Development and Application of High-gloss Injection Molding Technology

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Abstract. High-gloss injection molding technology is a new green injection molding technology based on dynamic mold temperature control strategy. Compared with the traditional injection molding technology, this technology can obviously improve the surface quality of products, and obtain high quality products with high gloss and no weld line. This paper introduces the principle and technological characteristics of high-gloss injection molding, analyzes the key technology and development of high-gloss injection molding. The key technologies of high-gloss injection molding mainly include high-gloss molding material, high-gloss mold, mold temperature control system, etc. Finally, the existing problems of high-gloss injection molding technology are analyzed, and the breakthrough direction in the field of injection molding in the future is proposed.

1. Introduction

With the development of injection molding technology and the continuous application of new materials, injection molding products are widely used in aerospace, automotive, electronic products, instrumentation and other fields. The quality requirements of injection products are becoming higher and higher. Traditional injection molding is often accompanied by weld lines, floating fiber, molding accuracy is not high quality defects. The secondary processing technology such as polishing and spraying will cause waste of raw materials and serious environmental pollution. The application and promotion of high-gloss injection molding technology provides an effective way to solve the above problems. high-gloss injection molding technology is realized by rapid heating and cooling of the mold, so it is also called rapid mold temperature change technology or rapid heat cycling molding (RHCM). RHCM technology is a high gloss plastic molding technology without weld lines, which can remove secondary processing technology such as spraying and electroplating. It can reduce environmental pollution, reduce production costs, shorten the production cycle of products. It is a green injection molding process with broad application prospect [1].

2. Principle and characteristics of high-gloss injection molding technology

High-gloss injection molding technology is a new green injection molding technology based on dynamic mold temperature control strategy. Based on the dynamic mold temperature control mode, mold temperature can be adjusted at any time according to the characteristics and requirements of different process stages. It can solve the defects of traditional injection process such as weld lines, warpage and floating fiber. The basic principle is as follows. According to the change process of mold
temperature in a molding cycle, the injection process can be divided into four stages, mold heating, high temperature holding, mold cooling and low temperature holding. Prior to injection, the mold cavity surface is heated to a high temperature value. In the process of melt filling flow, mold temperature is kept at a relatively high level. Later in the holding phase, mold temperature begins to decrease rapidly as the injection machine screw begins to rotate back. Based on this dynamic mode of mold temperature control, the mold filling ability and weld performance of melt can be improved, and the defects such as weld lines, flow marks and sag can be improved or eliminated. It can effectively improve the gloss of the surface of the plastic parts, improve the quality of the plastic parts, and save the subsequent processes such as secondary spraying which is seriously polluted to the environment. Figure.1 shows the temperature variation curves of the traditional injection molding process and the high-gloss injection molding process [2-4].

Figure 1. Change process diagram of mold temperature

3. Key technology of high gloss injection molding

According to the characteristics of high-gloss injection molding process, its key technologies mainly include three aspects, high-gloss molding material, high-gloss mold, and mold temperature control system.

3.1 High-gloss molding material

To form product of high-gloss injection molding, the raw material of high luster should be selected. This kind of material also calls to avoid spraying material. Spraying free material is a kind of material that can be injected directly. It can achieve colorful appearance without spraying. In addition to meeting gloss requirements, it also includes some major performance requirements. The fluidity of the material is high, which can reduce the shear and improve the filling condition of the mold. The surface hardness of the material is high, with good rigidity and scratch resistance, and the surface hardness is generally above H. The thermal stability of the material should be good to prevent the production of volatile substances [5-7].

In the high-gloss molding materials, the commonly used materials are: ABS, PA, PC/ABS, PMMA, ABS/PMMA, PC, ASA, etc. ABS fluidity and processing performance is good, but the hardness is low and easy to scratch, luster is general. The scope of application is limited. PMMA has good optical properties, good weather resistance, high surface hardness, but low impact strength. ABS/PMMA compatibility is good, hardness is higher. By preparing the two alloys, the alloy materials with high gloss, scratch resistance and high impact properties can be obtained [8]. The hardness of PC is higher,
it has a unique advantage in the molding transparent and radian products, and the product will not appear size shrinkage.

### 3.2 High-gloss mold

In the process of high-gloss injection molding, the temperature of the mold needs to rise and fall sharply, so the requirement of the thermal strength and expansion system of the mold materials are higher [7]. The cooling water hole of the mold is very close to the cavity, which is easy to cause the water hole cracking, so the steel of the mold is required to have enough toughness. In addition, the selection of high gloss mold materials should also consider the corrosion resistance, wear resistance, heat fatigue and processing performance of the material requirements.

At present, the use of more high-gloss mold materials are mainly high polished mirror plastic mold steel NAK80 from Datong, Japan. The mass fraction of each element is: C (0.15%), Ni (3.00%), Al (1.00%), Cu (1.00%), Si (0.30%) and Mn (1.50%), Mo (0.30%), Cr (0.30%). Datong's other high quality supermirror corrosion resistant plastic mold steel is S-STAR. Its composition is: C (0.38%), Si (0.90%), Mo (0.10%), Cr (13.50%), V (0.30%). The hardness of quenching tempering is about 53HRC, and the mirror degree is up to № 6000, which can be used to produce lens resin. Sweden's one hundred anticorrosive mirror mold material ASSAB(S136). The mass fraction of each element is: C (0.38%), Si (0.80%) and Mn (0.50%), Cr (13.6%), P (< 0.03%), S (< 0.03%) [9]. High mirror mold steel XPM VICTORY ESR, Grez Steel, Germany. The mass fraction of each element is: C (0.25%), Ni (0.60%), Si (0.30%) and Mn (0.40%), Cr (14.0%) and trace N [10]. In addition, there are high wear and corrosion resistant mirror mold material X13T6W(236) or X13T6W(236H) from Oberduy, France. Longji special steel LKM838H, LKM818H, LKM2711, etc.

### 3.3 High-gloss mold temperature control system technology

In the traditional injection molding, the mold temperature is always constant. It is difficult to optimize the product quality and molding cycle. In the high-gloss injection molding, mold temperature can be adjusted dynamically in real time by using the temperature control technology. It can effectively solve the shortage of traditional injection molding, and improve the quality of product molding. Therefore, the rapid heating and cooling technology of mold is the key technology of high-gloss injection molding. In recent years, many scholars have studied the methods of rapid heating and cooling of mold cavity. At present, the relatively practical and feasible temperature control system mainly includes temperature control system for heat transfer of high temperature oil, temperature control system for heat transfer of high temperature and high pressure water, electromagnetic induction heating control system, infrared radiation heating control system, etc.

#### 3.3.1 Temperature control system for heat transfer of high temperature oil

Oil is a common heat conduction medium in mold temperature control. Mold cavity design uniform heating or cooling pipeline, through the oil temperature system injection of a certain temperature (up to 350°C) high temperature oil to achieve the heating of plastic mold. The heat transfer conductivity of oil is small and the efficiency is relatively low. But the oil temperature control technology is relative mature, operability is strong, it is widely used in injection molding enterprises.

#### 3.3.2 Temperature control system for high temperature and high pressure water heat transfer

The mold is designed with uniform heating or cooling pipes, using water at different temperatures at different stages. TITAN system from South Korea is used more often. TITAN system uses high pressure and high temperature water as the heating medium and replaces steam with high pressure hot water (up to 250°C) to heat the mold. When the injection molding machine closes the mold, high pressure hot water is injected, the mold temperature is raised to a temperature set value, and the plastic melt is injected into the mold cavity. When the injection molding machine completes the pressure holding and turns into cooling, cold water is injected, and the mold temperature drops sharply to another set value, then the mold is opened. Finally, air is blown into the mold to completely blow
away the cold water and complete the injection process. The operation process of TITAN is shown in Figure 2.

![Injection Molding Machine](image)

**Figure 2. The operation process of TITAN**

TITAN high-gloss injection molding can eliminate the quality defects such as surface melting lines, silver silk and floating fiber. It can solve the product surface shrinkage phenomenon, improve the product surface finish, achieve high-gloss effect. It can save the second spraying, electroplating and other steps, environmental protection and saving, shorten the product molding cycle.

3.3.3 Electromagnetic induction heating temperature control system

The electromagnetic induction heating method is mainly based on Faraday's electromagnetic induction principle. The skin effect and proximity effect are mainly used in the application of induction heating to mold heating. Due to the skin effect of induction heating, the induction eddy current is mainly concentrated on the surface of the mold cavity, but it is weak in the interior and close to zero in the core. By using this characteristic, the mold can be heated locally and the surface temperature of the mold cavity can be increased rapidly. The rest of the mold remains very cold. When high frequency currents in opposite directions are applied to two parallel plates in close proximity, the induced eddy current is concentrated on the surface of the two adjacent parallel plates. If the high frequency alternating current in the opposite direction is applied in the mold core, a large number of induced eddy current will be generated on the surface of the cavity, which can realize local rapid heating of the mold. Mold induction heating methods mainly include mechanical hand assisted induction heating, mold core induction heating with electricity, induction heating pipe heating, induction heating with inner coil of mold, etc [11].

Due to the skin effect of mould induction heating technology, there is no heat transfer medium between electromagnetic induction heating body and mould, heat transfer speed is fast and molding cycle is short. It can solve the problem of polymer injection molding with high viscosity and high melting temperature. However, electromagnetic induction heating is limited by the shape of induction coil, so it is more suitable for simple structure or small size mold.

3.3.4 Infrared radiation heating temperature control system

Infrared is an electromagnetic wave. Because the metal crystal of mold steel is very dense, the penetration depth of thermal radiation to the metal is only in the order of micron. Radiation is heating the mold surface, so as to achieve a rapid increase in the surface temperature of the mold. After heating, due to the heat conduction and heat loss of the mold, the surface temperature of the mold decreases rapidly, realizing the cooling process.
The principle of infrared heating is shown in Figure 3. The heating system is mainly composed of light source, reflector and heated surface. The radiation source emits infrared ray, and part of the energy is directly projected to the heated surface, and the other part is reflected to the heated surface through the reflector, so as to realize the rapid heating of the heated surface [12].

Duan [12] and others proposed the combination of near-infrared heating and circulating water heating to rapidly raise the temperature of the mold to higher than the glass transition temperature of the polymer. The near infrared heating device for microinjection mold with high depth-diameter ratio was developed by Tracepro analysis method. The filling quality of the plastic parts with high depth to diameter ratio was improved effectively. Saito [13] and others used external infrared ray to heat the surface of the mold, which improved the birefringent phenomenon of injection products and improved the molding quality of products.

![Figure 3. Principle of infrared heating](image)

Infrared radiation heating does not need to heat the air, it has a certain penetration. The heating device is simple, safe and efficient. It is more suitable for simple small mold. In addition, due to the poor flexibility of the infrared heating device, it is more difficult to realize the uniform heating of the complex mold cavity surface by infrared radiation heating.

3.3.5 Other heating control technologies

In the present research and application, other heating technologies mainly include steam heat transfer, flame heat transfer, electric heat pipe heat transfer, moldelectric heating, etc.

The principle of steam heat transfer is similar to that of water at high pressure and temperature. Steam is used as the heating medium to heat the mold. Steam is introduced during heating, and low temperature water is switched to cooling. The mold can be cooled quickly.

The application of this technology is relatively mature, and it is widely used in enterprises in Japan and South Korea. Typical application cases mainly include the steam heating mold temperature control system jointly developed by Hisense Mold Co., LTD and Shandong University. Steam heating mold change temperature control system developed by Ono Industrial Co., LTD. However, the specific heat capacity of the heated steam is small, the steam can not be recycled. In addition, it need to install boiler equipment, resulting in high production costs.

Flame heating is a technology that uses the heat energy and radiant energy released by the intense combustion reaction of combustible gas and oxygen. It has the characteristics of large heating power and fast heating speed [14]. Kim [15] and others realized instantaneous heating of molds by flame heating technology. High-gloss injection molding was used to improve the molding strength of plastic parts.

4. Conclusion

High-gloss injection molding technology is a new green injection molding technology based on dynamic mold temperature control strategy. High-gloss injection molding can improve the filling capacity and weld performance of melt. It also can improve or eliminate weld lines and other defects, reduce the injection pressure and residual stress of products. It can effectively improve the surface
gloss of plastic parts and save the subsequent processes such as secondary spraying which is seriously
polluted to the environment. It has great market application value. The key technology of high-gloss
injection molding mainly lies in the selection of high-gloss molding materials, the selection of mold
materials, the design of mold structure and the precise control of mold temperature.

At the same time, as a new green injection molding technology, high-gloss injection molding
technology has made rapid development, but there are still many shortcomings. Such as large complex
precision plastic parts of high-gloss injection molding, mold temperature precision control, etc. These
problems will be the future injection molding research breakthrough direction.

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References
[1] Zhao, G.Q., Wang, G.L., Li, H.P., et al. (2009) Research and application of rapid thermal cycle
injection molding technology. J. Journal of Plastics Engineering, 16: 190-195.
[2] Zhou, Y.G., Hua, C.C., Chen, Z.S., et al. (2010) CAE analysis of warpage of injection products
with variable mold temperature. J. Journal of Jiangsu University of Science and Technology,
24: 546-548.
[3] Wang, G.L., Zhao, G.Q., Li, H.P., et al. (2009) Thermal response simulation and mold structure
optimization for injection molding with variable temperature. J. Journal of Mechanical
Engineering, 45: 216-221.
[4] Zhu, J.J. (2014) Study on improvement of injection parts weld line by variotherm molding control
technology. J. Plastic Science and Technology, 42: 102-105.
[5] Zhou, Q.H., Zhang, Y., Lei, M.H. (2019) Overview of non-spraying materials and application.
J. Guangdong Chemical Industry, 46: 94-96.
[6] Song, R.J., Li, J.S., G, J.Q., et al. (2019) Study on influencing factors of plastic high-gloss
molding technology. J. Automobile Technologist, 10: 43-47.
[7] Jin, X. Y., Jia, B.Y., Yang. J. (2014) Development status and prospect of key technology of high-
gloss injection molding. J. Plastic Science and Technology, 42: 122-129.
[8] Meng, Z., Sun, Z.Y., Qian, J., et al. (2016) Research progress of high gloss non-spraying
ABS/PMMA alloys. J. Engineering Plastics Application, 44: 134-139.
[9] Tao, Y.L., OU, Y.T. (2020) Consideration on the selection of high-gloss non-trace injection mold
material. J. Rubber Technology and Equipment, 46: 31-34.
[10] Lu, C.J., Wu, X.C. (2017) Research status and prospect of advanced mirror plastic mold steel.
J. Mold Manufacturing, 10: 93-98.
[11] Jiang, B.Y., Lan, C.H., Chen, Wen., et al. (2008) Electromagnetic induction heating technology
for injection molding mold. J. Engineering Plastics Application, 36: 72-74.
[12] Duan, Q., Qou, Z.J., Fang, F.Z. (2013) Study on near infrared heating method and device of
microinjection mold. J. Plastics Industry, 41: 32-35
[13] Saito, T., Saito, I., Kurosaki, Y. (2002) A new concept of active temperature control for an
injection molding process using infrared radiation heating. J. Polymer Engineering & Science,
42: 2418-2429.
[14] Shi, Z.L., Zhang, L., Hou, J.J., et al. (2019) Review on the development of rapid thermal cycling
injection molding technology. J. Precision Forming Engineering, 9: 1-18.
[15] Kim, D.K., Kang, M.H., Chun, Y.H. (2001) Development of a new injection molding technology:
Momentary mold surface heating process. J. J Inject Mold Technol, 5: 229-232.