

Chapter 9

Heat Transfer Control Applicable to the Injection-Molding of Polymer

1. Heat Transfer between the Polymer Melt and the Mold Wall

As mentioned previously, the key phenomenon dominating high productivity of the injection-molding of polymers is rapid cooling of polymer due to unsteady heat conduction between the polymer and mold made of metals. Heat transfer rate per unit area, i.e. heat flux, at the interface between the polymer and the mold is analytically estimated by using the temperature distributions within the polymer described in Chapter 5 as follows:

$$q(t) = k_p \left. \frac{\partial T_p(z, t)}{\partial z} \right|_{z=0} = k_p \left. \frac{\partial}{\partial z} \left(T_{p0} - (T_{p0} - T_i) \operatorname{erfc} \left(\frac{z}{2\sqrt{\alpha_p t}} \right) \right) \right|_{z=0}$$

$$= \frac{\sqrt{\rho_p c_p k_p} \sqrt{\rho_m c_m k_m}}{\sqrt{\rho_p c_p k_p} + \sqrt{\rho_m c_m k_m}} \frac{1}{\sqrt{\pi t}} (T_{p0} - T_{m0}) \quad (9.1)$$

The heat flux is infinite at $t = 0$ and is quite large during a certain period after the polymer meets the mold surface as shown in Figure 9.1. In general injection-molding process, the period is almost equal to the time required for the filling stage, and thus the forming and cooling of polymer melt are achieved at the same time. Moreover, as a result of the rapid cooling, the temperature at the polymer-mold interface instantaneously becomes almost equal to the initial temperature of mold, which is usually set at temperature enough lower than the solidification temperature of polymer melt, as mentioned in Chapter 5. These are the reasons why the injection-molding of polymers shows high productivity. In other words, the high productivity is inherent in injection-molding process of polymers, in which the unsteady heat conduction between the polymer melt and metal mold takes place.

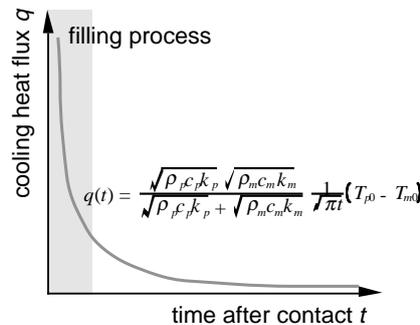


Figure 9.1 Heat transfer between the polymer and mold wall due to unsteady heat conduction.

In order to avoid the molding defects, however, rate of the heat transfer sometimes has to be reduced as mentioned in the previous chapter. This heat transfer control is quite difficult in reality because the high heat transfer rate results inevitably from the thermal characteristics of polymer and metal materials, and because the reduction of cooling directly lowers the productivity of injection-molding process. In this chapter, methods of heat transfer control applied in the practical injection-molding process are reviewed, and a novel technique for heat transfer control and its effects are discussed.

2. Methods of Heat Transfer Control Applied in the Practical Injection-Molding

As suggested from Eq. (9.1), there are only two parameters changeable for controlling the unsteady heat conduction between the polymer melt and the mold wall, if molding material (or its

density ρ_p , specific heat c_p and thermal conductivity k_p) and its initial temperature T_{p0} are prescribed by the specifications of products. Namely, initial temperature T_{m0} of the mold surface and thermal properties $\rho_m c_m k_m$ of the mold material. In the practical injection-molding process, therefore, mold temperature and/or mold material are changed to improve the quality of products. By using the material having lower $\rho_m c_m k_m$ or by setting the mold temperature higher, rate of heat transfer between the polymer melt and mold wall becomes lower, and it results in improvement of the quality of products. But the practical molding is not so simple. These measures reduce the cooling rate of polymer in the cooling stage as well, and thus the productivity is lowered by the measures. Therefore these simple measures are not often utilized in the practical injection-molding process.

In order to reduce the effect on productivity, following measures for reducing the heat transfer only in the filling stage are contrived.

2.1 Active control by changing the mold temperature

In order to reduce the heat transfer between the polymer melt and mold wall only during the filling stage, and in order not to restrict the heat transfer during the cooling stage, it is required to change the mold wall temperature actively. The measures for controlling the mold temperature actively can be classified into the following two groups.

2.1.1 Active control of the mold temperature by using heating/cooling media. In general, the mold used in the injection-molding of polymers has channels for cooling medium so as to remove thermal energy transferred from high temperature polymer melt, which is periodically injected into the mold cavity. By passing heating- and cooling-media through the channel alternately, the mold can be set at different temperatures at between during the filling- and cooling-stages. The concept of this method¹⁾ is shown in Figure 9.2. In the practical temperature control, steam, hot water or heated oil is often used as the heating medium, and cold water cooled by using a chiller is used as the cooling medium.

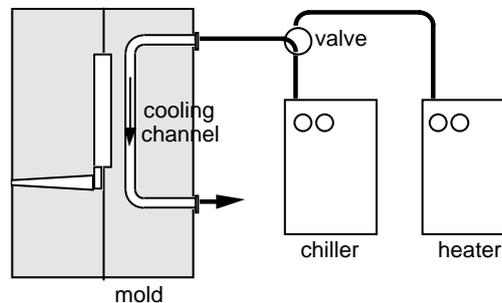


Figure 9.2 Active heat transfer control by using heating/cooling media.

The merit of this method is that the usual mold used in the normal molding can be used without any additional devices as it is. However this method has demerits related to the heating/cooling rate of the mold at the same time. Namely, in order to shorten the time required for heating or cooling the mold, one must use the heating/cooling media having large temperature difference. Otherwise the time required for heating/cooling of the mold becomes quite long, and the productivity is remarkably lowered by the temperature control. This is because heat capacity of the mold, which is usually made of metals, is quite larger than the polymer molded in the mold.

2.1.2 Active control of the mold temperature by using an electric heater. For a short period such as the time required for filling the mold cavity with the polymer melt, penetration depth of temperature change due to the unsteady heat conduction between two bodies is limited. Therefore, heat transfer between the polymer melt and the mold wall can be controlled by changing the initial temperature of the mold only in its surface region. If the heating region is limited, the time required for changing the temperature can be shorten dramatically. From the concept, the method²⁾ shown schematically in Figure 9.3(a) has been devised for controlling the heat transfer during the filling

stage. By using an electric heater installed on the surface of mold cavity, cavity surface is heated at high heating rate for a short period before the filling stage starts. After the melt filling, the heated region spreads through the mold wall, which is continuously cooled by the cooling medium flowing through the coolant channel, and thus the polymer filled in the mold cavity is cooled quickly during the cooling stage.

Indeed this method is quite smart for controlling the heat transfer between the polymer and mold wall with a minimum effect on the productivity, but the existence of the electric heater may be a restriction for practical moldings. In general, it is difficult to engrave minute structure on the electric heater installed on the surface of the mold cavity. This means that this method is hardly applied for injection-molding of the products having complicated surface structures. Durability of the electric heater may also be a difficulty for the practical injection-molding.

In order to minimize the effect on the productivity due to this method, it is important to reduce the depth of the heated region. Namely, it is desirable to heat the cavity surface at high heating rate for short period as possible. So, induction heating³⁾ (Figure 9.3(b)) or radiation heating is sometimes adopted for heating the cavity surface instead of the electric heater.

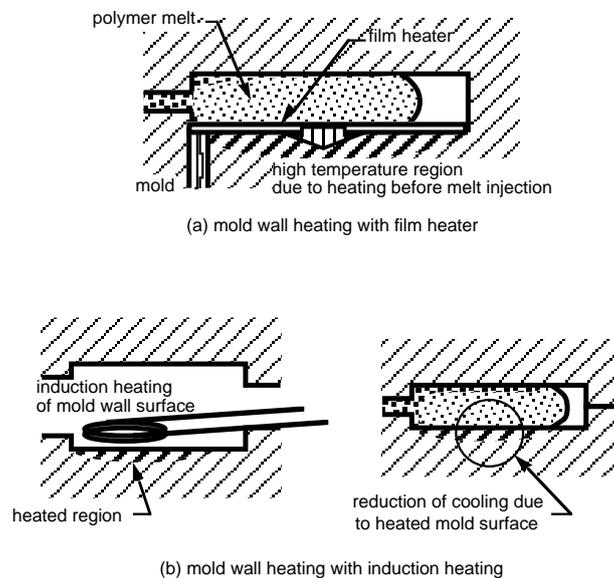


Figure 9.3 Active heat transfer control by heating the cavity surface transiently.

2.2 Passive control by changing the mold material

The methods described above are effective to control the mold temperature actively, but these are a little bit too much complicated to apply for the practical molding process. On the contrary, heat transfer control by changing the material of mold, i.e. passive heat transfer control, is quite simple to use, because neither additional energy source nor additional equipment are required in this method. However, if the whole mold is made of the insulative material having low $\rho_m c_m k_m$ value, heat transfer between the polymer and the mold is reduced in the cooling stage as well, and the productivity is remarkably lowered as the matter of course. In the passive heat transfer control⁴⁾ used in the practical molding, therefore, the insulative material is installed only on the surface region of the mold cavity as a thin film as shown in Figure 9.4, so as to reduce the cooling rate only in a short period after the melt comes into contact with the mold surface. The period in which the cooling rate can be reduced by this method strongly depends on the thickness of the insulative material; the period corresponds to the time when the penetration depth of temperature change due to unsteady heat conduction reaches to the bottom surface of the insulative material. This means that, in order to bring fully the merit of this passive heat transfer control method into play, one should select an appropriate thickness of the insulative material in advance.

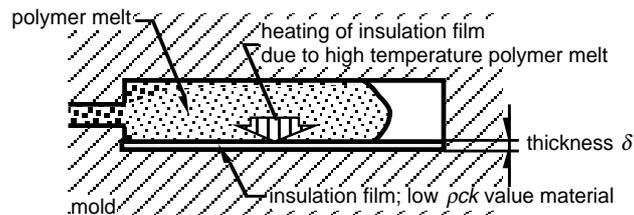


Figure 9.4 Passive heat transfer control by using a film of insulative materials.

3. A Novel Technique for Controlling the Cooling Rate of Polymer in the Mold Cavity

The heat transfer methods described above have already been applied in the practical injection-molding processes in some cases, and have shown actual results to some extent. Nevertheless these methods are not widely spread in the production of injection-moldings, because deterioration of the productivity due to heat transfer control is still not negligible.

Generally speaking, heat transfer control by changing the temperature of materials is time consuming process because heat capacity of the material is not negligible. In electric circuits, electric current can be switched at high frequency because path of the electric current is easily restricted so as to eliminate the effect of electric capacity by using insulative materials. By contrast, path of heat flow is hardly limited because the ratio of thermal conductivity of the insulative- and conductive-materials is not so large (note that the ratio of thermal conductivity is 10^4 at the most, while the ratio of electric conductivity reaches 10^{10} or more). From the sense, it is disadvantageous to control the heat transfer by changing the temperature of mold, heat capacity of which is quite larger than that of the polymer molded in it.

In order to overcome the disadvantage, one should remember the essential objective of the heat transfer control; that is to keep the temperature of polymer in the surface region of the product high during the filling stage so as to avoid generation of mold defects originated from the solidification of polymer during the filling stage. The simplest measure faithful to the essential objective above is to keep the polymer temperature by putting thermal energy directly into the surface region of polymer as shown in Figure 9.5(a). If the putting rate of thermal energy is identical to the heat transfer rate due to unsteady heat conduction between the polymer and mold, temperature of polymer is kept constant. Because the polymer is continuously in contact with the cold mold surface, the polymer is quickly cooled due to the unsteady heat transfer immediately after the energy supply is stopped as shown in Figure 9.5(b).

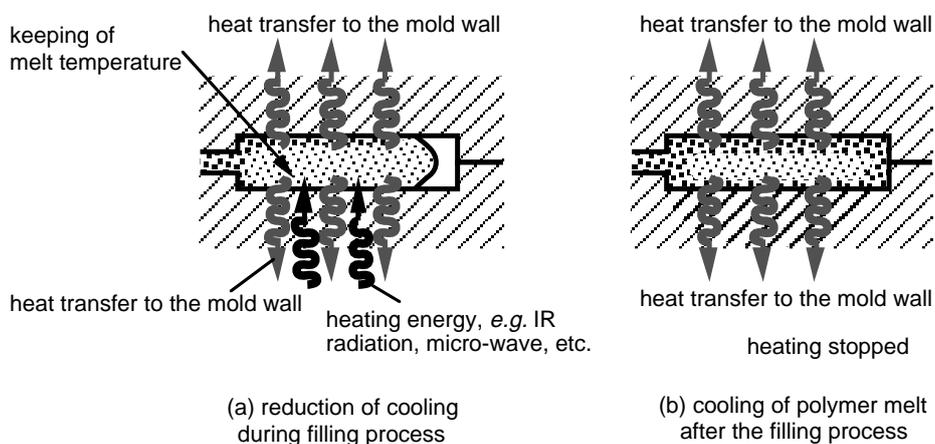


Figure 9.5 The concept of temperature control by putting energy directly into the polymer.

In my lab, feasibility of this concept has been studied⁵⁾ by using a CO₂ gas laser as the energy source. Figure 9.6 shows the experimental setup used in this study. As shown in this figure, a window made of ZnSe was installed on a part of the mold wall so as to introduce the infrared laser to the polymer in the mold cavity. Typical effects of the laser irradiation, i.e. heat transfer control, are shown in Figures 9.7 through 9.9. Defects such as the poor transcription (Figure 9.7), short-shot (Figure 9.8) and residual birefringence (Figure 9.9) are effectively eliminated by the heat transfer control. At the same time, since the amount of energy poured into the polymer is small (irradiation time is only 1 - 2 seconds), it was confirmed that the productivity is hardly affected by the laser irradiation.

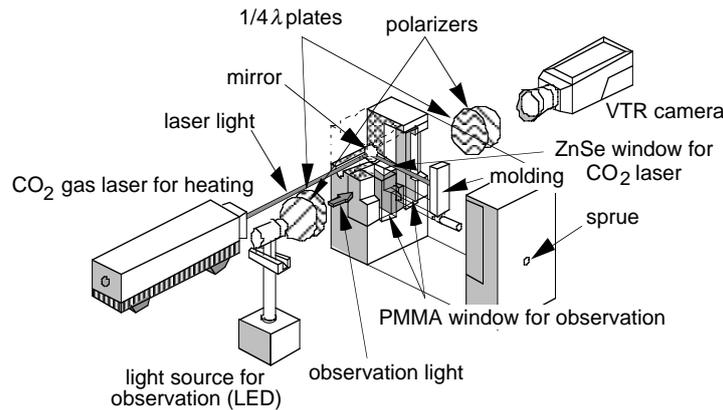


Figure 9.6 Experimental setup used in the feasibility study of heat transfer control by using laser irradiation.

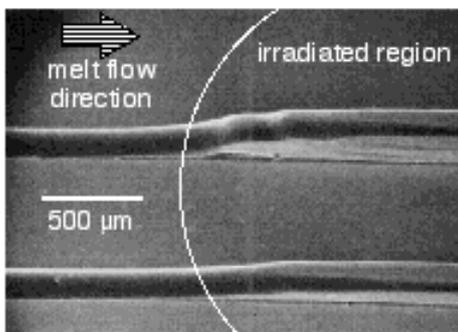
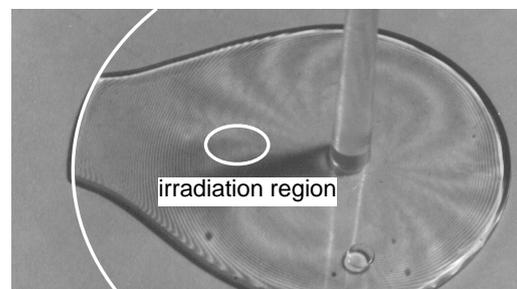


Figure 9.7 Improving the transcription.



shape of mold cavity
Figure 9.8 Improving the short-shot.

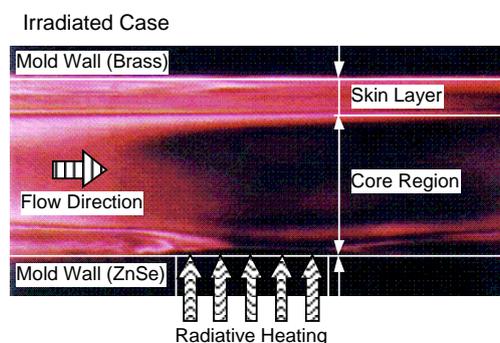


Figure 9.9 Eliminating the residual birefringence.

From the practical point of view, however, the window installed on the mold wall restricts the applicability of this method. Materials of the window transparent for the infrared light, such as ZnSe, are generally brittle. Thus it is quite difficult to engrave a minute structure on its surface, and

durability for a mold wall is inferior to metals. In order to avoid this problem, one should use the energy source transmittable through the metal mold wall, such as ultrasonic energy, instead of infrared light. No matter what kind energy is used, relation between the penetration depth of the energy, i.e. absorption coefficient for the energy, and the thickness of cooled layer developing during the filling stage, i.e. thermal diffusivity of the polymer material, should be adjusted appropriately in order to optimize the effect of heat transfer control based on this concept.

Problem

Suppose a polymer material, a mold material, and injection-molding conditions such as polymer initial temperature, mold initial temperature, time required for melt filling. By using Eq. (9.1), estimate average heat flux transferred from the polymer to the mold wall for the filling stage, and discuss the magnitude by comparing it to those of heat transfer in daily life.

References

- [1] For example, Senda, T. and Tahara, H.: Seikei-Kakou Symposia '95 (Proc. JSPP Autumn Meeting '95) (1995) pp. 193-196.
- [2] For example, Nakamura et. al.: Seikei-Kakou Symposia '94 (Proc. JSPP Autumn Meeting '94) (1994) pp. 42-46.
- [3] For example, Asahi Kasei Chemicals Co., <http://www.akchem.com/emt/EG00511.html>.
- [4] For example, Ishimi et. al.: Seikei-Kakou Symposia '94 (Proc. JSPP Autumn Meeting '94) (1994) pp. 52-55.
- [5] Kurosaki, Y., Satoh, I. and Saito, T.: Trans. JSME, 62-599C (1996) pp. 2864-2871.

Chapter 10

Novel Functions Produced by Heat Transfer Control

1. Characteristics of Heat Transfer Control by using Laser Irradiation

In the heat transfer control described in the previous chapter, laser was used for delivering energy directly and remotely to the polymer in a mold cavity. This is enabled by a characteristic of the laser; the monochromaticity of laser. Generally speaking, absorption of light depends upon the wavelength of the light, and the absorption spectra of materials differ from one another. Therefore one can select a combination of materials so that one material absorbs a monochromatic light and the other does not. If the light hits the combination of these materials, only the material that absorbs the light is heated. In the heat transfer control described in the previous chapter, the polymer was the absorbing material, and the window made of ZnSe was the inabsorbing material. Such a "selective" heating is one of the strong points of the laser heating, and thus the heating of polymer within the mold cavity can be achieved with little influence on the productivity. The selective heating based on the monochromaticity of laser is applied not only for the heat transfer control in injection-molding process, but also for overlap welding of polymer sheets¹⁾ and for improving the morphology of polymer blends²⁾.

Characteristics of laser other than the monochromaticity are also applicable for heat transfer control due to laser irradiation. For example, coherency is another property of laser. By making use of this property, one can easily control the distribution of laser intensity as a pattern. Figure 10.1 shows the simplest optical setup for making the laser pattern. In this setup, the laser is separated into two beams having identical intensity first, and then they intersect with each other at a shallow angle. At the intersection, a striped pattern of laser light takes place due to interference between these two laser beams. When an absorbing material is placed at the intersection, the surface of this material is heated as the pattern. If properties of the material change due to the heating, therefore, the irradiation may result in "recording" of the pattern. Minuteness of the pattern depends upon the wavelength of laser; if the CO₂ gas laser wavelength of which is 10.6 μm is used as the light source, the minimum spacing of the striped pattern is about several 10 μm. This phenomenon would be a potential method for producing novel functions onto the polymer products, but there has been very limited number of studies reported concerning the heat transfer control by using interfered laser irradiation so far.

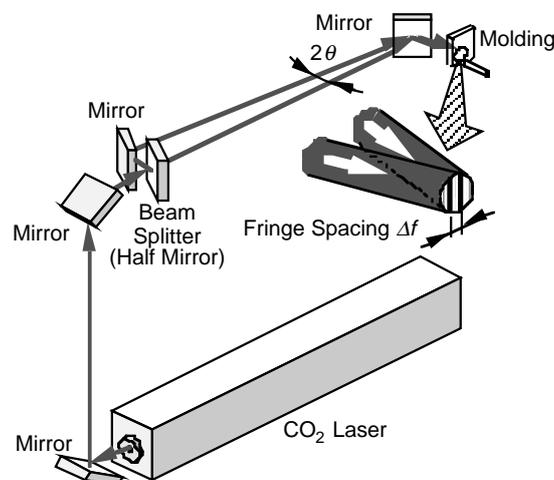


Figure 10.1 Optical setup for obtaining interfered laser.

In my lab, the method was applied for recording a birefringence pattern on the injection-molded polymer, and the effects were experimentally examined³⁾. The effects and an

example of novel function produced by the method are discussed in the next section.

2. Novel function produced by the interfered laser irradiation

As mentioned previously, injection-molded polymer products inherently have skin layers on their surface, in which birefringence due to molecular orientation is highly frozen. This skin layer is originated by the cooling of polymer melt simultaneously occurred with the polymer flow due to the filling stage of the injection-molding process. The residual birefringence can be eliminated by avoiding the rapid cooling during the filling stage by some measures. If the polymer surface is irradiated by the interfered laser during the filling stage, therefore, one can deduce that the birefringence in the "bright" region in the interfered laser is eliminated while that in "dark" region remains. Namely a birefringence pattern can be recorded on the injection-molded polymer product by using the interfered laser irradiation.

Figure 10.2 is a polarized microscope image showing the birefringence pattern recorded in the surface region of an injection-molded polymer strip. As shown in this figure, a stripe pattern of birefringence corresponding to the interfered laser irradiated on the polymer surface. The distribution of retardation, the product of birefringence and the thickness of material in which the birefringence takes place, in the transverse direction is shown in Figure 10.3. Dips in the retardation profile in this figure, which correspond to the bright region of the interfered laser, are not zero because the polymer melt was being contact with the cold window during the polymer is irradiated with the laser. The reason is described later in detail. On the other hand, the retardation at the peaks, which correspond to the dark region of the interfered laser, is a little bit smaller than that in the case without laser irradiation. This is because of thermal diffusion within the polymer; the polymer in inirradiated region is heated by the thermal diffusion from the neighboring irradiated regions.

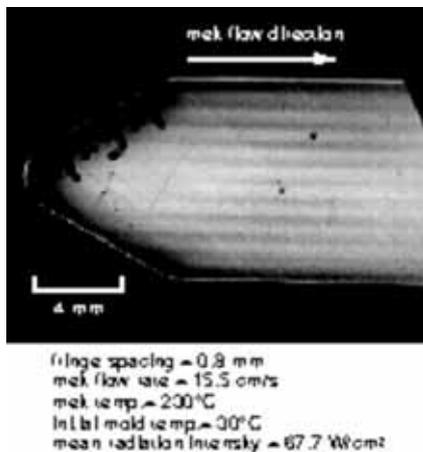


Figure 10.2 Birefringence pattern recorded on the surface region of an injection-molded polymer.

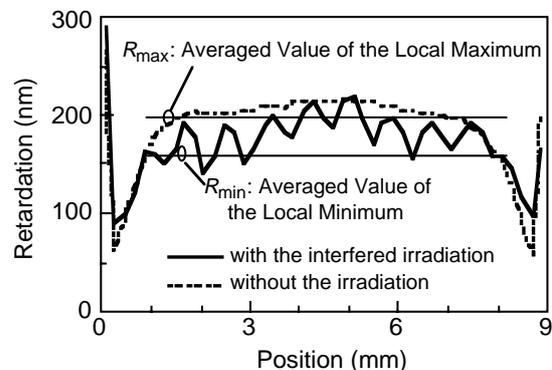


Figure 10.3 Typical retardation distribution in the surface region of an injection-molded polymer.

Success of the "recording" of birefringence depends upon the contrast of the retardation recorded on the surface of products. Average retardations at the peaks and dips are measured under various molding conditions, and the contrast, i.e. difference in retardations at peaks and dips, are calculated from the results. Typical results are shown in Figures 10.4 through 10.8. As shown in Figures 10.4 and 10.5, the contrast of birefringence recorded onto the polymer surface becomes more distinct as the initial temperatures of polymer and mold is lower. This is because, under these conditions, birefringence remaining in the skin layer becomes evident originally. The contrast also depends on the irradiating laser power and pattern spacing; the contrast increases monotonously with increasing the laser power, and decreases with decreasing the pattern spacing as shown in Figures 10.6 and 10.7. On the contrary, the effect of melt velocity is a little bit complicated as

shown in Figure 10.8. The contrast increases with increasing the melt velocity at first, but then decreases as the melt velocity exceeds a certain value. This is explained by the facts that thermal diffusion within the polymer between the irradiated and inirradiated regions is weaker, and thus temperature difference between these two regions becomes larger, as the melt velocity becomes faster, while that faster injection velocity results in thinner skin layer, and thus the layer in which molecular orientation takes place tends to be out of the heating region due to laser irradiation. Figure 10.9 is a typical numerical result of the temperature distribution within the polymer irradiated with an interfered radiation. As shown in this figure, the hottest region exists not on the polymer surface, but in a region somewhat inner from the surface. This is because the polymer surface is cooled due to heat conduction to the cold (unheated) window, while the heating due to absorption of radiation is strongest at the polymer surface and decreases as the light penetrates. Under a simplified conditions that both the polymer and the window are semi-infinite bodies and that the temperature of window does not affected by irradiation, one can theoretically estimate the position x_{peak} at which the temperature takes the maximum value as follows:

$$x_{peak} \approx 2\alpha\beta t \left(1 - 1 + \frac{1}{2} \frac{\ln(\beta\sqrt{\pi\alpha t})}{\alpha\beta^2 t} \right) = \frac{\ln(\beta\sqrt{\pi\alpha t})}{\beta} \quad (10.1)$$

where α the thermal diffusivity and β the absorption coefficient of polymer. When the polymer is polystyrene ($\alpha = 1 \times 10^{-7} \text{ m}^2/\text{s}$) and the laser is CO_2 gas laser (at the wavelength, absorption coefficient of polystyrene $\beta = 1 \times 10^4 \text{ m}^{-1}$), the position x_{peak} at which the temperature takes the maximum value can be estimated as about $200 \mu\text{m}$. If the thickness of skin layer, i.e. the thickness of the frozen layer developed during the filling stage, is much thinner than the position x_{peak} , the laser irradiation has no effect on the elimination of residual birefringence. The retardation at the dips shown in Figure 10.3 not to be zero is due to the same reason.

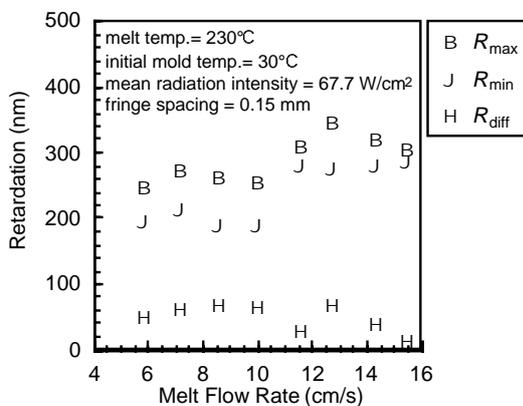


Figure 10.4 Effect of melt velocity.

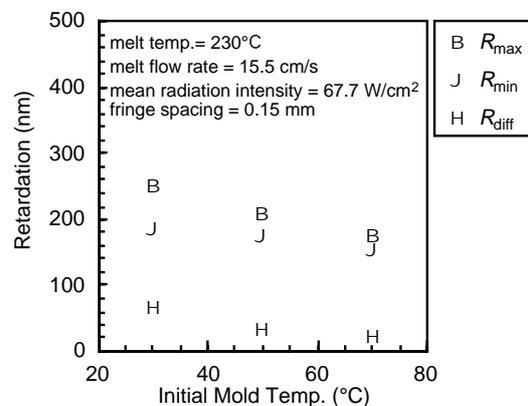


Figure 10.5 Effect of melt temperature.

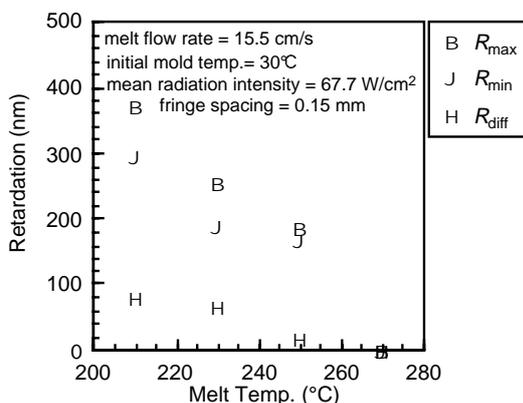


Figure 10.6 Effect of mold temperature.

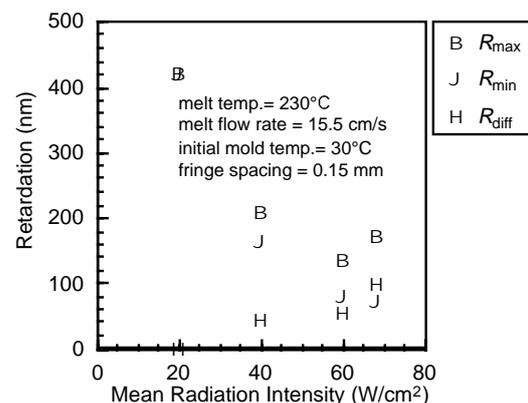


Figure 10.7 Effect of laser intensity.

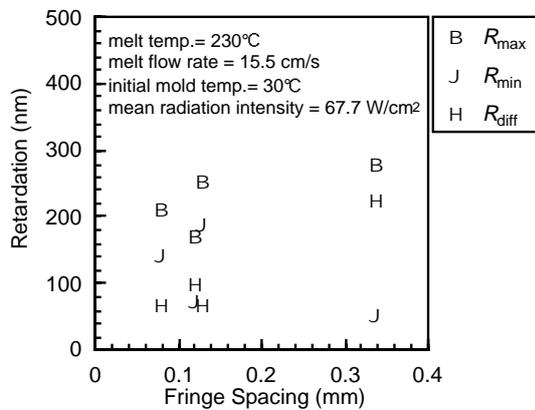


Figure 10.8 Effect of fringe spacing.

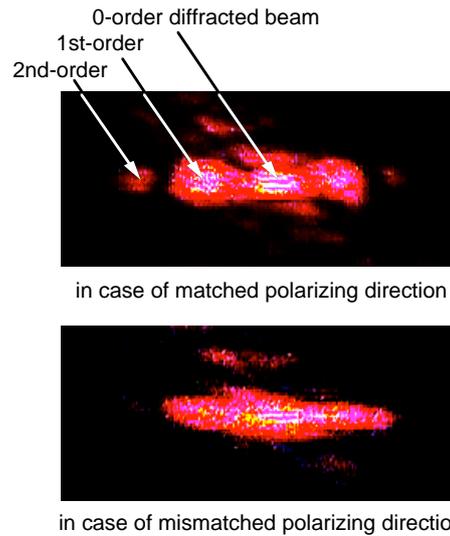


Figure 10.10 Function of the birefringence pattern as a diffractive grating.

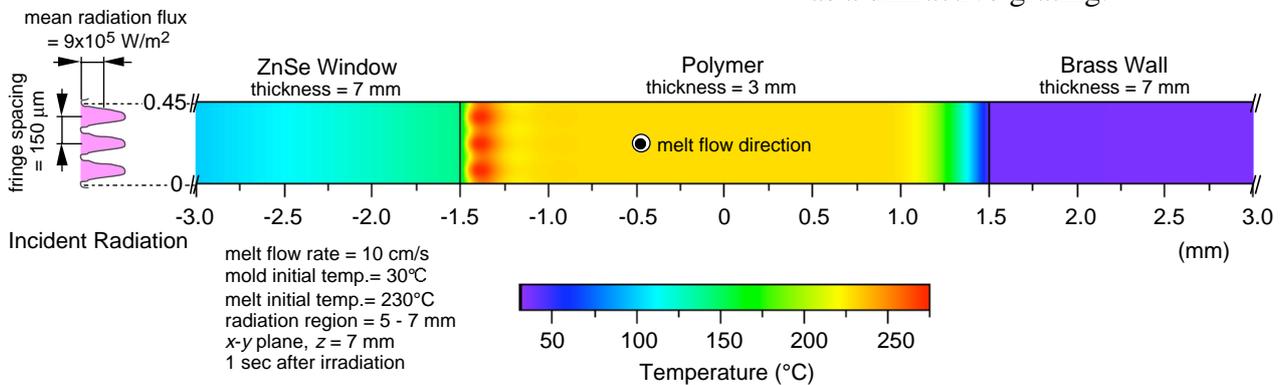


Figure 10.9 Temperature distribution within the material irradiated with the interfered laser.

The birefringence pattern recorded on the surface of polymer products can be used as a kind of diffractive gratings. Noting that the birefringence is the difference of refractive indices for two orthogonal polarizing planes of light, one would easily understand that the birefringence pattern acts as the pattern of refractive index for a polarized light having a certain polarizing plane. If the pattern is grating-like, it would be a diffractive grating for the polarized light as shown in Figure 10.10. It should be pointed out that the function is produced independently from the shape of products. Namely new function may be added onto the injection-molded polymer products by using the heat transfer control.

3. Profits and Losses of Heat Transfer Control in Melting Process - From the Thermal Engineering Point of View

In this lecture, taking illustrations of the case of injection-molding of polymer, characteristics of heat transfer in melting process were discussed, and the method and the effects of heat transfer control were shown in connection with the quality improvement of products and with the productivity of the process. As mentioned in Chapter 2, the purpose of heat transfer in the melting process is that, in general, shape and properties of most of all materials can be changed more easily at higher temperature. In other words, the purpose of heat transfer is to reduce mechanical energy required for forming the material into a prescribed shape. However, as also mentioned in the chapter, the heat transfer in the melting process consumes exergy as well. The profits and losses of heat transfer in the melting process should therefore be discussed from the viewpoint of total energy consumption.

In ancient days, since the mechanical energy, which was produced from human, livestock, and/or waterpower, is more valuable than the thermal energy easily extracted from fire, it was important to reduce the consumption of mechanical energy required for processing. In the melting process of today, however, the mechanical and thermal energies are supplied from the same source such as electricity. So the reduction of the exergy consumption becomes also important nowadays. As mentioned in the appendix in Chapter 2, the exergy consumption in the heat transfer in melting process depends mainly on the temperature level of the heat source/sink and on the temperature difference between the material under processing and the heat source/sink. In order to reduce the exergy consumption due to the later factor, it is required to reduce the heat transfer rate from/to the material, and this results directly in decline of the productivity of process. Since this contradicts the process itself as the economic activity, efficient heat transfer process that transfers thermal energy at higher rate with smaller temperature difference is utilized in the practical melting processes. In the injection-molding of polymers, it is the unsteady heat conduction between the polymer melt and mold wall. This type of heat transfer is utilized in the processing of materials other than polymers. Relative cooling rate of molten materials in the mold can be compared consistently with each other by using the relation between the normalized solidification temperature T_s^* of the material and the normalized interface temperature T_i^* between the material and the mold. T_s^* and T_i^* are defined as follows.

$$T_s^* = \frac{T_s - T_{m0}}{T_{p0} - T_{m0}} \tag{10.2}$$

$$T_i^* = \frac{T_i - T_{m0}}{T_{p0} - T_{m0}} \tag{10.3}$$

Where T_{m0} and T_{p0} the initial temperatures of mold and molten material, T_s the solidification temperature of material, and T_i the interface temperature between the molten material and mold surface, which is estimated by Eq. (5.3). Figure 10.11 shows the comparisons of the relation between these two normalized temperatures for various melting processes. As shown in this figure, the interface temperature is enough lower than the solidification temperature in the polymer injection-molding process, and thus the molten material in the mold is cooled quickly as mentioned previously. This type of heat transfer takes place also in the press molding of glass. On the other hand, the interface temperature and the solidification temperature are close with each other in the metal casting using sand molds. In the process, cooling of molten material is dominated by the heat transfer within the material, and whole material tends to solidify gradually in the mold.

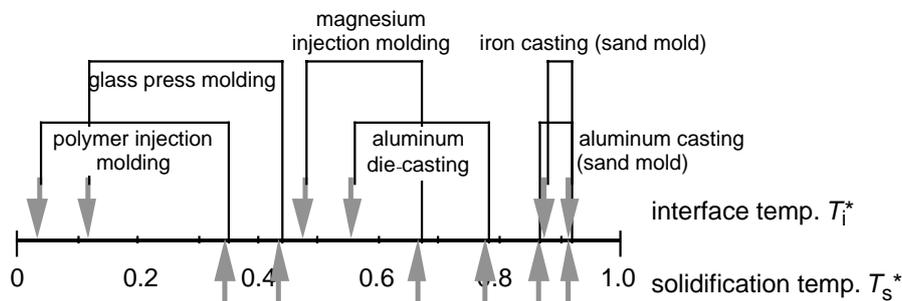


Figure 10.11 Comparisons of the relation between normalized solidification/ mold-material interface temperatures for various melting processes.

On the contrary, the consumption of exergy due to the former factor, i.e. the temperature level of the heat source/sink, is basically depends upon the material under the processing, because the temperatures of heat source/sink used in melting process are related to the melting/solidification temperature of the material. In this sense, it can be said that polymer processing is one of the least exergy consuming process, since the melting/solidification temperature of polymeric materials is

closer to the ambient temperature than other materials such as metals.

If heat transfer in the injection-molding of polymers is controlled by some means so as to improve the quality of products, exergy consumption due to the process increases in general because additional energy sources are required for the heat transfer control. Particularly, the heat transfer control technique utilizing laser heating consumes large amount of exergy; note that the laser oscillators consume electricity that is one of the energy of highest "quality," and that the electricity-light conversion efficiency of the laser oscillators is quite low (about a few percent) in general. This means that the improvement of products' quality can be obtained in exchange for the increase of exergy consumption during the process. If this is the case, should we give up on improving the products' quality by using the heat transfer control technique in order to reduce the exergy consumption? I believe the answer is NO.

As the science and technology are making progress, peoples' demands for industrial products increase as well. We, engineers, must satisfy the demands through our own efforts. During the efforts, we should take the reduction of exergy consumption into consideration. Namely, we should make an effort to reduce the exergy consumption per functions added to the products during the production process.

4. Epilogue

In this lecture, I have discussed the way-of-thinking in synthetic research in thermal engineering, taking illustrations from the thermal engineering applied for manufacturing processes. Synthetic research is the mainstream in the fields of material science, electronics, robotics, and so on, while the mainstream in the mechanical engineering is still analytical research. Indeed analytical research is important to obtain better understanding of the physical aspect of phenomena related to the mechanical engineering, but synthetic research is required for expanding the application field of mechanical engineering. I hope all of you will acquire the sense of the way-of-thinking in synthetic research, and will open up a new field in mechanical engineering.

Problem

With a full understanding of the substance of this lecture, discuss what we, researchers in engineering fields, should consider, how we should behave, what we should develop, and/or how we should lead the public/society, in order to promote people's quality of life, and to encourage sustainable development of this society.

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