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Adaptive system for electrically driven thermoregulation of moulds for injection moulding

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Abstract

One of the basic problems in the development and production process of moulds for injection moulding is the control of temperature conditions in the mould. Precise study of thermodynamic processes in moulds showed, that heat exchange can be manipulated by thermoelectrical means. Such system upgrades conventional cooling systems within the mould or can be a stand alone application for heat manipulation within it.

In the paper, the authors will present results of the research project, which was carried out in three phases and its results are patented in A686\2006 patent. The testing stage, the prototype stage and the industrialization phase will be presented. The main results of the project were total and rapid on-line thermoregulation of the mould over the cycle time and overall influence on quality of plastic product with emphasis on deformation control.

Presented application can present a milestone in the field of mould temperature and product quality control during the injection moulding process.

Keywords: Injection moulding; Mould cooling; Thermoelectric modules; FEM simulations

1. Introduction, definition of problem

Development of technology of cooling moulds via thermoelectrical (TEM) means derives out of the industrial praxis and problems, i.e. at design, tool making and exploitation of tools. Current cooling technologies have technological limitations. Their limitations can be located and predicted in advance with finite element analyses (FEA) simulation packages but not completely avoided. Results of a diverse state of the art analyses revealed that all existing cooling systems do not provide controllable heat transfer capabilities adequate to fit into demanding technological windows of current polymer processing technologies.

Polymer processing is nowadays limited (in term of shortening the production cycle time and within that reducing costs) only with heat capacity manipulation capabilities. Other production optimization capabilities are already driven to mechanical and polymer processing limitations [3].

1.1. Thermal processes in injection moulding plastic processing

Plastic processing is based on heat transfer between plastic material and mould cavity. Within calculation of heat transfer one should consider two major facts: first is all used energy which is based on first law of thermodynamics—law of energy conservation [1], second is velocity of heat transfer. Basic task at heat transfer analyses is temperature calculation over time and its distribution inside studied system. That last depends on velocity of heat transfer between the system and surroundings and velocity of heat transfer inside the system. Heat transfer can be based as heat conduction, convection and radiation [1].

1.2. Cooling time

Complete injection moulding process cycle comprises of mould closing phase, injection of melt into cavity, packing pressure phase for compensating shrinkage effect, cooling phase, mould opening phase and part ejection phase. In most cases, the longest time of all phases described above is cooling time.

Cooling time in injection moulding process is defined as time needed to cool down the plastic part down to ejection temperature [1].

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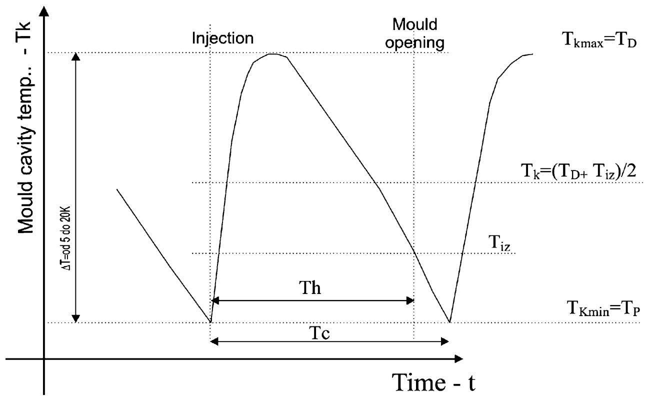

Fig. 1. Mould temperature variation across one cycle [2].

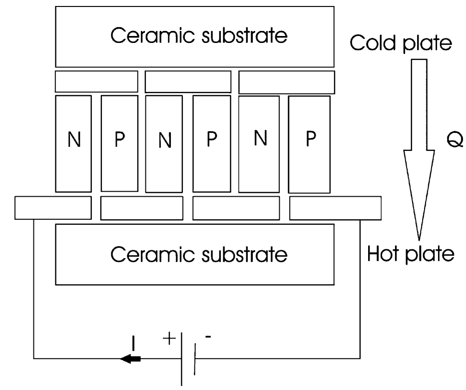

Fig. 2. TEM block diagram.

The main aim of a cooling process is to lower additional cooling time which is theoretically needless; in praxis, it extends from 45 up to 67% of the whole cycle time [1,4].

From literature and experiments [1,4], it can be seen, that the mould temperature has enormous influence on the ejection time and therefore the cooling time (costs).

Injection moulding process is a cyclic process where mould temperature varies as shown in Fig. 1 where temperature varies from average value through whole cycle time.

2. Cooling technology for plastic injection moulds

As it was already described, there are already several different technologies, enabling the users to cool the moulds [5]. The most conventional is the method with the drilling technology, i.e. producing holes in the mould. Through these holes (cooling lines), the cooling media is flowing, removing the generated and accumulated heat from the mould [1,2]. It is also very convenient to build in different materials, with different thermal conductivity with the aim to enhance control over temperature conditions in the mould. Such approaches are so called passive approaches towards the mould temperature control.

The challenging task is to make an active system, which can alter the thermal conditions, regarding to the desired aspects, like product quality or cycles time. One of such approaches is integrating thermal electrical modules (TEM), which can alter the thermal conditions in the mould, regarding the desired properties. With such approach, the one can control the heat transfer with the time and space variable, what means, that the temperature can be regulated throughout the injection moulding cycle, independent of the position in the mould. The heat control is done by the control unit, where the input variables are received from the manual input or the input from the injection moulding simulation. With the output values, the control unit monitors the TEM module behaviour.

2.1. Thermoelectric modules (TEM)

For the needs of the thermal manipulation, the TEM module was integrated into mould. Interaction between the heat and electrical variables for heat exchange is based on the Peltier effect. The phenomenon of Peltier effect is well known, but it was until now never used in the injection moulding applications. TEM module (see Fig. 2) is a device composed of properly arranged pairs of P and N type semiconductors that are positioned between two ceramic plates forming the hot and the cold thermoelectric cooler sites. Power of a heat transfer can be easily controlled through the magnitude and the polarity of the supplied electric current.

2.2. Application for mould cooling

The main idea of the application is inserting TEM module into walls of the mould cavity serving as a primary heat transfer unit.

Such basic assembly can be seen in Fig. 3. Secondary heat transfer is realized via conventional fluid cooling system that allows heat flows in and out from mould cavity thermodynamic system.

Device presented in Fig. 3 comprises of thermoelectric modules (A) that enable primarily heat transfer from or to temperature controllable surface of mould cavity (B). Secondary heat transfer is enabled via cooling channels (C) that deliver constant temperature conditions inside the mould. Thermoelectric modules (A) operate as heat pump and as such manipulate with heat derived to or from the mould by fluid cooling system (C). System for secondary heat manipulation with cooling channels work as heat exchanger. To reduce heat capacity of controllable area thermal insulation (D) is installed between the mould cavity (F) and the mould structure plates (E).

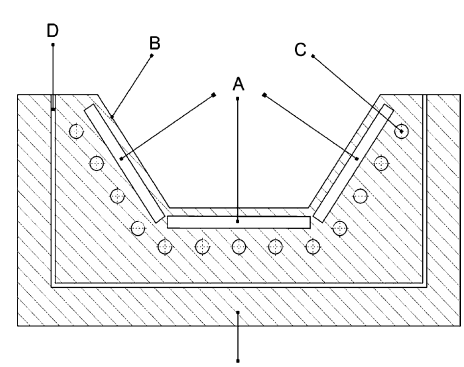

Fig. 3. Structure of TEM cooling assembly.

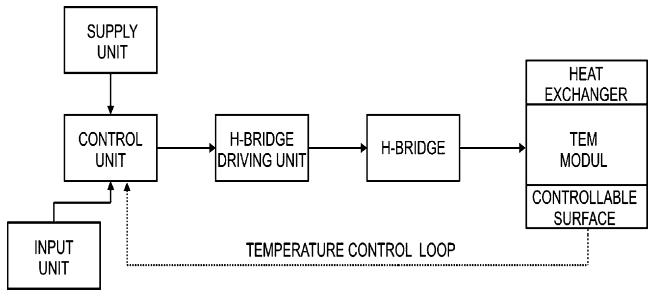

Fig. 4. Structure for temperature detection and regulation.

The whole application consists of TEM modules, a temperature sensor and an electronic unit that controls the complete system. The system is described in Fig. 4 and comprises of an input unit (input interface) and a supply unit (unit for electronic and power electronic supply—H bridge unit).

The input and supply units with the temperature sensor loop information are attached to a control unit that acts as an execution unit trying to impose predefined temperate/time/position relations. Using the Peltier effect, the unit can be used for heating or cooling purposes.

The secondary heat removal is realized via fluid cooling media seen as heat exchanger in Fig. 4. That unit is based on current cooling technologies and serves as a sink or a source of a heat. This enables complete control of processes in terms of temperature, time and position through the whole cycle. Furthermore, it allows various temperature/time/position profiles within the cycle also for starting and ending procedures. Described technology can be used for various industrial and research purposes where precise temperature/time/position control is required.

The presented systems in Figs. 3 and 4 were analysed from the theoretical, as well as the practical point of view. The theoretical aspect was analysed by the FEM simulations, while the practical one by the development and the implementation of the prototype into real application testing.

3. FEM analysis of mould cooling

Current development of designing moulds for injection moulding comprises of several phases [3]. Among them is also design and optimization of a cooling system. This is nowadays performed by simulations using customized FEM packages (Moldflow [4]) that can predict cooling system capabilities and especially its influence on plastic. With such simulations, mould designers gather information on product rheology and deformation due to shrinkage as ell as production time cycle information.

This thermal information is usually accurate but can still be unreliable in cases of insufficient rheological material information. For the high quality input for the thermal regulation of TEM, it is needed to get a picture about the temperature distribution during the cycle time and throughout the mould surface and throughout the mould thickness. Therefore, different process simulations are needed.

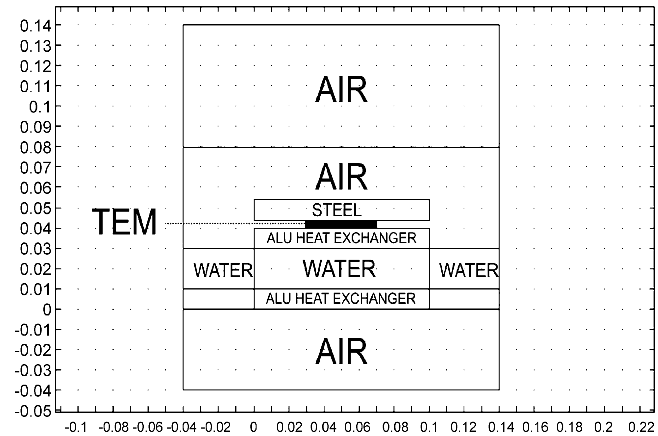

Fig. 5. Cross-section of a prototype in FEM environment.

3.1. Physical model, FEM analysis

Implementation of FEM analyses into development project was done due to authors' long experiences with such packages [4] and possibility to perform different test in the virtual environment. Whole prototype cooling system was designed in FEM environment (see Fig. 5) through which temperature distribution in each part of prototype cooling system and contacts between them were explored. For simulating physical properties inside a developed prototype, a simulation model was constructed using COMSOL Multiphysics software. Result was a FEM model identical to real prototype (see Fig. 7) through which it was possible to compare and evaluate results.

FEM model was explored in term of heat transfer physics taking into account two heat sources: a water exchanger with fluid physics and a thermoelectric module with heat transfer physics (only conduction and convection was analysed, radiation was ignored due to low relative temperature and therefore low impact on temperature).

Boundary conditions for FEM analyses were set with the goal to achieve identical working conditions as in real testing. Surrounding air and the water exchanger were set at stable temperature of 20 °C.

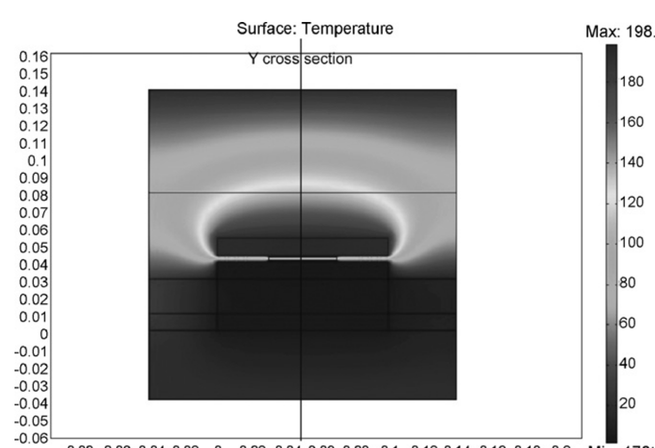

Fig. 6. Temperature distribution according to FEM analysis.

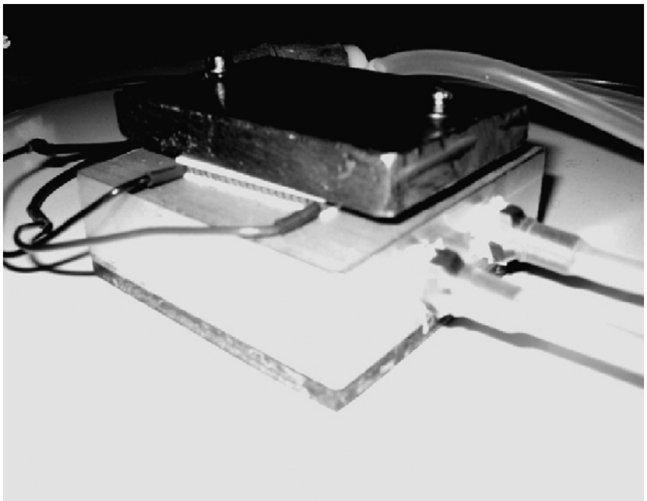

Fig. 7. Prototype in real environment.

Results of the FEM analysis can be seen in Fig. 6, i.e. temperature distribution through the simulation area shown in Fig. 5. Fig. 6 represents steady state analysis which was very accurate in comparison to prototype tests. In order to simulate the time response also the transient simulation was performed, showing very positive results for future work. It was possible to achieve a temperature difference of 200 °C in a short period of time (5 s), what could cause several problems in the TEM structure. Those problems were solved by several solutions, such as adequate mounting, choosing appropriate TEM material and applying intelligent electronic regulation.

3.2. Laboratory testing

As it was already described, the prototype was produced and tested (see Fig. 7). The results are showing, that the set assumptions were confirmed. With the TEM module it is possible to control the temperature distribution on different parts of the mould throughout the cycle time. With the laboratory tests, it was proven, that the heat manipulation can be practically regulated with TEM modules. The test were made in the laboratory, simulating the real industrial environment, with the injection moulding machine Krauss Maffei KM 60 C, temperature sensors, infrared cameras and the prototype TEM modules. The temperature response in 1.8 s varied form +5 up to 80 °C, what represents a wide area for the heat control within the injection moulding cycle.

4. Conclusions

Use of thermoelectric module with its straightforward connection between the input and output relations represents a milestone in cooling applications. Its introduction into moulds for injection moulding with its problematic cooling construction and problematic processing of precise and high quality plastic parts represents high expectations.

The authors were assuming that the use of the Peltier effect can be used for the temperature control in moulds for injection moulding. With the approach based on the simulation work and the real production of laboratory equipment proved, the assumptions were confirmed. Simulation results showed a wide area of possible application of TEM module in the injection moulding process.

With mentioned functionality of a temperature profile across cycle time, injection moulding process can be fully controlled. Industrial problems, such as uniform cooling of problematic A class surfaces and its consequence of plastic part appearance can be solved. Problems of filling thin long walls can be solved with overheating some surfaces at injection time. Furthermore, with such application control over rheological properties of plastic materials can be gained. With the proper thermal regulation of TEM it was possible even to control the melt flow in the mould, during the filling stage of the mould cavity. This is done with the appropriate temperature distribution of the mould (higher temperature on the thin walled parts of the product).

With the application of TEM module, it is possible to significantly reduce the cycle time in the injection moulding process. The limits of possible time reduction lies in the frame of 10–25% of additional cooling time, describe in Section 1.2.

With the application of TEM module it is possible to actively control the warping of the product and to regulate the amount of product warpage in the way to achieve required product tolerances.

The presented TEM module cooling application for injection moulding process is a matter of priority note for the patent, held and owned by TECOS.

References

[1] I. Čatić, Izmjena topline u kalupima za injekcijsko prešanje plastomera, Društvo plastičara i gumaraca, Zagreb, 1985.

[2] I. Čatić, F. Johannaber, Injekcijsko prešanje polimera i ostalih materiala, Društvo za plastiku i gumu, Biblioteka polimerstvo, Zagreb, 2004.

[3] B. Nardin, K. Kuzman, Z. Kampuš, Injection moulding simulation results as an input to the injection moulding process, in: AFDM 2002: The Second International Conference on Advanced Forming and Die Manufacturing Technology, Pusan, Korea, 2002.

[4] TECOS, Slovenian Tool and Die Development Centre, Moldflow Simulation Projects 1996–2006.

[5] S.C. Chen, et al., Rapid mold surface heating/cooling using electromagnetic induction technology: ANTEC 2004, Conference CD-ROM, Chicago, Illinois, 16–20 May, 2004.