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TEMPERATURE ADAPTIVE CONTROL USING THE ADDITIVE MANUFACTURING FOR INJECTION MOLDING POLYMERIC PRODUCTS

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Abstract: *This paper presents the adaptive control of the temperature in the injection mold using additive manufacturing in order to achieve the controlled and specific cooling channels in the components parts of the injection molds of polymeric products. The increasing complexity of technical characteristics by construction and technology of the polymer products lead to increasingly stringent specifications for their dimensional stability and to complicated injection molds cost prices involving high reliability issues. The adaptive control of the temperature in the injection molds produced polymeric is the solution that solves these performance requirements. The main problems in the adaptive control of the temperature by injection molds is given by the thermodynamic characteristics of active plate material of the mold and by the distribution of the thermal fields and the cooling of the polymer product injected. The differential temperature control of the various areas of the active plaque cavity by injection mold using the conventional or assisted cooling systems lead to high manufacturing times and the bad quality of the product. This paper presents ways to realize of specific cooling channels so that they will be conform to the contour of the parts or integrated in the specific heat conductive material, embedded in the active plate for the injection polymer product. It is also presents the technologies used to achieve the specific cooling channels like direct laser metal forming, "direct metal laser sintering" (DMLS) and the method of introduction of high conductivity material in the active areas of the injection molds plate. Each type of product requires a specific construction technology to achieve specific.By creating these specific channels occurs adaptive temperature control in injection mold active areas resulting low manufacturing times and conformal quality.*

Keywords: *temperature adaptive control, additive manufacturing, injection molding,direct metal laser sintering*

1. INTRODUCTION

Of particular importance for injection molds is that they allow obtaining products injected for material losses to a minimum, in compliance with technical requirements. The injection parts of complex shapes, concave, must apply an injection temperature controlled by the surface of the part while maintaining pressure duration further. When opening the mold can occur in parts molded internal tensions that can cause cracking of parts (in case more rigid amorphous thermoplastics such as polystyrene shock-resistant PAS) or their deformation (in the case of semi-crystalline thermoplastics such as PE-polyethylene flexible . Temperature plays an important role influencing mold: internal stress, deformation, dimensional accuracy, weight, surface quality. Cooling time is determined by the temperature of the mold surface. The heating equipment - cooling must ensure a constant temperature of the mold with some limitations related to the cooling channels position closer to the nest mold. The characteristic cooling time of the cooling process during the longest part of the injection cycle representing approximately 68% of the total duration of the cycle. To achieve, in view of a high productivity, short cycle time, shall be provided reduction measures for the cooling. Injection technology, involves getting a time and cooling rate so as to ensure the quality prescribed injected part. By varying the cooling time and mold temperature (which determines the cooling rate) is depleted the technological possibilities of influencing the process of cooling in the mold. Although these technological possibilities seem easy to achieve, the cooling process involves many technical difficulties. This paper presents adaptive control temperature in the mold using manufacturing technologies through the generation of material to achieve controlled and specific cooling channels in injection molds components of polymeric products.

2. COOLING SYSTEMS OF INJECTION MOLDS

The higher the temperature of the thermoplastic material is higher, the more it is fluid filled lighter mold and injection time are reduced. Mold temperature is decisive phase cooling and solidification of the part.

Table 1: Temperatures of major thermoplastics and molds

Code	Material	The temperature of the molten material [°C]	Mould temperature [°C]
PS	Polystiren	190-220	40-50
ABS	Acrilonitril-butadien-styren Copolymer	210-240	60-70
P.A.6	Polyamid	230-250	100-110
P.A.6.6	Polyamid	270-290	100-110
PP	Polypropilene	240-270	30-50
PMMA	Polimetacrilat Metil (Plexiglas)	200-240	50-80
POM	Poliacetatpolioximetilen	200-220	60-100
PC	Policarbonat	290-310	80-120
PTFE	Politetrafluoretylene (Teflon)	340-370	140-230

In terms of technology, cooling channels position to the part, especially in parts of complex shapes is an intractable problem technologically. Such a classic mold LTPC existence in the laboratory of the University Politehnica of Bucharest, for a common part, as well as can be seen in Figure 1 where the cooling channels are driven on straight paths, trajectories relatively easily obtained in terms of technology. Rectilinear trajectory cooling channel can not be too close to a piece of complex size and different thickness. It is therefore very important that the cooling channels position to make the play closer or mold nest.

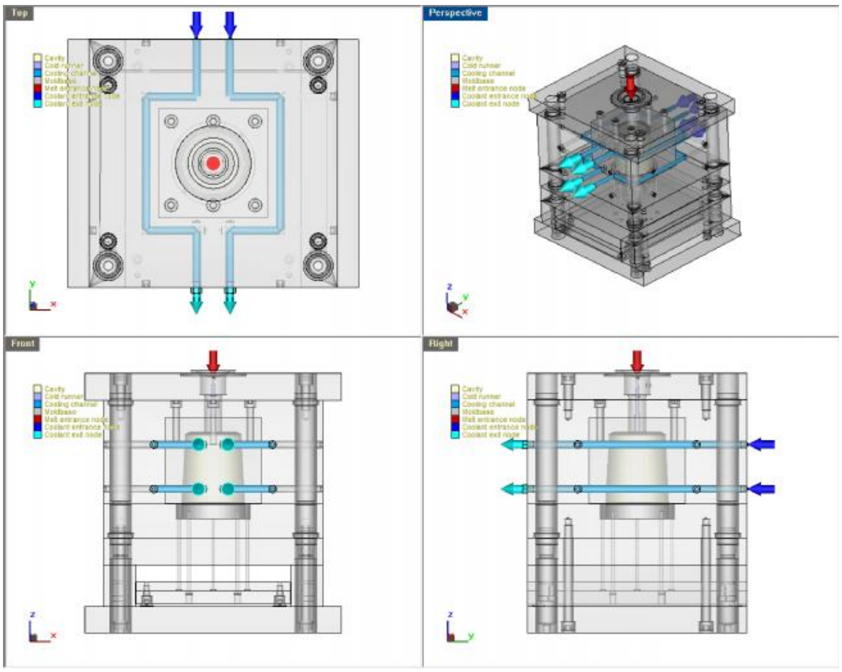


Figure 1: Making a mold cooling channels for a common parts (made in Moldex 3D)

Adaptive control temperature inside the mold must however be optimized relative to the temperatures of the injected material, mold temperature and cooling system after the injection mold piece. The main problem is the cooling of injection molds mold steel heat resistance. Depending on the quality of steel used typical thermal conductivity values are approximately 25 W/mk and down to about 12 to 15 W/mK, depending on the proportion of alloy additives. Tool steels are poor conductors of heat as compared to copper alloy or pure copper which has a thermal conductivity of approximately 390 W / mK. Figure 2 illustrates the situation of a conventional cooling heat the molds during the manufacturing process [1].

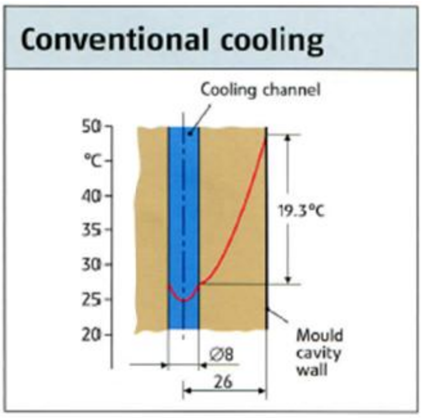


Figure 2: The temperature in the injection mold walls as compared to the reference temperature of the cooling medium

Although the distance from the cooling channel to the wall of the mold cavity is only 22 mm, the mold wall temperature increases only about 19°C to a core temperature of the cooling medium. If we consider now the situation in the mold installation channel, channel cooling situation that is far away from the mold wall, or even a region whose thin-walled cavity is completely encased in the polymer, the temperature difference between the cooling medium and the wall mould often reach values of 60 °C and more.

Such hot spots are due to the considerable extension of the time of closing of the mold and also may affect the quality of parts and the injection itself.

The problem can be addressed only by the arrangement of cooling channels so that they conform to the contour or integrated in highly thermally conductive material to be clamped tightly in tool steel workpiece regions.

The polymeric material of the nest during a cycle gives mold injection mold body, the amount of heat Q, which is calculated using the equation:

$Q=m(i_2-i_1)$ *kcal*

m – mass injected part, kg;

i_2 – enthalpy of the polymeric material from entering the mold;

i_1 – enthalpy of the polymeric material to mold release.

The enthalpy of the polymeric material is calculated using the equation:

$\Delta i= i_2- i_1=c_p(T_{Mp}-T_D)$ *[kcal/kg]*

c_p – specific heat of the polymeric material kcal/kg°C;

T_{Mp} – temperature of the material in the nest;

T_D – mold release temperature;

The amount of heat transfer of the piece is taken by mold and transported to the environment of moderation. The amount of heat Q is determined by the relationship:

$$Q = \frac{\lambda_M}{\delta} S(T_{pc} - T_{pT}) \quad [W]$$

where:

λ_M – thermal conductivity of the mold =0,197 [W/m·K]

δ – Channel Tempering distance from the mold surface,[m]

S – the active cross-sectional area of the mold ,[m²]

T_{pc} – The average temperature of the wall of the cavity =433 [k°]

T_{pT} – channel wall average temperature tempering =333 [K°]

Heat transfer from the mold (solid medium) to the tempering environment (liquid medium) is by convection and can be expressed by the relation:

$Q=\alpha_T S_T(T_{pT} - T_T)$ [W]

where:

α_T – heat transfer coefficient tempering environment =1310 [w/m²K]

S_T – active surface tempering channels, [m²]

T_{pT} - channel wall temperature tempering, =433 [k°]

T_T - ambient temperature tempering =393 [k°]

Heat transfer coefficient is calculated using the equation:

$$\alpha_T = \frac{\lambda}{d_c}[3{,}65 + \frac{0{,}0668 p_e \frac{d_c}{L_c}}{1 + 0{,}045(p_e \frac{d_c}{L_c})^2}] \qquad [w/m^2K]$$

where:

d_c – Channel Tempering diameter , [m]

L_c – Channel Tempering length, [m]

3. MANUFACTURING TECHNOLOGY USE OF COOLING CHANNEL USING TECHNOLOGY GENERATION OF MATERIAL

The increasing complexity and geometry of injection molded parts and the more stringent specifications for dimensional stability increased the parts cost to put pressure in the injection molds and enhance feasibility problems already difficult. A recently launched service that has already gained attention is the direct laser metal forming (Direct Metal Laser Sintering-DMLS). This process generates an insert molded from a metal powder bed, which often is a material inserted in the original mold. A fine metal powder is placed in a heated room built on a platform that can be lowered. A direct laser melting the powder layer, which was initially leveled with a slide according to a 3D model, to directly form the contour of the part webs, and the powder is welded to a monolithic workpiece subsequent to the final hardness about 52 Rockwell C (fig. 3).

The conformal cooling, or the segmented mold cooling is a new technology that meets these chalenges.

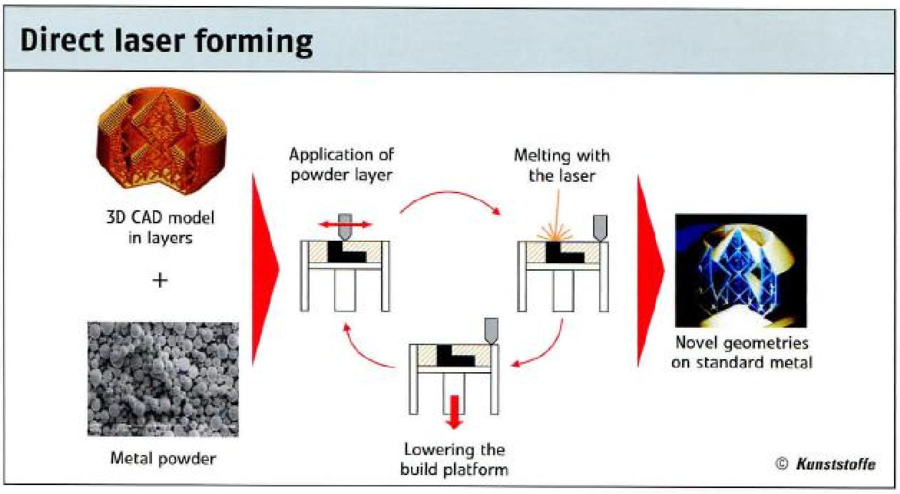


Figure 3: Laser Sintering using the method of 3D generating metal powder directly [2]

The steel in the mold has a density of about 100%. If the position of the cooling channel is in accordance with the shape of a part of the plastic material of the workpiece then is introduced into the 3D data set, which is then further insertion of the printed precisely on the three-dimensional matrix in the form of a channel. The advantage of the above-mentioned manufacturing process is complete freedom of design in creating channel. Although the method does not require cooling medium flowing through conformal channels, it provides adequate heat transfer due to high thermal conductivity of the material. Heat conductive needles, such as copper of high purity which can achieve a thermal conductivity of 390 W/mK can be inserted into the powder bed by taking the shape of the contour. [1]

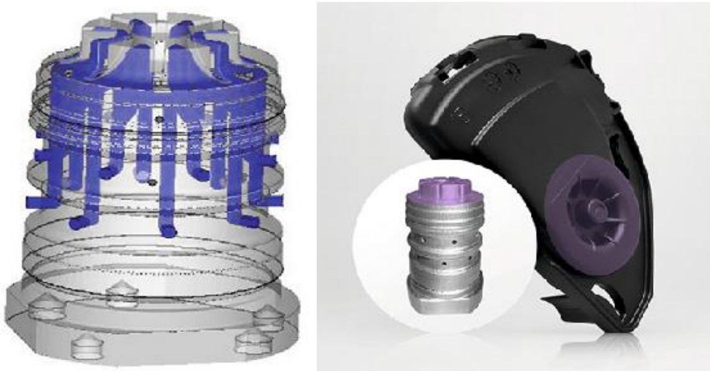
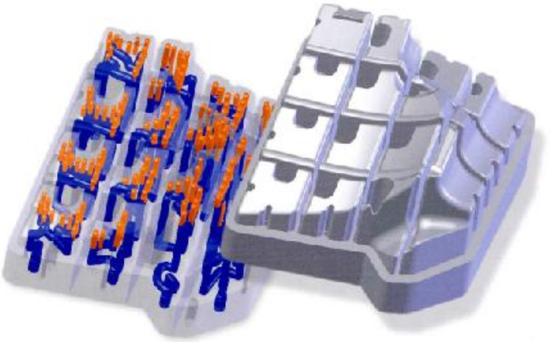


Figure 4: A 3D view of the inner cooling chanels of a tool insert, wich could not be manufactured using conventional machining [3]



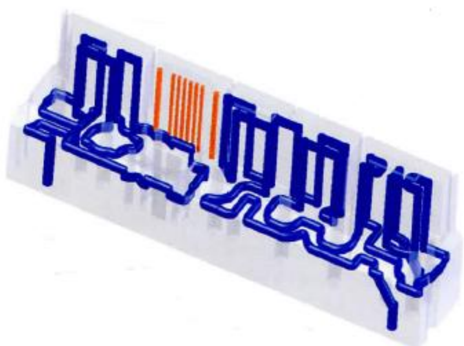


Figure 5: The mold for producing a liquid-cooled engine [3] ; **Figure 6** : Electronic Parts from ABS [3]

In the case where such copper elements are welded or sintered high-purity (by diffusion bonding) placed in the cavities prior to the insertion of the mold, average thermal conductivity of the new composite steel/copper is much higher than that of the steel used in the mold conventional manner. Depending on the design of the mold insert, such items steel/copper can reach or even exceed the thermal conductivity values, which are usually carried out only by copper alloys are also used in the manufacture of the mold .

Examples of building cooling channels to achieve a consistent cooling using modern additive manufacturing technologies for material generating are shown in Figures 4, 5 and 6.

The position and shape of the channels to be determined from the point of view of 3D additive manufacturing technologies being achieved by the design and proper segmentation of the individual channels. This segmentation is essential especially for large surface components because then the form is usually operated at different temperatures - in accordance with the various areas of the part. This means that mold temperatures are tailored to specific thermal balance of the piece. Such segmentation is a segmentation channels under different water temperatures and helps to influence and control the contraction of individual areas play actively. [4]

Figure 6 shows an example of an automotive cooling comply. The core of electronic parts ABS is about 300 mm long, 50 mm wide and about 100 mm in height. For the ABS-based core, defining the shape is controlled two separate cooling channels running beneath it. [5]

In the narrower base region, the heat transfer copper-composite steel pins provide for adequate heat removal. Placing the lower half of a mold core of a coolant tank for the engine shown in Figure 5 shows how impressive the different technologies interact to provide a viable solution. Space cooling channels in figure are projected on a technical level of production possible, being designed only to supply the coolant core regions and to allow application in channel cross sections. In further narrow base regions can be observed copper pins embedded in mold steel needles remove heat efficiently, even in areas with narrow contour regions.

Figure 7 and Figure 8 is trying to achieve cooling channels made by generating a 3D printer . These tests were obtained by the Polytechnic University of Bucharest.

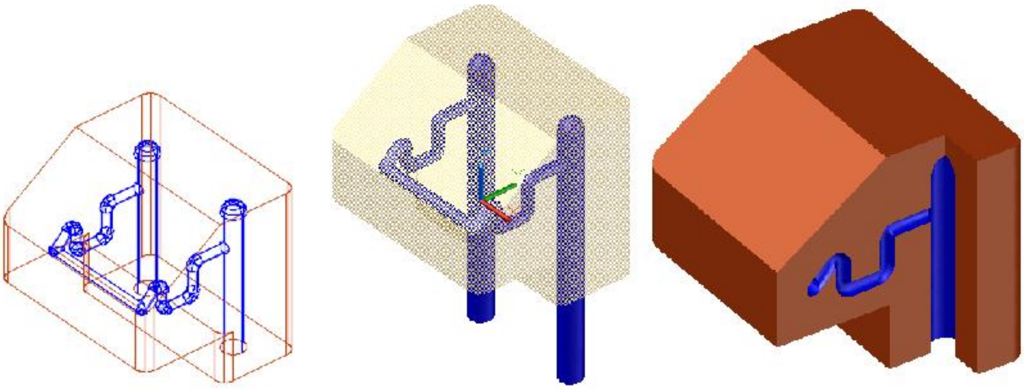


Figure 7: Cooling channels made for a sample generated by 3D printing through the additive manufacturing technologies

Figure 8: Physical part performed in a 3D printing machine

4. CONCLUSION

Mold productivity increases with the quality and efficiency of the cooling system. The ability to remove heat as quickly as the design of more efficient cooling channels and the choice of materials as appropriate and without making too complicated mold, mold will increase productivity. Copper-steel composite solutions are not subject to the disadvantages of the known copper-based alloys, such as reduced resistance to bending (due to the low modulus of elasticity), hardness and even less costly processing. A reduction of cycle time by an average of 30%, with lower rates for scrap, can quickly lead to a reduction in unit costs by 15% for injectable products. Differential temperature control of various areas of active plaque cavity injection mold using conventional cooling systems or assisted stroke lead to high manufacturing quality and conform.
New technologies used to produce specific cooling channels and direct laser metal forming "direct metal laser sintering" (DMLS) and the method of introduction of high conductivity material in the active areas of the plate as a cooling injection molds comply with contour.
By creating these specific channels trough additive manufacturing technologies occurs adaptive temperature control in injection mold active areas resulting in low and quality manufacturing times comply.

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