THERMOELECTRICAL REGULATION OF MICROINJECTION MOULDS

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Abstract

Microinjection is one of the major replication techniques for producing low cost micro parts.

The small scale of the microinjection processes presents different challenges from those usually encountered in conventional injection moulding. One particular aspect, very important for part quality, is mould temperature control.

In conventional injection moulding, the temperature control system is set to a fixed value during the injection cycle. In microinjection moulding such behaviour is not acceptable, which as lead to the development of "active" control temperature of the mould named "variotherm" systems.

In the present paper a study will be presented for the implementation of thermo electric elements in dynamic temperature control of microinjection moulds and its impact on the process cycle time and part quality.

Introduction

Market trends and technological evolution are continuously pushing forward the possibilities of new processes. Medical devices, telecommunication equipment, large consumer electronic goods and devices are getting ever smaller, with added features and functions. For large scale production, replication processes are ideal for achieving large manufacturing number of parts with high accuracy and low cost. Micro injection moulding is one of such technologies.

The scale dimension of micro injection moulding poses different challenges to those presented to conventional, normal sized, injection moulding. One particular issue is mould temperature regulation. The mould thermodynamic behaviour and its relation with processing parameters are quite different due to the scale factor. In conventional moulding the mould surface will heat up and cool down with the entrance and cooling of the melted polymer, but the function of the mould's temperature regulation devices is to ensure a constant temperature. In microinjection moulding such procedure is not satisfactory. If the mould is at a low temperature, filling of the part will be very hard or impossible. If the mould is at a high temperature, the ejection of the moulding part will be difficult or the part will be damage, cycle time will be very large, inhibiting the economic value of the process. This has lead in recent times to development of "variotherm" systems. Such systems ensure heating of the mould prior to the filling stage and cooling of the mould after filling is completed. However, the current systems are still not able to unleash microinjection full capability regarding low cycle time.

The present paper reports an ongoing research which aims at answering some fundamental questions:

- Can Peltier elements be used to provide both cooling and heating on a microinjection mould?
- Are there already commercially available Peltier elements capable of providing such capability?
- Is it possible to design and build a totally electrically controlled and driven system for active temperature control of micro injection moulds based on Peltier modules?
- Will such system need special rules or practices for mould design?

These questions will need an answer in order to determine if electric driven temperature regulation is possible in micro injection moulds.

Injection Moulding Performance and Mould Temperature Control

Injection moulding of polymers is a complex process, with several stages that include plasticizing of the raw polymer and metering, closing of the mould, filling of the mould, packing and cooling of the moulding, opening of the mould and ejection of the plastic part. It is beyond the scope of this paper to further analyze the injection moulding cycle, but it is an established fact the filling and packing and metering stages are the most relevant considering the thermal behaviour of the mould and with great impact on part quality and process performance (Postawa et al., 2008).

In conventional injection moulding the temperature control is performed by a system composed of series of channels where a fluid will ensure that the mould temperature is stable. Its main objective is to maintain the mould at an average temperature adequate for the polymer to be injected. Usually the mould temperature is higher than room temperature, but the excess heat brought by the melted polymer is usually sufficient to ensure that the adequate temperature is maintained.

In micro injection moulding, the flow can be blocked by the skin layer, preventing replication of small details or even complete filling of the mould. Increasing the mould temperature prior to the filling stage may overcome this effect (Gornik, 2004). After filling, the mould must be cooled to allow ejection of the micro parts. Otherwise the cycle time will be too long and the polymer may degrade. The temperature control system should then be able to heat the cavity to an adequate temperature for filling of the part and then cool the cavity to allow rapid ejection of, so that cycle time is small for low part cost.

For use in micro injection process, the conventional cooling systems present some important drawbacks, mainly because such systems usually operate in a static regime, where a dynamic system, capable of both cooling and heating would be most beneficial. New methods for controlling the mould's temperature are currently being developed, that present the ability to heat and cool along the injection cycler as needed (Wang et al., 2009).

Thermoelectricity

Thermoelectric effects are a class of physical phenomena where conversion from heat to electric voltage and vice versa occurs. Thermoelectric (TE) devices are capable of producing an electric current in presence of a temperature differential or of producing a temperature differential when an electric current is applied to them.

These effects can be used to cool or heat objects. Since the direction of heating or cooling is determined by the sign of the applied voltage, thermoelectric devices can be used as temperature controllers, providing heat or cooling as needed.

Three different effects are usually considered when referring to thermoelectricity: the Seebeck effect, the Peltier effect and the Thompson effect. The Joule resistive heating phenomenon is usually not considered as a thermoelectric effect, since it is regarded as loss mechanism due to non-ideality in thermoelectric devices. Furthermore, Joule heating is not considered to be thermodynamically reversible, whereas the thermoelectric effects are, at least in principle.

Peltier Effect

The Peltier Effect is a known thermoelectric phenomenon of direct conversion of an electric current in a thermal gradient. This effect was discovered in 1834 by Jean-Charles Peltier (Lewis, 2006), a French physicist that observed that heat would be created at one junction of two different materials and cooling would be created at the other junction, when a current was made to flow across the materials.

An interesting feature of the Peltier effect is that direction of heat transfer is controlled by the polarity of the current; reversing the polarity will change the direction of transfer and thus the sign of the heat absorbed or devolved.

Current Applications for TE Devices

Thermoelectric devices are solid state devices, able to add or remove heat from a location due to an applied load or to produce electricity from a heat differential. They only became practical recently, with developments in semiconductor thermocouple materials and are currently being used in many industrial, laboratorial and consumer applications. Thermoelectrics still present great potential and applications are still being developed in very different fields. In small scale electronics, thermoelectric devices are being researched as power generators (Snyder, 2008) (Kishi, 1999), as well as temperature regulators (Fukutani and Shakouri, 2006).

Peltier modules are thermoelectric devices used for temperature control purposes (heating or cooling of devices or controlled environments). Being solid state heat pumps, they have no moving parts, fluids or gases. The laws of thermodynamics apply to these devices the same way they apply to any other conventional heat pump or any device that will transfer heat in its operation. They present low thermal efficiency, however they have significant advantages when high reliability, small size, low cost, low maintenance, safety and precise temperature control are needed.

Thermoelectric devices can be used on:

- air conditioning equipment to control operating environment of medical or industrial equipment, specially equipment or components sensitive to vibration;
- chillers and heaters for different medical, industrial, LASER and industrial applications, providing and maintaining adequate operating climate control in closed electric enclosures;
- microscope thermal stages or hot/cold chucks based on the Peltier effect for sample inspection or manipulation at precise temperature, like in liquid crystal applications;
- cooling electronic circuits and computer components.

For thermoelectric temperature control of microinjection moulds, the already available applications for temperature of electronic circuits and components are the most promising namely because of their size.

Thermoelectric Control of Injection Moulds

Recently promising research work has been done on the usage of Peltier effect for thermal electric regulation of injection moulds (Nardin et al., 2007). These researchers have developed a concept and constructed a prototype which was able to achieve a operating maximum temperature of 200ºC. However this was performed on a prototype apparatus and not on a functional mould and only in thermodynamic static regime.

Dimensioning of Thermoelectric Systems

TE modules are available in great variety of sizes, shapes, operating currents, operating voltages and ranges of heat capacity. For choosing the thermoelectric module that meets the specific set of requirements, three specific system parameters must be considered before selecting the device:

- Cold Surface Temperature – TC;
- Hot Surface Temperature – TH;
- The Thermal load- Q

Temperatures T_C and T_H and their difference, ΔT, are very important parameters. They must be accurately determined so that the device can operate as designed. The amount of heat, Q_C, that must be removed at the cold junction also has to be calculated.

Single stage thermoelectric devices are capable of producing a no load temperature differential of approximately 70ºC. Stacks of thermoelectrics can provide a greater ΔT. This practice is referred to as “cascading”.

To reduce (or increase) the temperature of an object, heat must be removed from it (or supplied to it) faster than it enters it (or exits it). This will happen at a given rate, which will determine the time needed to heat or cool the object. The time (t) needed to change the temperature of an object can be given by (Lewis, 2006):

$$t = \frac{m \cdot c_p \cdot \Delta T}{Q} \quad \text{(equation 1)}$$

Where m is the mass of the object, C_p is the specific heat of the object’s material and Q is the heat to be exchanged.

Prototype Assembly

An experimental prototype was assembled to test the Peltier concept. The main objective of the test was answer the first research question: are Peltier modules capable of providing both cooling and heating? The second objective was to determine the temperature profile (temperature vs. time while heating and cooling).

The prototype concept is represented in Fig. 1. It comprised a mould plate (A) with cooling channels, a Peltier module (B) and a steel plate (C).

The base mould plate was connected to a conventional injection moulding thermal regulator, providing the same temperature control and in any conventional mould cooling system. The objective was to provided constant temperature to the cold side of the Peltier module.

The thermoelectric module was a commercial available TEM element from the manufacturer Supercool®, ref. ET-127-20-15-RS. This module was chosen based on its claimed power output of 128W. Other specs of this module are the maximum current of 15,7 Amps, maximum voltage of 15,7 V and maximum temperature difference between hot and cold side, ΔT, is 74K. This module would be feed by a current source with a maximum output of 5 Amp.

The base mould plate temperature was set at 80ºC during testing, to allow the maximum temperature of 150ºC to be reached at the hot side of the Peltier module while respecting the maximum temperature difference of 74ºC between hot and cold side.

On the hot side of the module, a 76x66x6mm steel plate would be heated and cooled by the Peltier module.

The experimental assembly is shown in Fig. 2.

A thermographic camera from the manufacturer FLIR Systems, model ThermaCAM SC 640, was used to record the temperature at the plate, collecting infrared infra red readings (Fig. 3). To allow proper temperature readings with the thermographic camera, the top steel plate was coated in flat black color. The emissivity of the coating, 0,95, is well known.

Test Results

Preliminary calculations, using (equation 1), determined that 150 seconds would be needed to heat the top plate from 80ºC to 150 ºC. Calculations considered the mass of the top plate at 235 g, the specific heat of steel at 465 J/kg.K and the temperature difference of 70 ºC. The Q quantity was considered as the power output of the Peltier module. Since the module was not going to operate at maximum current, the power output was estimated at 50W, considering electrical consumption of 5 Amp at 10 V, with no losses. Additionally, the heating profile was plotted (Fig. 4 – “Preview” curve).

Testing was performed starting with a stabilized temperature of the assembly near to 80ºC The maximum temperature reached during testing, as recorded by the thermographic camera, was 145,8ºC, while the minimum temperature was 60,5ºC. The recorded data was used to construct the graph plots of Fig. 4.

The time needed to go from 60 to 145 ºC was recorded at 3:10 min. The time needed for heating from 80 ºC to the maximum temperature was lower, yet very close to the estimated (see Fig. 4). To cool down the top plate using the Peltier effect, the current direction was reversed and the time needed was a little over 4 minutes. If natural cooling of the assembly was allowed (without the Peltier module pumping heat out of the top plate), at 4 minutes the temperature of the assembly would be near 90ºC (**Erro! A origem da referência não foi encontrada.**). The assembly temperature would stabilize at 80ºC past 9 minutes of cooling.

The graphs show the non linear heating and cooling behaviour of the Peltier module. In contrast, (equation 1) is a linear model. The graphs also show that the greater the temperature difference, both in heating or cooling, the harder it is to enlarge that temperature difference. Conversely, the greater the temperature difference, the easier it is to decrease said difference.

The assembly testing proved that dynamic control of temperature is possible with Peltier modules. It was possible to both heat the plate to near 150ºC and subsequently cool the plate to 60ºC, respectively 70ºC above and 20ºC bellow the temperature of the base plate, set at 80ºC.

The time needed to heat or cool was deceivingly high, surely due to low power output of the single Peltier module. Once again, using (equation 1), it was estimated that more than 700W would be needed to heat the top plate from 80 ºC to 150 ºC in 10 seconds.

Mould Design

A mould is being designed using Peltier modules to provide the dynamic temperature control ability (**Erro! A origem da referência não foi encontrada.**).

Based on the prototype testing, the heat pumping capacity of the temperature control system will need special attention. Peltier modules both small, so as to fit the mould, and able of providing enough power, to allow rapid heating and cooling of the moulding cavity, will be sourced.

The insulation the Peltier modules takes also special attention, as to avoid heat exchange between hot and cold side of the modules and between the modules and the mould plates. . All mechanical interfaces between the objects to be cooled or heated and the operating environment are thermal interfaces that inhibit the heat flow. All interfaces add thermal resistance to the system. Special attention has to be taken on the assembly techniques, which should consider the need to minimize thermal resistance.

Conclusions

Thermoelectric devices are able of performing both heating and cooling task. Peltier modules are capable of performing both functions. The possibility of integrating such elements into a microinjection mould is very promising, since it will enable the capability of using a dynamic temperature profile during the injection cycle. It could provide great interest among the academic and industrial sectors.

On the present paper, these claims were tested. The Peltier module demonstrated capability of providing both heating and cooling, although long time was needed to achieve the target temperatures. Preliminary results from testing the prototype are both promising and challenging.

Further work will be made to find Peltier modules compatible with microinjection moulding needs. A mould using the concept is being designed and will be fabricated to assess the concept potential in a real micro injection moulding environment.

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Keywords

Micro injection; mould design; thermoelectric regulation.

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Illustrations

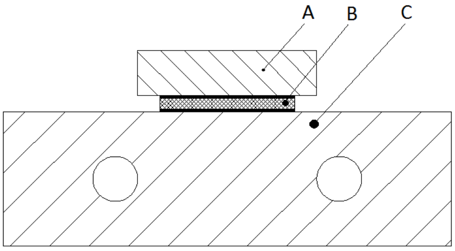

Fig. 1. schematics of the prototype: A) top plate; B) Peltier module; C) cooled base plate

Fig. 2. prototype assembly

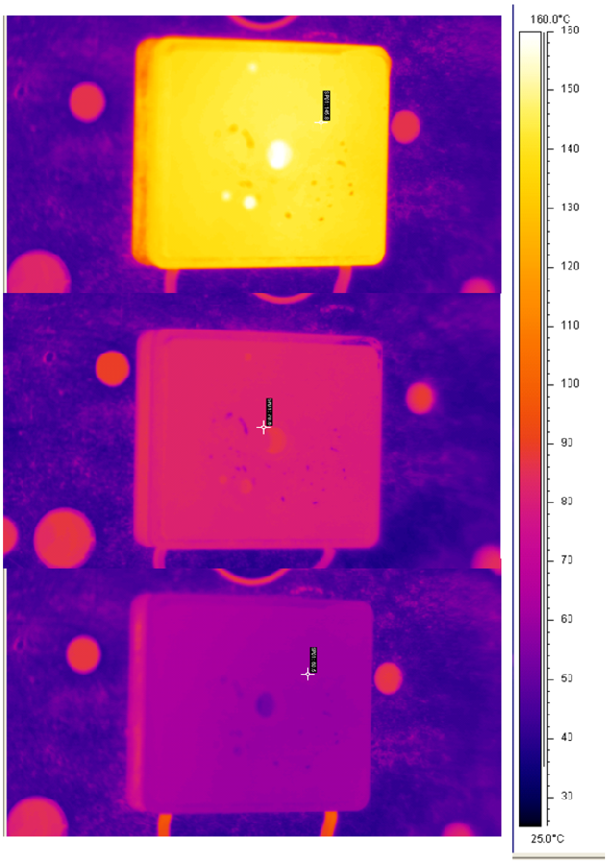

Fig. 3. Infra red image capture

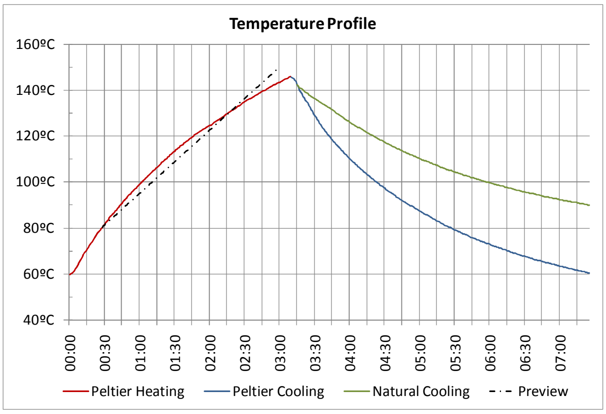

Fig. 4. Temperature profiles