# Investigation into the Effects of Fins and Internal Cooling in Rotomoulding

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**Abstract**

The paper presents an investigation into how the introduction of internal cooling in rotomoulding influence the overall cooling rates. For the purpose of this investigation a simple cub mould is considered. The coupled fluid flow – heat transfer process, has been modelled by using ANSYS Flotran 2D. The mould motion was simulated, by implementing rotating boundary conditions. For the purpose of industrial design a comparative solution have been obtained, by using two moulds inside of the oven with the same dimensions and material characteristics. The first mould is with internal cooling device, while the second is without. From the results it is clear, that the internal cooling in rotomoulding can provide cooling rate inside of the mould, similar to the one outside or even better. This high cooling rate offers many practical advantages, including shortening the total production cycle by more than 40%. It also stabilise the plastic product and reduce the distortions during the rapid temperature change.

## Introduction

Rotational moulding is a process for producing hollow plastic products. Unlike most other moulding processes, rotational moulding does not utilize pressure to force the melt into shapes and thus provide stress-free products. Compared to injection or blow moulding it is very slow process, but what makes it competitive is the low cost of the equipment. This makes the process ideal for low volume production. The cooling stage is much longer compared with the heating stage for large moulds. Hence, reducing the time for cooling will shorten the whole production process and increase the productivity.

The rotomoulding process cycle begins with placing a pre-measured plastic powder in an empty mould (see Figure 1). The closed mould is then heated in a hot oven of about 250–375 $^0C$ while subjecting to a biaxial motion with a relatively low rotational speed of about 4–20 rpm. The plastic tumbles, melts and sticks inside the rotating mould. The heating cycle ends when all the powder melts completely and sticks onto the mould surface. Then the cooling cycle proceeds until the plastic achieves its demoulding temperature. The rigid part is removed to end the rotational moulding cycle. The prediction of these heating and cooling cycles times is generally done by monitoring the internal air temperature.

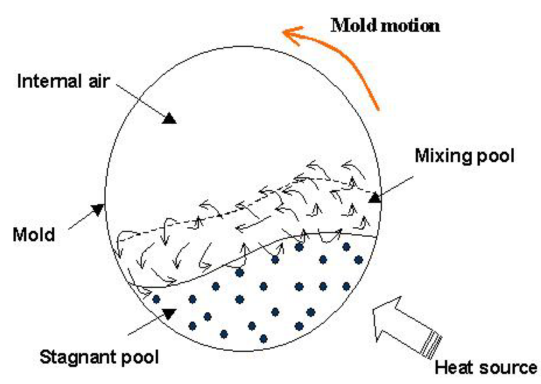


**Figure 1. Rotomoulding – schematic diagram**

Rotormoulding is essentially a complex transient heat transfer process. The whole process can be split into several stages, where the heat is transferred first, from the air in the oven to the metal mould, then through the metal mould, then from the metal mould to the plastic bed, further through a plastic bed and finally into the internal air space. The complexity arises from the interaction between these heat transfer processes, the variations of the conditions from one part of the system to another, and the interaction of the thermal properties of the plastic.

To date, the effects of tumbling due to the rotation of the heated mould on the plastic powder, together with the interaction between process variables and their properties have been examined Gogos et al [4], Nugent et al [5], Crawford et al [6]. Crawford and Scott [7] have studied the formation and removal of gas bubbles in the polymer melt. The effects on wall thickness variation, when different mould shapes are rotated at various plate and arm speeds have been investigated by Crawford et al [8]. Crawford and Sun [9] and Crawford and Xu [10] introduced better heat transfer mechanisms inside the mould for the powder bed during rotational moulding. Olson et al [1] and Gogos et al [2-3] have used a new finite element approach by employing axisymmetric Arbitrary Lagrangian Eulerian (ALE) techniques to model the moving plastic interface. By using this technique, the plastic layer thickness can be predicted as a function of heating time. However, although previous work has identified the heat transfer phenomena to be the dominant factor during the whole moulding process, no optimization, taking into account all of the above requirements has so far been carried out.

There are considerable difficulties in producing rotomoulded products with very large wall thickness (over 40 mm). The cooling stage is much longer compared to the heating stage for large moulds. Hence, reducing the time for cooling will shorten the whole production process and increase productivity. There are several possibilities to intensify the convective heat transfer during rotomoulding: a) design additional surface areas in the mould, b) change the characteristics of the fluid (water sprays, etc.) c) use different fluids with better thermal characteristics, d) apply internal cooling Lim et al [11].

In the present paper the author investigates how internal cooling influence the cooling process in a standard cube mould.

## Convective Heat Transfer

The heating and cooling process in rotomoulding is in fact an exercise of convection heat transfer. The rates of heat transfer from a surface at a temperature *T* to a surrounding medium (air) at $T_\infty$ is given by Newton's law as,

$$\dot{Q} = hA\left(T - T_\infty\right) \qquad (1)$$

where ***A*** is the heat transfer surface area and ***h*** is the convection heat transfer coefficient. When the two temperatures are fixed by the requirements of the manufacturing process, there are two ways to increase the rate of heat transfer: firstly to increase h the convection heat transfer coefficient or secondly to increase the surface area. Traditionally, the increase the active surface area, requires extended surfaces like fins or pin fins. If the process is cooling the temperature of the fin gradually decrease towards the fin tip. Convection from the fin surface causes the temperature at any cross-section to drop from the fin middle towards the surface. Since the fin thickness is usually small, this difference can be neglected. The preliminary analysis has shown that introduction of fins in rotomoulding creates stagnated areas at the mould surface and the effect of the extended areas is to a large extent lost.

The conductivity of the polyethylene, the widely used material in rotomoulding is 687 times lower than the same characteristic for the mould material - aluminum. If we consider the design of a simple cube mould, that it will be used in this analysis, it is obvious that, when cooling is initiated the internal surface of the mould will be covered with plastic with not very good conductivity coefficient. This will mean that all the mould internal air will be effectively isolated from the cooling process. To a very large extend there will be a hot ball of air sitting inside the mould and isolated from the external cooling. In this respect it is natural to consider using internal cooling.

The introduction of internal cooling creates additional problems like how the cooling air to be supplied to a moving mould, what kind of vents to be used, so that they are not blocked during the heating process, etc. All these additional measures would require resources, which need to be proven.

## Finite Element Model and Numerical Analysis

For the simulations aluminum square mould 0.37 x 0.37 m externally has been selected. The coupled fluid flow heat transfer process, has been modeled by using ANSYS FLOTRAN 2D. Mould rotation creates modeling problems and a true modeling will require using a moving mesh. In order to simplify the modelling the author assumes that the moulds are stationary and the flow is rotating. In reality it is the opposite, the cold air is coming from static inlet and the moulds are rotating. In the present model the author simulates the relative motion, which is important. Since the deposition of the melted plastic is directed to a large extend by the gravity, the gravity vector have to be rotated as well. A batch file has been written to control the simulation. It reads the geometry and moves the BC (the inlet and outlet of the air flow) around the periphery of the mould and also rotates the gravity vector. All the steps are placed in two DO cycles since the process (rotation) is repeated action.

The main feature of this problem is that it is computationally very intensive. A transient heat transfer - fluid flow analysis need to be repeated many times for single rotation and again for any further rotation of the mould. For the purpose of rapid industrial design a comparative solution has been obtained by using two moulds inside of the oven with the same dimensions and material characteristics (See Figure 2). The two moulds are with identical sizes, nearly identical meshes, in symmetrical position inside the mould. The first (upper) mould is with enabled internal cooling, while the second mould (lower) is without. The main aim is to compare the rate of the cooling process for the two moulds.

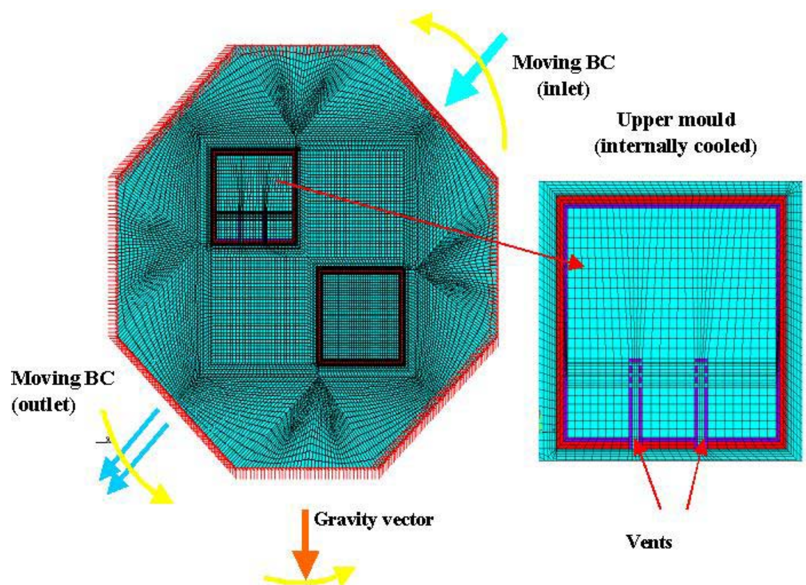


**Figure 2. Moulds and oven finite elements model**

The analysis that has been performed is a transient analysis, aimed at studying how the overall heat transfer is influenced by the introduction of internal cooling. The cooling fluid flow patterns are shown for four different angles of the inlet, $0^0$, $135^0$, $225^0$ and $300^0$ (see Figure 3). The author assumed that these four angles illustrate sufficiently the cooling air flow during the rotomoulding process. In a similar way the streamlines patterns for the same inlet angles are useful indicator for the intensity of the cooling (see Figure 4). It is obvious from the last two figures that the internal flow of the upper mould (internal cooling) is with much higher intensity compared to the lower mould (without internal cooling). Ultimately it is important to see how the temperatures of the moulds are changing in time. To do this four time stages corresponding to four different time intervals have been selected to show the changes of the moulds temperatures (the same angles as in the previous two figures but taken from different rotations in order to have sufficient temperature difference). It is clear, that the internal temperature of the upper mould is falling much faster compared to the lower mould. (See Figure 5).

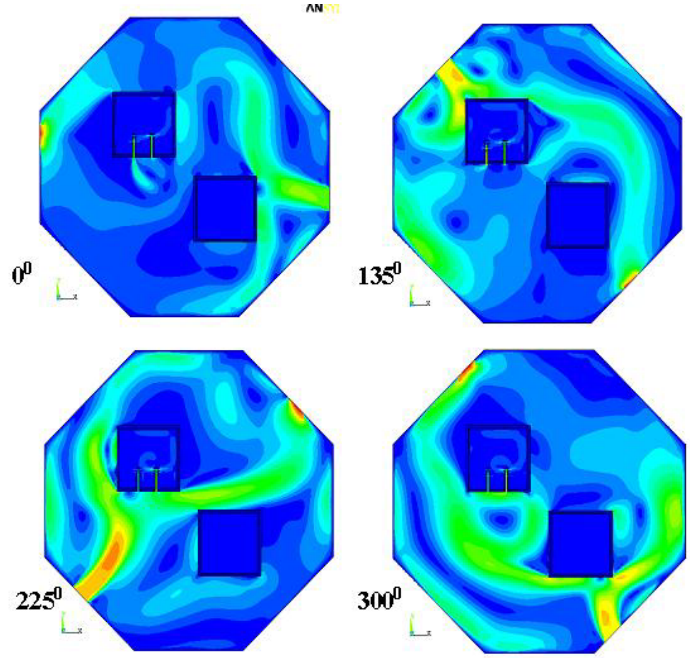


**Figure 3. Fluid flow at four angles of the inlet $0^0$, $135^0$, $225^0$ and $300^0$**

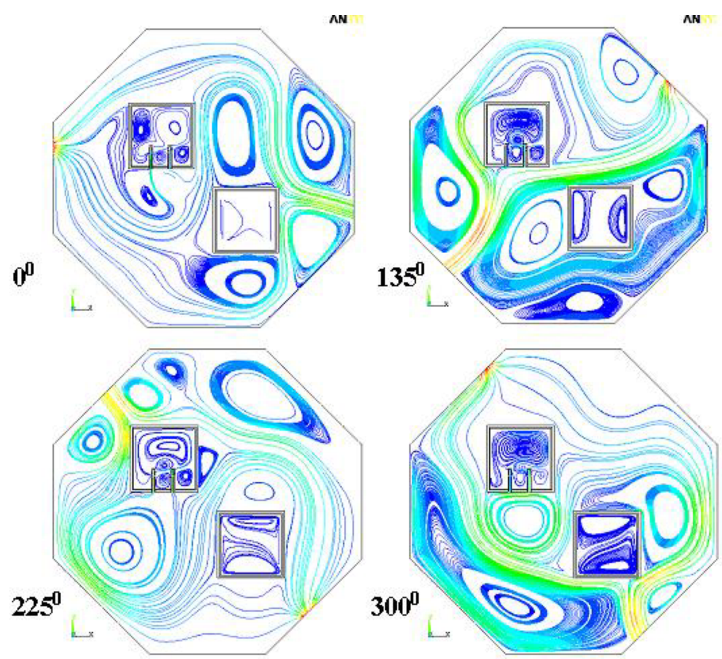


**Figure 4. Streamline plots at four angles of the inlet $0^0$, $135^0$, $225^0$ and $300^0$**

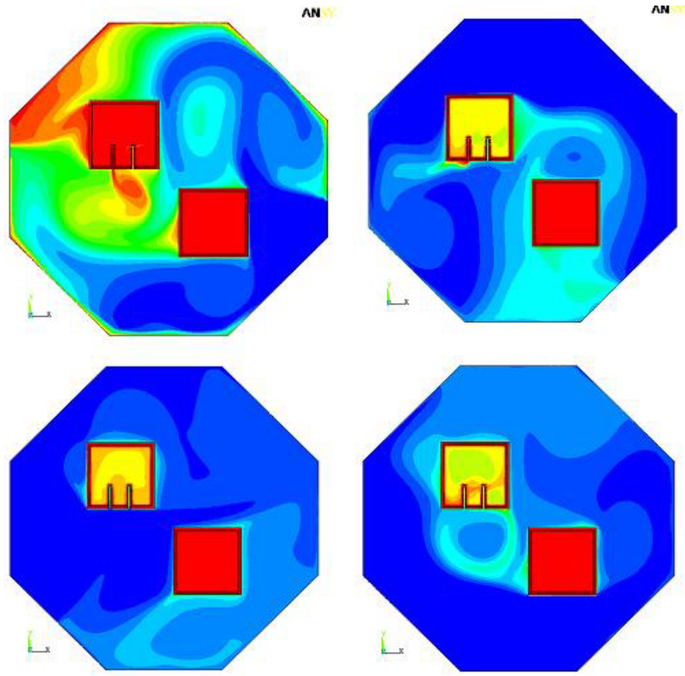

**Figure 5. Temperature distribution at four time intervals**

In order to illustrate the temperature rates of the cooling process, four nodes have been selected, two from each mould - one internal and one external, (See Figure 6). The transient effects are reflected in the best way by a temperature-time plot for the four selected nodes (See Figure 7). It is evident that for the internal node (N18439) and outside node (N4591) of the upper mould (with internal cooling) the temperature is changing with the same rate. For the lower mould (without internal cooling) the outside node (N2532) the internal node (N6827) have different cooling rates. In fact for the internal node (N6827) of the lower mould the temperature is nearly stagnant, which indicate not a significant cooling process. It is clear that with internal cooling the mould internal temperature can follow quite closely (the same rate) the temperature of the mould, which in practice is regarded as the best pattern of cooling.

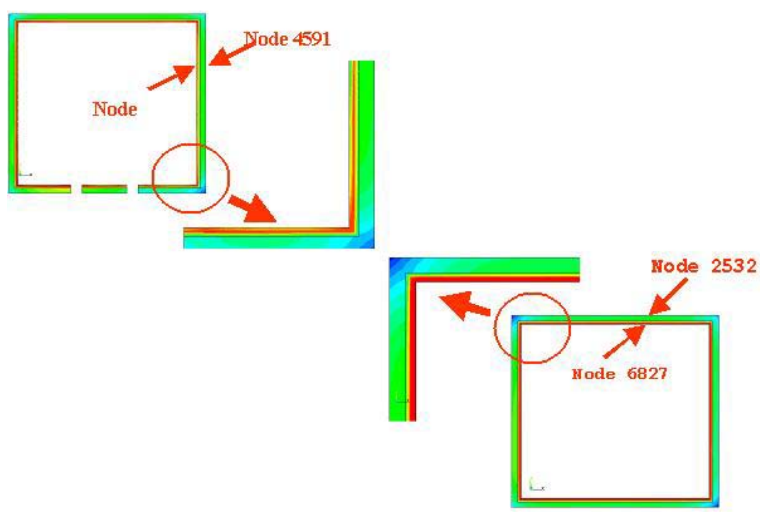


**Figure 6. Selected nodes inside and outside the two moulds for monitoring the temperature rates**

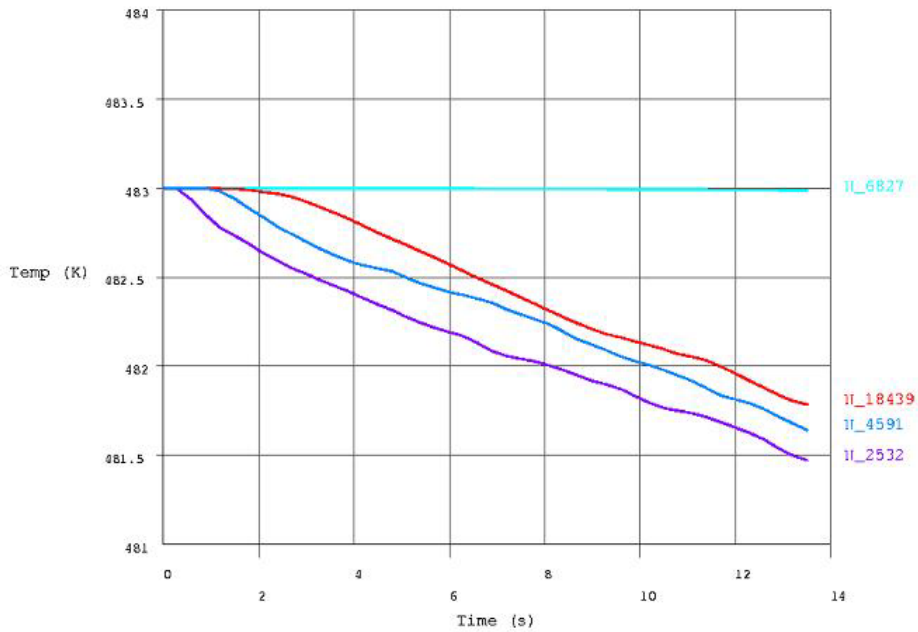


**Figure 7. Temperature/time cooling rates for nodes inside and outside the two moulds**

# Conclusion

The analysis performed in this paper show, that the internal cooling in rotomoulding can provide cooling rate inside of the mould, similar to the one outside or even better. This high cooling rate offers many practical advantages, including shortening the total production cycle by more than 40%. The sharp internal cooling rates also stabilize the plastic product and reduce the distortions due to the rapid temperature change. Also the present investigation is showing that Flotran 2D can successfully be used to simulate a complex convection heat transfer process in rotomoulding.

## *References*


1. OLSON, L.G., CRAWFORD, R.J, KEARNS, M., GEIGER, N. Rotational Moulding of Plastics: Comparison of simulation and experimental results for an axisymmetric mould. *Polymer Engineering and Science*, Vol. 40, No8 (2000) 1758-1764.
2. GOGOS, G. OLSON, L. LIU, X., PASHAM, V.R. New models for rotational moulding of plastics. . *Polymer Engineering and Science*, Vol. 38, No9 (1998) 1387 - 1398.
3. GOGOS, G. OLSON, L. LIU, X. Computational model for rotational moulding of thermoplastics. *SPE ANTEC Paper,* 21, 1997.
4. GOGOS, LIU, X, OLSON, L. G. Cycle time predictions for the rotational moulding process with and without mould/part separation *Polymer Engineering and Science*, Vol. 39, No4 (1999) 617-629.
5. NUGENT, P.J., CRAWFORD, R.J. & XU, L. Computer prediction of cycle times during rotational moulding of plastics. *Advances in Polymer Technology*, 11(3),(1992) 181-191.
6. CRAWFORD, R.J. & SCOTT,J.A. An experimental study of heat transfer during rotational moulding of plastics. Plast. Rubb. Process. Appl. 5(3) (1985) 239-248.
7. CRAWFORD, R.J. & SCOTT,J.A. The formation and removal of gas bubbles in rotational moulded PE. *Plast. Rubb. Process. Appl.* 7(2)(1987) 85-99.
8. CRAWFORD, R.J. & NUGENT,P.J. Computer simulation of the rotational moulding process for plastics. *Plast. Rubb. Process. Appl.* 11(1989) 107-124.
9. CRAWFORD, R.J. & SUN, D.W. Computer simulation of the rotational moulding heat transfer processes. *Plast. Rubb. Process. Appl.* 19(1993) 47-53.

10. CRAWFORD, R.J. & XU, L., Computer simulation of the Rotational Moulding Process. *Plast. Rubb. Process. Appl. 1994.*

11. LIM, K.K., IANAKIEV, A. & HULL J.B., Numerical Modelling For Rotational Moulding With Non-Isothermal Heating, *Journal of Plastic, Rubber and Composites: Macromolecular Engineering*, 2003, 32, 10, pp. 421-430.