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Development and evaluation of a new rapid mold heating and cooling method for rapid heat cycle molding

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ABSTRACT

A new rapid mold heating and cooling method is developed in this study. For rapid mold heating, cartridge heaters are assembled in the holes of the mold. Between the heaters and the corresponding mounting holes, there are annular gaps which are full of water. During mold heating, the heat generated by the heaters passes through the water gaps firstly and then transfers into mold base to raise cavity surface temperature. For rapid mold cooling, pressured cooling water is passed though the annular gaps. Firstly, a cell model was established to evaluate the effectiveness of the new rapid mold heating and cooling method. Thermal response analysis based on numerical simulations was conducted to investigate the influences of the gap size, the power density of the heaters and also the layout of heaters on thermal responses of the cavity surface. Further, the injection mold of a large LCD TV frame was designed and manufactured based on the developed rapid mold heating and cooling method. Both numerical simulations and experiments were performed to evaluate the thermal response efficiency of the cavity surface. The results show that the cavity surface temperature can be changed in a large temperature range within relatively short time. The simulation results are consistent well with the experimental results, which verifies the effectiveness of the established analysis method. Finally, production testing was conducted to produce the LCD TV panel. The results show that the weld marks on the outer surface can be eliminated completely and the outer surface gloss of the part can reach higher than 90 GU with a molding cycle of about 60 s. The consumption of energy and water can be greatly reduced by comparing with other conventional rapid mold heating and cooling methods.

1. Introduction

Mold temperature control is of great significance in injection molding process because it not only directly affects the molding cycle, but also has a great effect on the quality of the molded product. In conventional injection molding (CIM) process, mold temperature is controlled based on the continuous cooling method, in which coolant is passed through the cooling channels in the injection mold during the whole molding cycle. As a consequence, mold temperature will almost keep constant during the whole molding cycle. To shorten molding cycle, mold temperature should be much lower than the frozen temperature of the polymer melt. As a result, hot polymer melt will be frozen once it contacts with the relatively cold mold wall, which leads to a premature solidification of the polymer melt as early as the filling stage and hence a frozen layer at the mold wall. Such premature solidification will bring a series of problems for injection molding, such as weld mark, flow mark, jetting mark, short shot and floating fibers.

To solve these problems, the most effective method is to raise the mold temperature during filling. However, this will in turn prolong the molding cycle and hence decrease productivity. In order to solve the contradiction between the product quality and molding cycle, the ideal mold temperature control strategy should be keeping a higher mold temperature during melt filling stage while a lower mold temperature during cooling stage. The higher mold temperature during filling is used to enhance product quality while the lower mold temperature during cooling is used to shorten molding cycle. To achieve such mold temperature control object,

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rapid mold heating and cooling techniques are necessary. Injection molding process based on rapid mold heating and cooling techniques are the so-called rapid heat cycle molding (RHCM) process. For rapid mold cooling, the conventional mold cooling method by passing coolant through the cooling channels is feasible. However, the coolant temperature should be much lower than that in CIM. For rapid mold heating, a lot of heating techniques have been introduced and tried in recent years and some of them have been successfully utilized in industrial production of RHCM.

The existing mold heating techniques can be divided into two categories including exterior heating and inner heating methods. For exterior heating, the heat source or heating device locates outside mold base. The typical exterior mold heating methods include flame heating [1], induction heating [2–4], infrared heating [5], and also surface resistance heating based on multi-layer mold structure [6,7]. In exterior mold heating, most of the generated heat by the heat source mainly focuses on the surface of the mold cavity. As a consequence, the temperature of cavity surface can be raised very rapidly due to a small metal volume that has to be heated and hence small heat capacity [8]. The main drawbacks of these exterior mold heating methods are that the relatively poor design flexibility of the external heating source or device leading to uneven temperature distribution of the cavity surface, low coating layer strength for multi-layer mold and also safety issues for flame heating method. Besides these methods, there is another special external mold heating method in which a thin layer of material with low thermal conductivity is coated or sticked on the mold surface for rapid mold heating [9,10]. The uniqueness of this heating method is that it does not need any external heating source or device. The cavity surface is heated by the injected hot polymer melt during filling. However, it is difficult for the cavity surface to be heated to a very high temperature for such inactive heating method.

For inner mold heating, the heat source locates inside the mold base. Convective heating based on hot medium and electric heating based on cartridge heaters are two typical inner mold heating methods used in injection molding. Since the whole mold base should be heated to raise the cavity surface temperature, they are thought to be with low heating efficiency and high energy-consuming in traditional view. However, many recent researches have shown that the inner mold heating methods can also achieve high heating efficiency via innovative and/or optimal design of the heating and cooling system [11–13]. At present, the inner mold heating methods, especially steam heating method and electric heating method, have been widely used in industrial production of RHCM [14–15]. The related plastic parts involve consumer electronics products including cell phone, computer and television, automotive products and also some transparent optical products.

Despite the successful application of inner mold heating methods in industrial production, there are still some problems to be solved. For RHCM based on steam heating, a high-temperature and high-pressure steam generator or boiler, and also the corresponding delivery lines are necessary to supply the steam used for mold heating. The utilization and maintenance of the high pressure boiler is relatively complex, high cost and also has some security risks. Additionally, the recycling of the steam running out of the mold is very difficult and usually it is directly discharged into the return pipe connecting to the cooling tower, which results in a large waste of energy. From the perspective of mold heating effect, the temperature distribution of the cavity surface along the direction of the axis of the heating channels in the mold is not very even since the pressure and temperature of the steam reduces gradually from the inlets of the channels to the outlets of the channels. In addition, the temperature of the steam supplied by the boiler is generally smaller than 200 °C, which in turn determines the mold cavity surface cannot be heated to a very high level [16]. For RHCM based on conventional electric heating, the mold structure with a floating cavity plate and separate cooling plates is usually necessary to achieve a high heating and cooling efficiency [17]. However, such mold structure is very complex, which leads to a high mold cost and a reduction of mold strength. To obtain a high heating speed of the cavity surface, the electric heating elements are tightly mounted in the holes or grooves in the cavity block. As a consequence, it is very difficult or even impossible for the electric heating elements to be pulled out from the holes after installation, which brings great difficult of the replacement of the electric heating elements if they are damaged. In addition, overheating is also a potential risk since it is difficult for the electric heating elements to contact uniformly with the hole walls, especially for long heating elements.

In response to these problems of inner mold heating methods, a new rapid mold heating and cooling method based on electric heating and water cooling was developed. The factors affecting heating efficiency were analyzed. Based on the developed mold heating and cooling method, an injection mold of a LCD TV panel was designed and manufactured. Both numerical simulations and experiments were conducted to evaluate heating and cooling efficiency of the cavity surface. Finally, production testing with the developed mold was also performed to verify the effectiveness of the new inner mold heating and cooling method.

2. Rapid mold heating and cooling method

The developed rapid mold heating and cooling method is based on electric heating and water cooling. Compared with conventional electric heating mold, the most significant difference for the newly developed one is that there is an annular gap between the electric heating element and the corresponding hole. The presence of the annular gaps can greatly simplify the installation and removal of the electric heaters. In addition, the annular gap can also be used as the coolant channel to cool the mold. Fig. 1 shows the heating and cooling system of the developed electric heating mold. Therefore, external separate cooling channels for conventional electric heating mold can be eliminated.

In mold heating, the annular gaps between the electric heaters and the walls of the corresponding mounting holes should be firstly filled with water, as shown in Fig. 2. By doing this, the heat transfer performance of the annular gaps can be improved significantly. Besides, the water surrounding the heaters can effectively avoid overheating of the heaters, thus improving the service life of the heaters. Afterwards, the electric heaters are powered on to heat the mold. Owing to the presence of the water in the annular gaps, the heat generated by the heaters can transfer quickly across the annular gaps to the cavity block, thus elevating the temperature of the mold surface rapidly. Since nearly all the heat generated by the heaters has been finally used to raise the mold temperature, the energy efficiency of the electric heating method is much higher than the steam heating method. In mold cooling, the control valves are turned on to pass the low-temperature water through the annular cooling channels to cool the mold. Since the area of the annular cooling channel is much smaller than that of the conventional cylinder cooling channel, cooling water in the annular channels can reach a turbulent state with a much smaller flow rate of cooling water. Therefore, the consumption of the cooling water can be reduced. Of course, because the hydraulic loss will be increased for the annular cooling channel, a high-pressure pump is absolutely necessary for the new method. Additionally, compared with the conventional electric heating mold, the cooling channels in the new one are much closer to the mold surface, which is also very helpful to improve the cooling efficiency. Besides the above advantages, since the new electric heating mold does not need any external holes to act as cooling channels, it is useful to