THERMAL PERFORMANCE OF HYBRID INJECTION MOULDS WITH MOLDING ZONE MADE FROM NON-METALLIC MATERIALS

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Matrițele de injecție hibride cu componente nemetalice în zona de modelare sunt considerate ca fiind singura posibilitate pentru realizarea de serii scurte sau unicate. Metoda utilizată pentru realizarea cuiburilor de formare din materiale neconvenționale (ceramici, betoane) constă în turnarea răşinii deasupra piesei master. În cercetări proprii am folosit pentru experimente 75% răşină epoxidică armată cu 25% pulbere de aluminiu produsă de firma Weicon – „Weidling C”. Acest material prezintă proprietăți termice reduse din care cauză s-a mărit durata unui ciclu de injecție. În lucrare se analizează performanțele termice ale matrițelor având cuiburile de formare realizate din materiale neconvenționale, cu sau fără canale de răcire.

Hybrid injection molds with non-metallic components in the molding zone are being considered as the single possibility to realize short runs or single parts. The technique used for making the cavity from non-conventional materials (ceramics, concrete) is the mould of the resin above the master part. In ours researches we used for experiences epoxy resin filled with aluminum powder - Weicon "Weidling C" made from 75% resin and 25% aluminum powder). This material presents poor thermal properties which increase the molding cycle. In this study, we will analyze thermal performances of moulds with non-metallic forming nests having cooling channels or without cooling channels.

Keywords: moulds with non-metallic forming nests; epoxy resin aluminum filled; thermal performances.

1. Introduction

Today, we need to produce plastic parts cheaper, in short period of time. So, the mold maker has to take in consideration methods for rapidly develop new products and consequently reduce the time to market.

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The procedure of making injection moulds with forming nests from non-metallic materials permits manufacture of tools for thermoplastics injection quickly and cheaper.

Forming nests from non-metallic materials could be manufactured epoxy resin or other material on a master part placed into the mould cavity.

In the thermoplastics injection molding industry, an important aspect to deal with is given by the influence of the processing conditions on the product properties.

These techniques are developed with the objective of producing prototype or development injection molds for the pre-production stages of the design cycle.

The concept of hybrid injection molds (figure 1) in which metallic materials (defining the mold structure) and non-metallic materials in the molding zone coexist is currently one of the possibilities for short run injection molds.

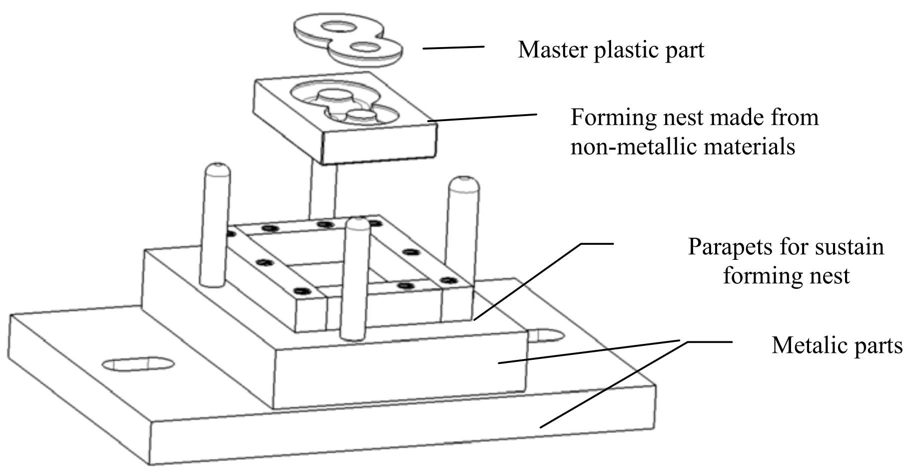


Fig. 1 – Hybrid mould

In this case, the mould is made using subtractive (for making metallic plates) and additive (for making non-metallic forming nest) techniques.

The use of conventional subtractive techniques, with the additive techniques for producing molding zones, brings about new possibilities and new challenges for the mold makers resulting from the shorter manufacturing time and the suitability for short runs [1].

Nowadays, mold making technique associated to hybrid injection molds is unknown or unused.

Understanding the new techniques and materials, their influence on the injection cycle, the predictable run size, and the final part properties are topics requiring attention from the injection molding and mold making industries.

The understanding of the thermal and mechanical behavior of this type of molds is an important step in the mold design process.

The significant difference between the thermal properties of non-metallic materials and metals (as seen in Table 1) have to be taken into consideration in the hybrid mold design process.

The low thermal conductivity of the epoxy resins, used in the molding inserts, does not allow for heat transfer rates similar to those in conventional metal molds.

This implies differences in the cooling phase of the injection molding cycle and consequently on the product properties.

Table 1

Material data

Material	**Density (Mg/m3)**	**Specific heat (J/kg ºC)**	**Thermal conductivity (W/m ºC)**
Steel	7.82	460	36.4
Epoxy resin	1.8	1115	1.43
ABS	1.05-1.07	1500-1510	0.17-0.24

The cast resin tooling technique was chosen to produce a mold with epoxy-based composite resin inserts. In order to assess the influence of the cooling layout on the thermal performance of hybrid molds, the temperature at the polymer/mold interface was recorded and the experimental data compared with results obtained by simulation using the injection molding software Moldflow.

2. Materials of the mold forming nests.

The mold structure was made from steel.

The epoxy resin “Weidling C” (75% resin+25% aluminum powder) was used to manufacture the mold forming nest. Weilding C is a liquid, aluminum-filled, high temperature resistant -35^{0}C up to +220^{0}C. For pouring out moulds (e.g. vacuum and foam moulds), fixing devices and tools exposed to high temperature.

For moldings was used ABS resin (material data is shown in table 1).

3. Hybrid mold manufacturing and molding conditions

In order to analyze the thermal performance of hybrid molds, two different mould types were assessed, one without cooling channels, and the other one with conventional cooling channels.

A mold with epoxy resin inserts was produced using in-house facilities. The master pattern was bought from market.

The processing conditions are described in Table 2.

4. Experiments

In order to create the forming nest, the epoxy resin was inserted into parapets, which created a cavity (7,0 × 5,0 × 1,2 cm parallelepiped) and made dry to obtain the first half of the tool (fig. 1 and fig. 2).

Finally the epoxy resin inserts are submitted to a final drying process so that the material acquires its final properties and it is able to be submitted to the injection molding process.

Table 2

Processing conditions

Process condition	
Injection temperature	200ºC
Ejection temperature	90ºC
Cooling temperature	45ºC
Holding pressure	20 MPa
Coolant flow rate	5 l/min

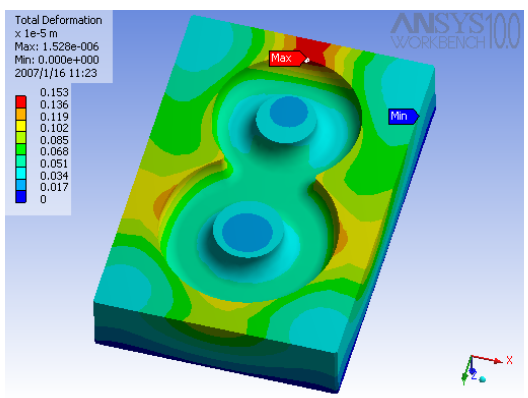


Fig. 2. Non-metallic forming nest

The low thermal conductivity of the epoxy resins, about 5% of the thermal conductivity of the metals, have a substantial influence in the heat transfer process.

One of the current possibilities to overcome the lower thermal properties of the materials is the incorporation of cooling channels within the mold. Hot spots, occurring in low cooling areas, can be minimized leading to the desirable homogeneous temperature field throughout the part.

The software Moldflow was used in this study to simulate the injection molding process. This software isn't able to simulate all of the hybrid mold structure; it is able to analyze only the molding zone. This leads to some simplifications such as disregarding the metallic components in the mold, considering only the epoxy inserts.

One of the results obtained with the Moldflow simulations, that allow the evaluation of the mold thermal behavior, is the polymer/mold interface temperature. In order to complement and validate the simulations of Moldflow, a thermocouple was used for a direct temperature measurement.

5. Results and discussion

For comparison purposes, Moldflow was used to predict the injection molding cycle time (tc) using different inserts materials as steel and epoxy resins. The results showed a significant difference on the thermal performance of these materials: for steel the value is tc = 1,835 sec, while for epoxy resin inserts the value is tc = 1,940 sec. That comparison shows that the heat transfer process is slower when epoxy resins are used (fig. 3).

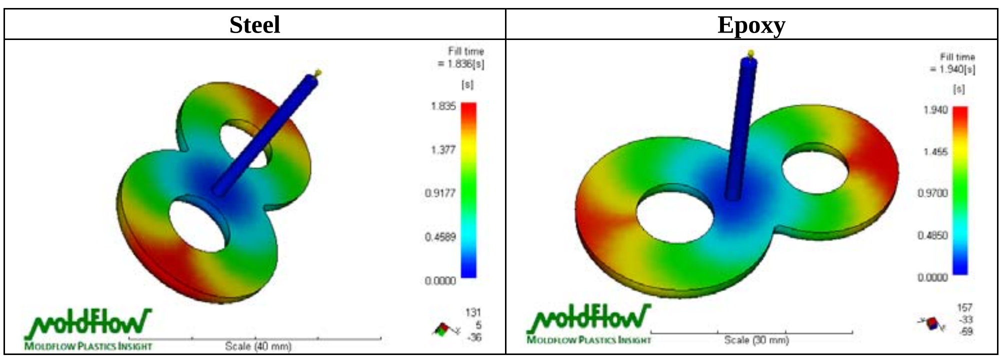


Fig. 3. Injection molding cycle time

After analyzing the molding zone temperature distribution, hot spots and cooling channel efficiency results predicted by Moldflow, a cooling layout was implemented and analyzed (fig. 4).

The results obtained without cooling channels and with cooling layouts show a substantial heat transfer difference between them. The cooling layout contributes to a superior heat removal flux from the thermoplastic material, resulting in a shorter injection molding cycle time.

The cooling time without cooling layout is of 90,42 seconds whereas the cooling layout reduces it down to 53,91 seconds, resulting in a gain of 40% over the conventional time (Fig. 5).The maximum temperature difference in the part reduced from 243.5 to 185.6 ºC (Fig. 6).

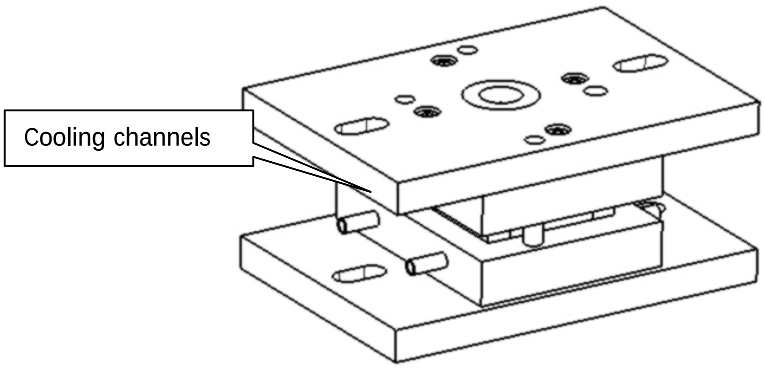
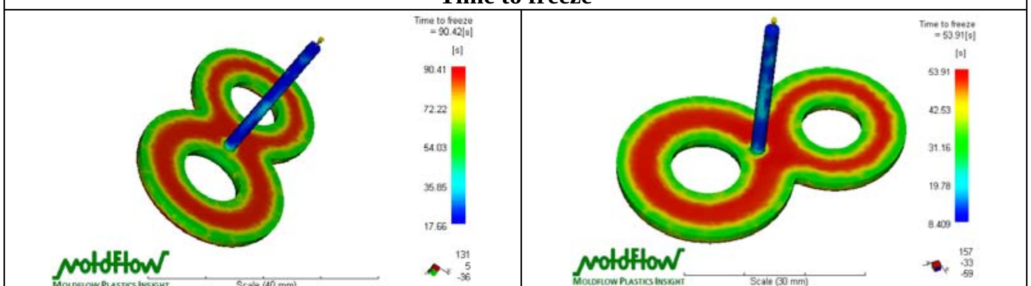


Fig. 4. Placement of cooling channels

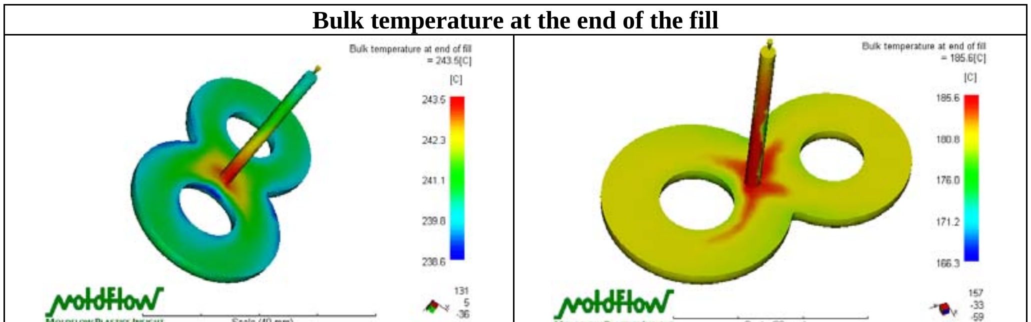
Time to freeze



a) without cooling channels	a) with cooling channels

Fig. 5. Time to freeze

Bulk temperature at the end of the fill



a) without cooling channels	a) with cooling channels

Fig. 6. Bulk temperature at the end of the fill

The data obtained by thermocouple in the two cases, for the conventional and for the conformal cooling layout (fig. 7), enhance the differences between the temperatures in the polymer/mold interface, and suggest the likely gains in the injection molding cycle time. In spite of the temperature in the injection and holding phases rising higher with the conformal cooling layout, the subsequent fastest heat transfer process results in an inferior cycle time.

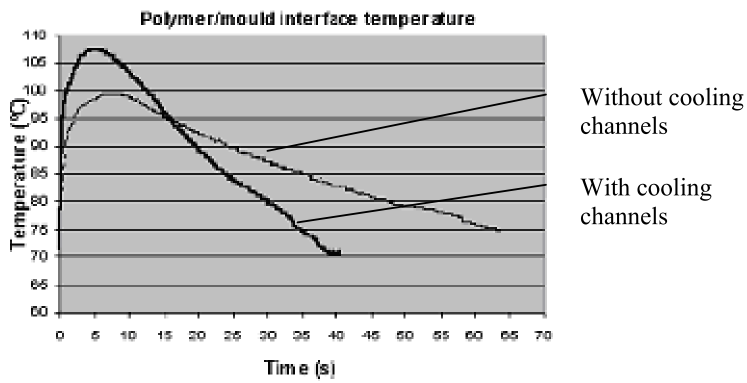
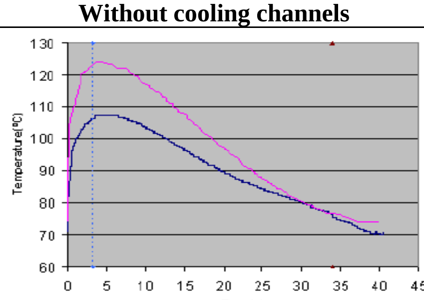
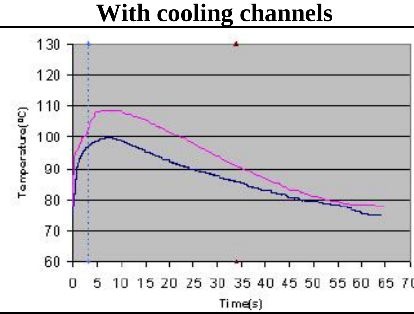


Fig. 7. Polymer/mould temperature evolution

Comparing the predicted Moldflow polymer/mold interface temperature with the experimental data some differences are identified (Fig. 8).

Without cooling channels	With cooling channels
	

LEGEND:

Termocouple

Moldflow

End of holding phase

…. Mould opening

Fig. 8. Temperature readings – thermocouple/Moldflow

Following the temperature evolution in the injection molding cycle, the major differences exist at the beginning of the injection cycle, during the injection and the holding phases.

Analyzing the maximum interface temperature, a difference can be detected between those two moulds (without cooling channels and with cooling layout – Fig. 8).

These differences may occur due to experimental and numerical reasons. Due to the cast resin process, the thermocouple-measuring junction may not have the same contact surface with the epoxy resin insert and with the thermoplastic material as it would be necessary to a correct temperature reading. Faulty heat conduction between the thermocouple measuring junction and the reference junction can be another possible source of error. On the Moldflow side, the analysis made in this study only considered the epoxy inserts, this leading to some erroneous output in the heat transfer simulation.

6. Conclusions

This study on the thermal performance of hybrid injection molds suggests the following conclusions:

The thermal performance of hybrid molds is strongly dependent on the thermal properties of the epoxy material.

The possibility of incorporating cooling channels in the cast resin tooling improves the efficiency of the heat transfer process, contributes to the homogenization temperature field, and raises the heat transfer rates.

-The use of CAE analysis helps to obtain significant improvement in the thermal performance of hybrid injection molds.

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