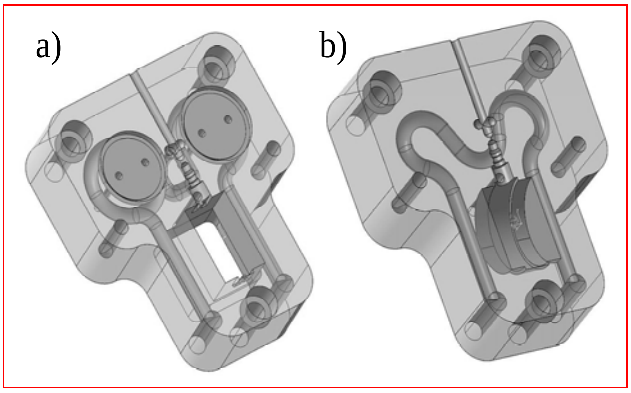

Fig. 6: Insert board of injection mould
a) moveable part of mould b) fixed part of mould

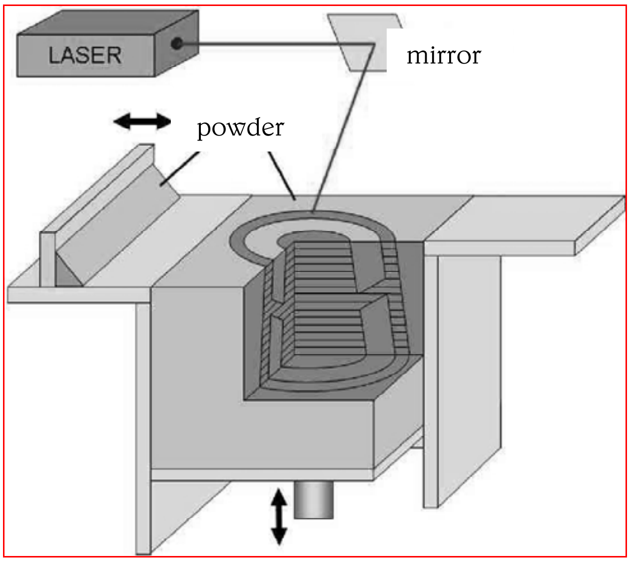

Fig. 7: Scheme of DMLS method /11/

CONCLUSION

From written examples and results of experiment is clear that cooling system of injection moulds and course of injection part cooling influences not only process quality, dimensional and shape accuracy of injection part (by means of rapid and homogenous heat removal from shape cavities of mould) but also its final properties (through changes in morphological structure).

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