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Effect of asymmetric cooling system on in-mold roller injection molded part warpage ☆

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ABSTRACT

In-mold decoration (IMD) injection molding has been the most promising surface decoration technique in recent years, with the in-mold roller (IMR) injection molding being the most automated production process. During the IMR process, heat transfer in the cavity surface is significantly retarded because of the low thermal conductivity of film. As a result of the asymmetric melt and mold temperature, thermal-induced part warpage easily occurs. To understand the variation in the temperature field of the core and cavity caused by the plastic film, this research uses simulation and experiments to investigate the influence of the mold's (core-and-cavity) asymmetric cooling system temperature on product warpage, and examines the impact of the film's heat retardation effect on the crystallinity, tensile strength, and surface roughness of the treated products. Our results show that the film causes a higher contact temperature between the hot melt and mold during the molding process, resulting in asymmetric temperature in the mold (core and cavity), increasing the crystallinity of the cavity and consequently increasing product warpage. In plastic, the warpage increase is from 0.03 mm to 0.62 mm when the film thickness is 0.175 mm and the temperatures of the mold and hot melt are 50 °C and 230 °C, respectively, a great increase than with steel (P20). With the asymmetric cooling system design, in which the cavity temperature is 50 °C and the core temperature is 65 °C, the warpage can be reduced by 53%. For crystallinity and crystalline size, the film heat retardation effect of the IMR process increases the crystallinity of the cavity by 16%, and the crystallite size by 12%, along with some increase in tensile strength. In addition, the IMR process can also increase the smoothness of the product surface, reducing the surface roughness by 50%.

1. Introduction

Among various plastic fabrication processes, injection molding has the advantages of low cost, mass production, and one-step forming for products with complex shapes. Hence, it has become the most widely used technique [1] in the plastics industry. Because of the diversification of consumer products in the market, the variety of requirements from product developers, and rising environmental protection awareness, conventional injection molding techniques no longer meet the demands of the new era. In response, using high-performance plastic materials and advanced injection molding processes, several techniques have been developed. Among them, in-mold decoration (IMD) injection molding is a recently-evolved process [2] which combines several machining techniques and mold fabrication technology. During the IMD process, a pre-printed film is placed in the mold prior to injection. Injection is then executed after the mold is closed. Compared to conventional injection molding without the film, IMD can save post processing costs (spraying, coating, screen printing, or plating). In addition, IMD products can have beautiful and precise surfaces with diversified patterns and brilliant colors, which are durable against friction and scratches [1–4]. Because of its advantages, it has been used to make many current products, such as cellphone shells, household appliance panels, automobile dashboards, cellphone keys, and mouse shells, which demand good feel in the hand and a precision appearance. This technique has three major categories: in-mold label (IML), in-mold roller (IMR), and in-mold forming (IMF) [3].

During the IMR process, the pre-printed film transfers ink to the product surface through the roller and the feeder. As the ink and film separate, the next cycle of the injection molding process begins again. During the molding process, because the film is attached to the cavity wall, the heat transfer along the flow path causes different temperature boundaries for the cavity surface (with film) and core surface (without film). The non-uniform heat transfer in the cavity induces a non-uniform temperature distribution across the gapwise direction during the filling and cooling stages [5–7]. As a result of the asymmetric temperature distribution in the cavity wall, unbalanced flow front

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advancement, severe warpage and stress, and other effects may impact the part's properties, and non-uniform crystallization and orientation may occur [3,4,8–12]. To date, most research has only explored the heat retardation effect caused by the film attached to the product. Few investigations have examined the effect of the asymmetric cooling system temperature on products [3–5,13–15]. This study, through analysis and experiments, observes the effect of the film heat retardation during the IMR process on product warpage and the temperature variation of the contact surface between the hot melt and mold, and performs an asymmetric cooling system temperature design for the core and cavity. The impact on product crystallinity, tensile strength, and product surface roughness is also investigated, given that supporting industrial needs is the motivation and purpose of this research.

2. Experimental work

2.1. Materials

In this study, the plastic material is polypropylene (Globalene 7533, Taiwan Polypropylene Co., Ltd) with a density of 897 kg/m^3, a heat-

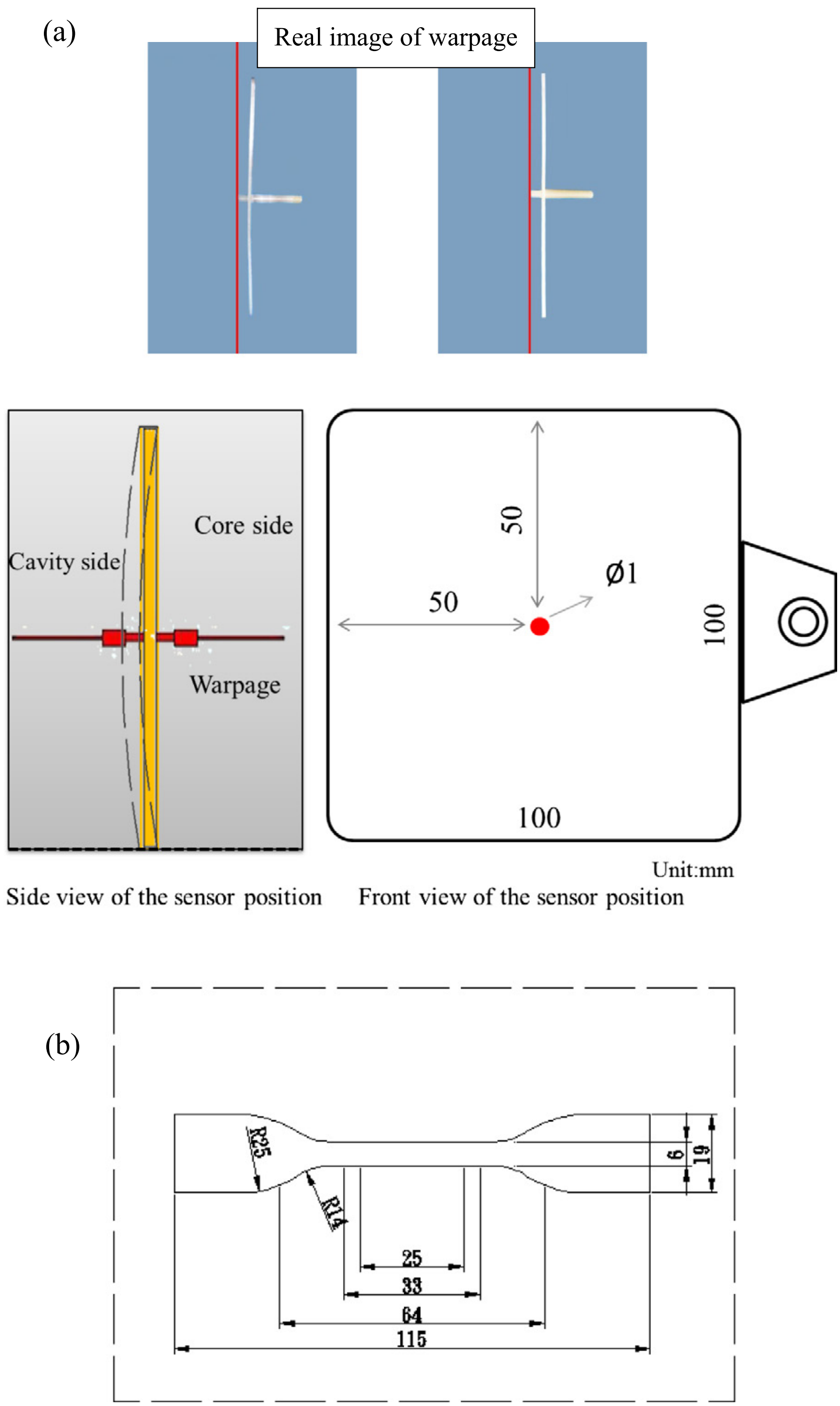

Fig. 1. Schematic of molding part's geometry. (a) Definition of warpage is also identified. (b) Specimen dimensions for tensile strength.