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Progress in Visualization and In-process Measurement Technologies in Injection Molding

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Abstract

For elucidating the injection molding process and the undesirable injection molding phenomena, it is important to establish the visualization technology and the method for measuring the resin temperature and pressure distribution. At Yokoi laboratory, Institute of Industrial Science, University of Tokyo, various measurement methods have been developed; (1) Glass-Inserted Mold for analyzing the melt flow behavior inside the cavity, (2) Glass-Inserted Heating Cylinder for analyzing the plastication process inside the screw channel, (3) Integrated Thermocouple Sensors for measuring the melt temperature distribution along the cavity thickness or inside the nozzle channel of an injection molding machine, (4) the pressure pin array and tactile sensors mold for measuring the cavity pressure distribution, and others. In this workshop, the principles of the above measurement methods and the measurement results obtained by Glass-Inserted Mold, Integrated Thermocouple Sensors and the pressure pin array and tactile sensors mold will be introduced.

Introduction

For elucidating the injection molding process and undesirable injection molding phenomena, it is important to measure the melt flow behavior inside a mold, plastication process inside a heating cylinder, melt temperature, and pressure profile. The Yokoi laboratory, Institute of Industrial Science, University of Tokyo thus initiated and organized a multi-client cooperative research program between the academy and industry on the subject "experimental analyses of injection molding phenomena", to develop new visualization technologies and new methods for measuring the melt temperature and pressure profile. Based on these technologies, various injection molding phenomena inside the mold and heating cylinder have been systematically analyzed.

This paper introduces the principles of the visualization and measurement technologies which have been developed at the Yokoi laboratory, and results of analyses using the above technologies. Two research projects that are currently being conducted at the Yokoi laboratory: (1) melt temperature distribution along the cavity thickness measured by the Integrated Thermocouple Sensor (Yokoi, *et al.* 1989), and (2) cavity pressure distribution on the injection mold cavity surface measured by mold incorporating a pressure transmission pin array and tactile sensor (Murata, *et al.* 1996), are also discussed.

Visualization and measurement technologies

Visualization analysis in heating cylinder

For the direct visualization of the plastication process, several types of practical Glass-Inserted Heating Cylinders (Yokoi, *et al.* 1989) have been developed to analyze processes aided by a high speed video and image processing system. Three long blocks of quartz glass are inserted into axial direction slots cut into the heating cylinder and clamped tightly to prevent the blocks from breaking during plastication and injection process as shown in Figure 1. Using this cylinder, the following shown in Figure 2 were investigated: (1) breaking–up generation process (Yokoi, 1994), (2) reciprocative plastication process (Yokoi and Tatsuno, 1996), (3) pellet behavior under hopper (Yokoi and Takatsugi, 1998), (4) melt velocity distribution inside reservoir (Yokoi and Kuroda, 1996), (5) check-ring behavior and others.

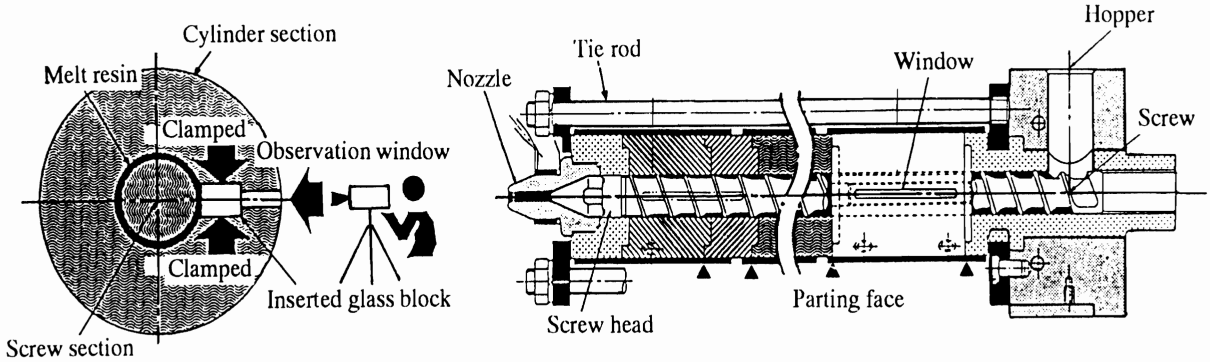


Figure 1 Schematic structure of Glass-Inserted Heating

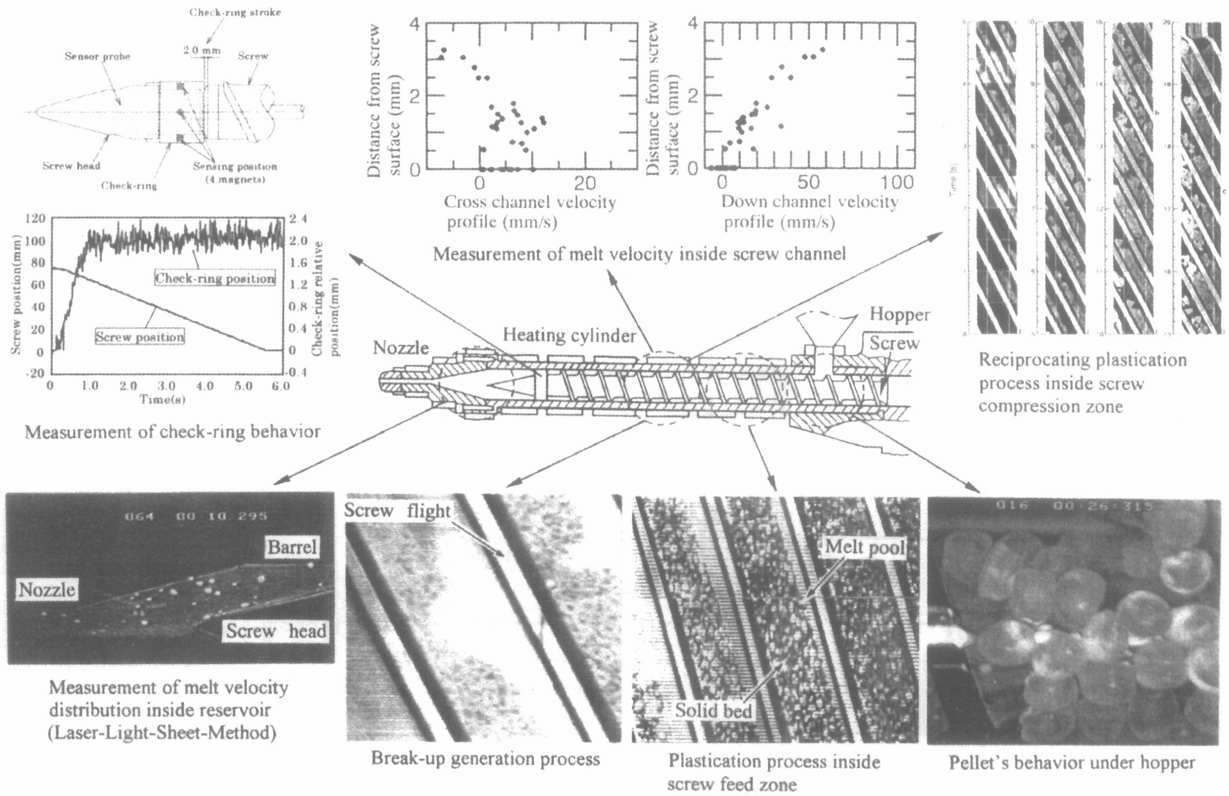


Figure 2 Visualization analysis inside heating cylinder

Visualization analysis in mold

To analyze some of the undesirable phenomena and unknown phenomena concerning the filling process, holding pressure process, and cooling process, effective tools such as the Glass-Inserted Mold (Yokoi, *et al.* 1988), Back-Lighting Mold (Yokoi, *et al.* 1994), 3-Dimesional Visual Mold (Yokoi, *et al.* 1992), Laser Light Sheet Mold (Yokoi and Inagaki, 1992), Gate-Magnetization Mold (Yokoi and Kamata, 1990), have been developed. Figure 3 shows the schematic structure of the Glass-Inserted Mold. A glass prism is inserted into a specially designed space cut into the steel mold base. One face of the prism adjoins the mold cavity and the other face adjoins a window built into the side wall of the mold at a location vertical to the parting face. Consequently, the inside of the mold can be observed from the images reflected from the tapered face. The Glass-Inserted Mold enables the analyzing of the (1) jetting generation (Yokoi, *et al.* 1988), (2) weld-line generation (Yokoi, *et al.* 1991), (3) flow-marks generation (Yokoi, 1994; and Yokoi, *et al.* 1999), (4) silver streak generation (Yokoi and Otake, 1999), (5)gas-assisted injection molding (Yokoi and Otake, 1998), (6)co-injection molding (Yokoi, *et al.* 1999), (7)foam injection molding, (8)3-dimensional flow (Yokoi, *et al.* 1997), (9)fiber orientation (Yokoi, *et al.* 1994; and Yokoi, *et al.* 1994) etc. as shown in Figures 4 and 5.

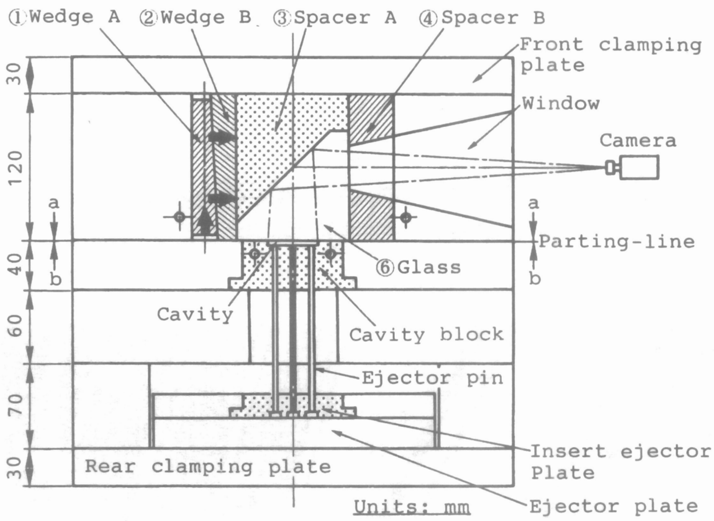


Figure 3 Schematic structure of Glass-Inserted Mold

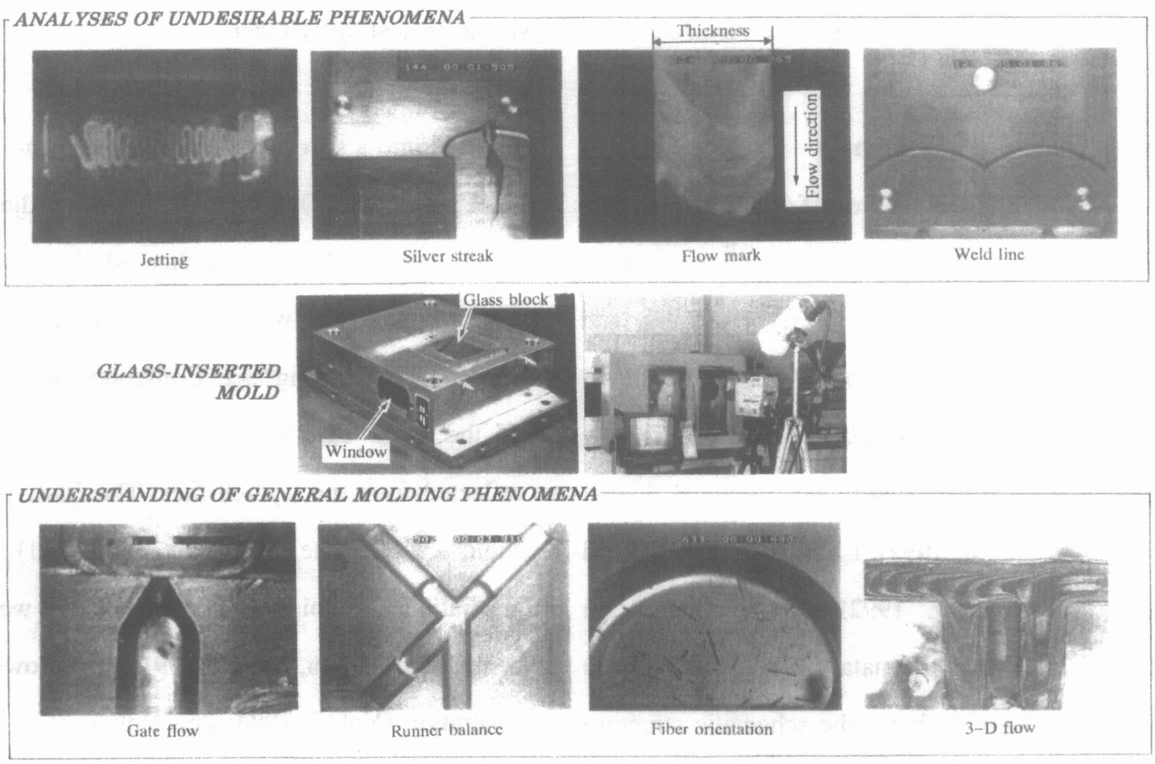


Figure 4 Visualization analysis inside injection mold (1)

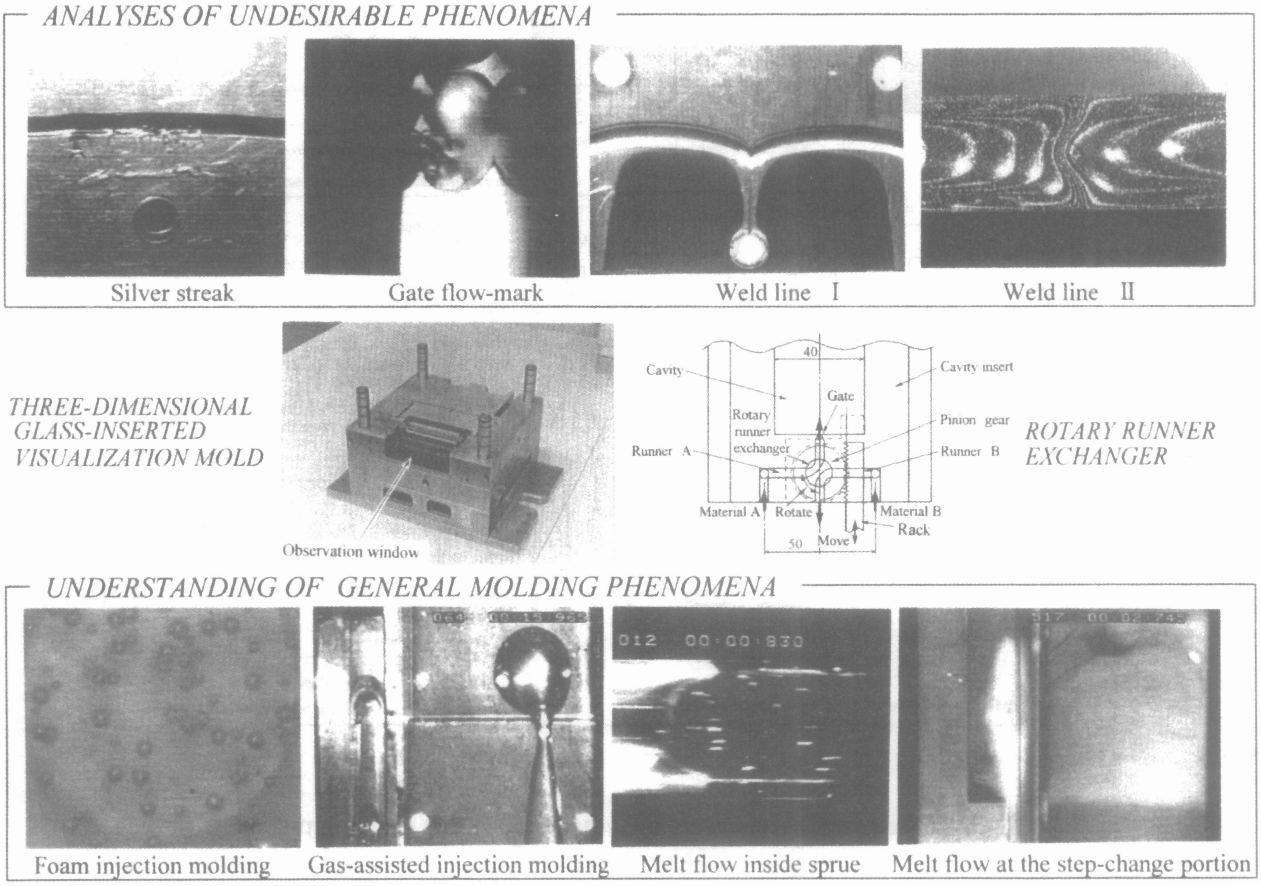


Figure 5 Visualization analysis inside injection mold (2)

Temperature profile measurement of flowing melt

An Integrated Thermocouple Sensor which consists of many thermocouples plated on a thin polyimide film or ceramic plate has been developed. Using this sensor, the melt temperature profile inside (1) a mold cavity (Murata, *et al.* 1998), (2) a nozzle channel (Yokoi and Kim, 1996), and (3) a screw channel (Yokoi, *et al.* 1995; and Yokoi, *et al.* 1998) are measured as shown in Figure 6.

Stress and torque distribution measurement

We developed a (1) cavity pressure distribution measurement mold with a pressure transmission pin array and tactile sensor (Murata, *et al.* 1996), (2) shear stress distribution measurement mold based on 3-component force transducer (Yokoi, *et al.* 1994), and (3) screw torque measurement screw in which each segment has strain gauges attached to the inner-hole surface (Yokoi and Kim, 1997) as shown in Figure 7.

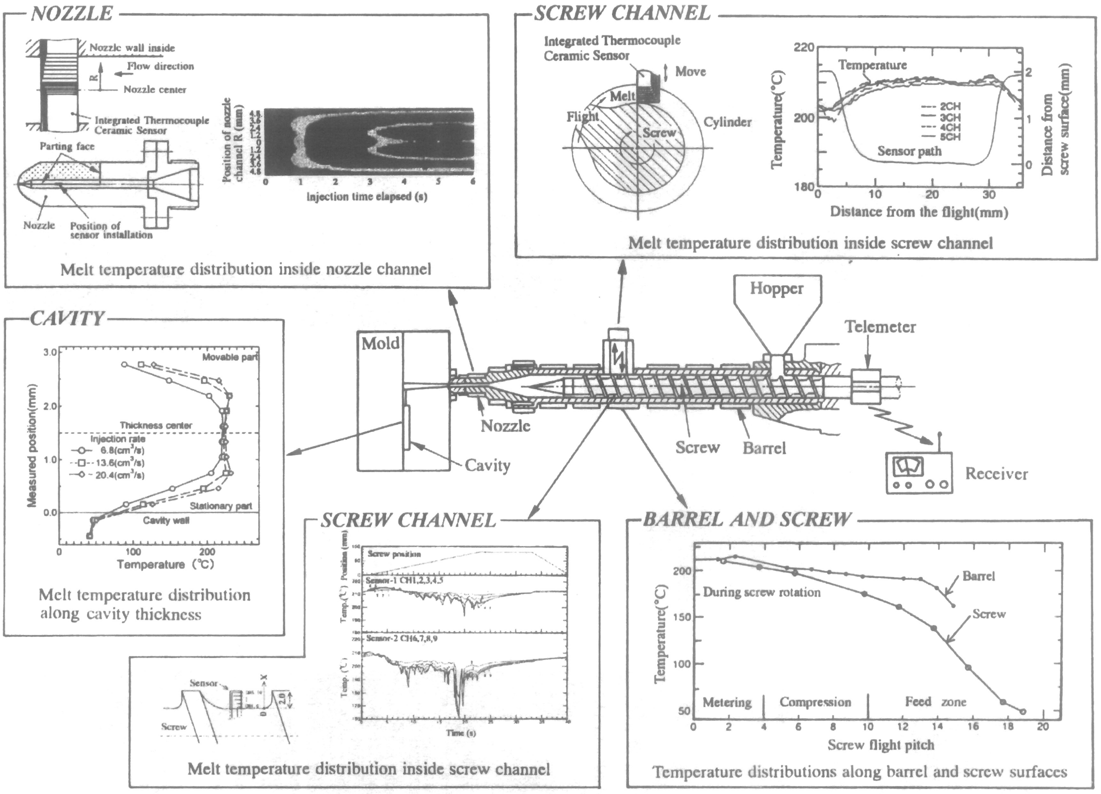


Figure 6 Temperature measurement during injection molding process

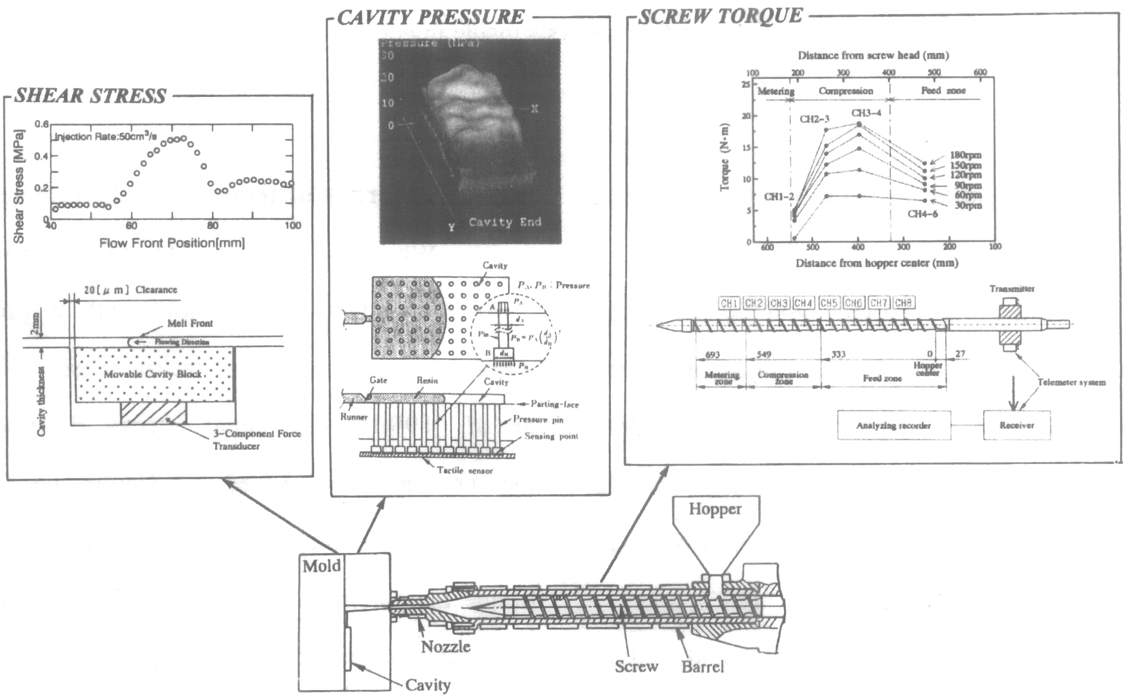


Figure 7 Stress and Torque distribution measurement

Measurement of melt temperature profiles along cavity thickness by integrated thermocouple sensor

Figure 8 shows the shape of the Integrated Thermocouple Sensor. Fifteen junctions consisting of copper and nickel are arranged for a length of 4.5 mm. This sensor is placed upright along the cavity wall in the melt flow direction as shown in Figure 9. The measurement results obtained by this sensor are introduced as follows.

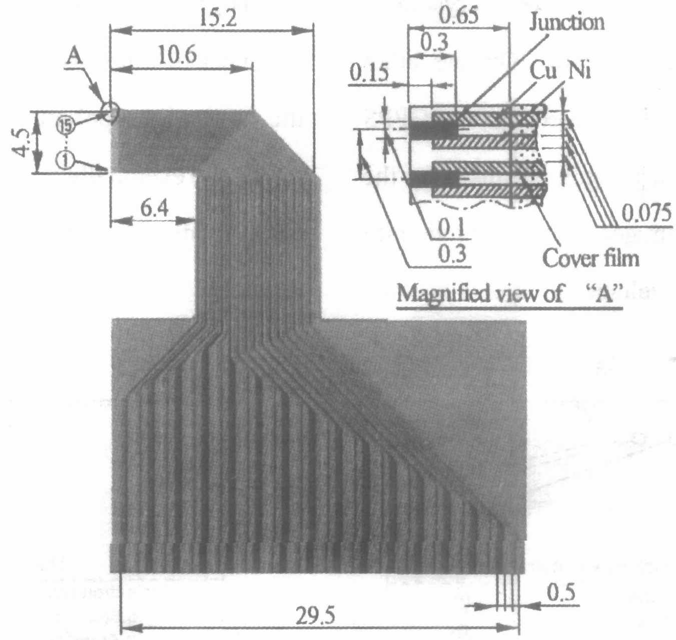


Figure 8 Shape of Integrated Thermocouple Sensor (Units : mm)

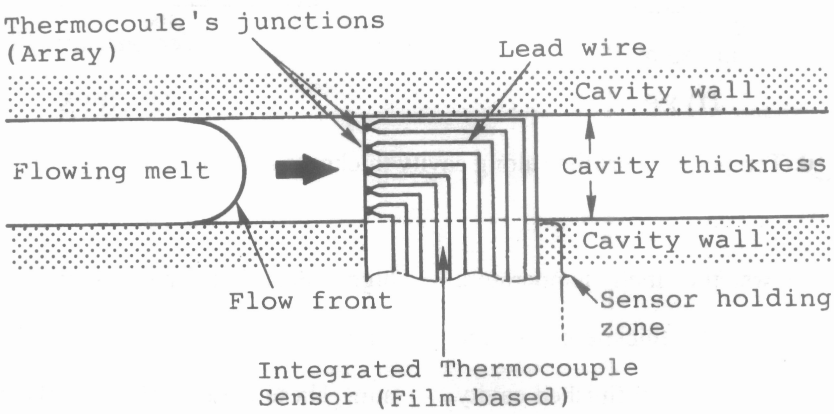
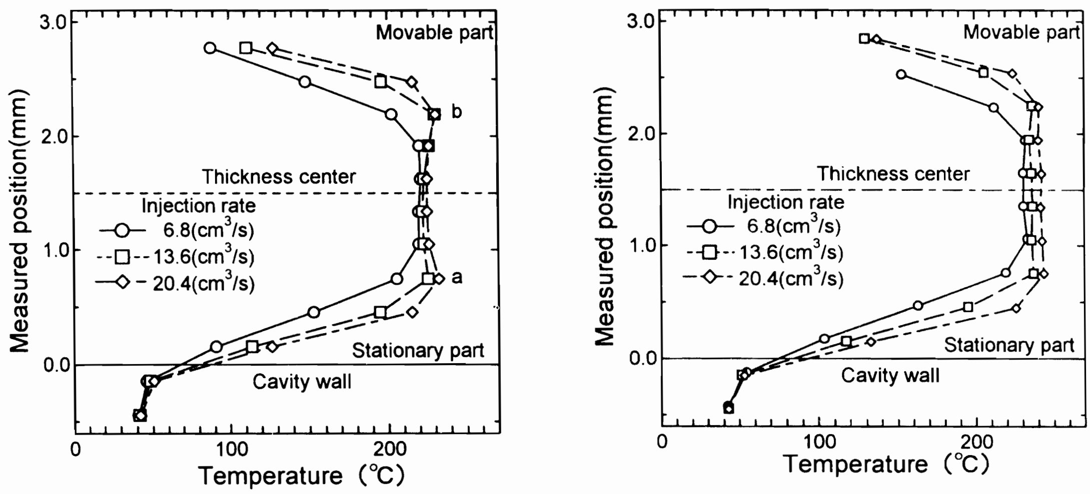


Figure 9 Measuring method for melt temperature distribution

Figure 10 shows the melt temperature distribution along the cavity thickness for Polypropylene (PP) and General Purpose Polystyrene (GPPS) at the end of the filling process (Murata, *et al.* 1998). The temperature peaks "a" and "b" caused by shear heating are generated at the vicinity of the cavity wall for PP crystalline polymer under high injection rates. On the other hand, these peaks are not generated for the GPPS amorphous polymer. Shear heating is caused by the steep melt velocity gradient generated at the vicinity of the cavity wall. These velocity gradients become steeper for the crystalline polymer than that of the amorphous because the viscosity of former changes markedly around the crystallization temperature. Consequently, the shear heating value of the crystalline polymer is higher than that of the amorphous. In addition, the crystalline polymer discharges latent heat when it crystallizes, making the shear heat become more difficult to dissipate in the crystalline polymer than in the amorphous, which is eventually stored at the vicinity of the cavity wall. These peaks were generated for these reasons.



(1) PP **(2) GPPS**

Figure 10 Temperature profiles along cavity thickness at the end of injection process

Figure 11 shows the melt temperature distributions along the cavity thickness for the mirror finished cavity face and satin finished cavity face for PP and GPPS at the end of the filling process (Murata, *et al. 1999*). The melt temperature measured for the satin finished cavity face becomes higher than that for the mirror finished cavity face within the measured position from 2.5mm to 3.0 mm. These suggest that the thermal resistance for the satin finished cavity face becomes larger than that for the mirror finished cavity face because a large air gap is generated at the interface between the melt and satin finished cavity faces.

Other than the above research, the authors research group have investigated (1) melt temperature distribution around the gate outlet (Murata, *et al.* 2000), and (2) temperature distribution for short glass fiber reinforced plastic (Abe, *et al.* 1999) using this sensor.

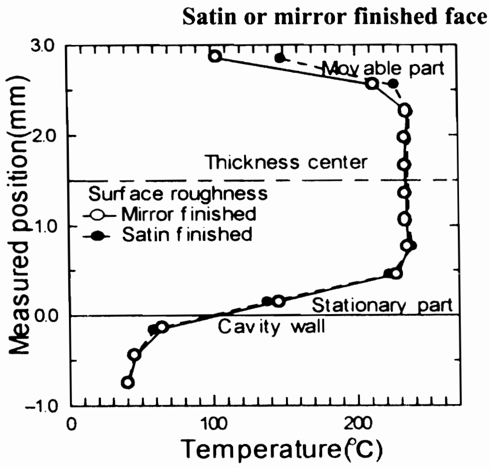


Figure 11 Temperature profiles along cavity thickness of mirror finished cavity face and satin finished cavity face

Measurement of melt pressure distribution on injection mold cavity surface

A tactile sensor film (I-SCAN100; NITTA) was set up under the pressure transmission pins which are laid out in a uniform array at the regular intervals as shown in Figure 7. Melt pressure is transmitted to each sensing point of the tactile sensor through the pins.

Figure 13 shows the cavity pressure distribution for Low Density Polyethylene (LDPE) in the rib-shape cavity shown in Figure 12. The pressure distribution is flatten from the gate to the end of the cavity during the holding pressure process, as shown in Figure13-(1). The crystallization sets in around the rib portion where the high pressure was maintained due to the effect of compensation flow during the holding pressure process Figure13-(2). The pressure around this portion thus rapidly falls to zero during the cooling process Figure13-(3). On the other hand, residual pressure is generated around the thin thickness portion which begins to solidify at an early part of the cooling process. Therefore, the pressure does not fall to zero until demolding Figure13-(4).

This method enables us to understand the complicated pressure distribution on the cavity surface. This method should be useful for the analysis of unknown injection molding phenomena in the future.

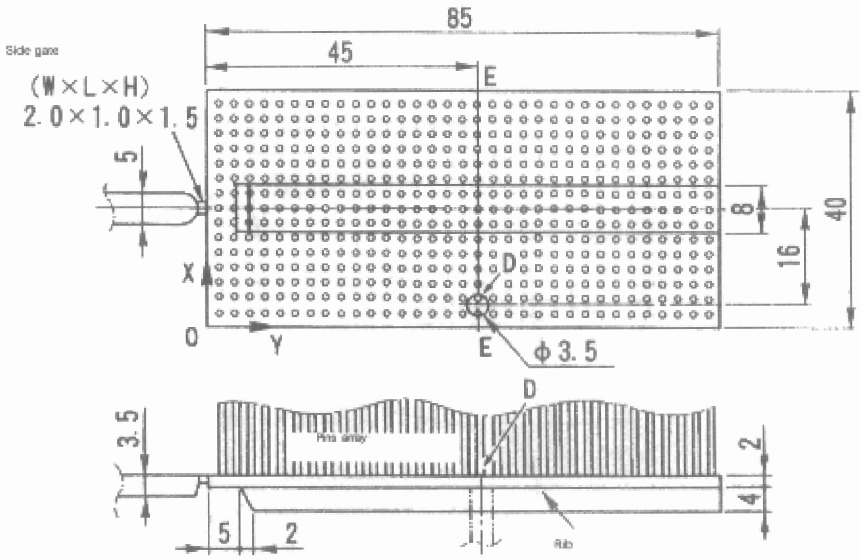


Figure 12 Cavity shape and pressure transmission pins arrangement pattern (Units : mm)

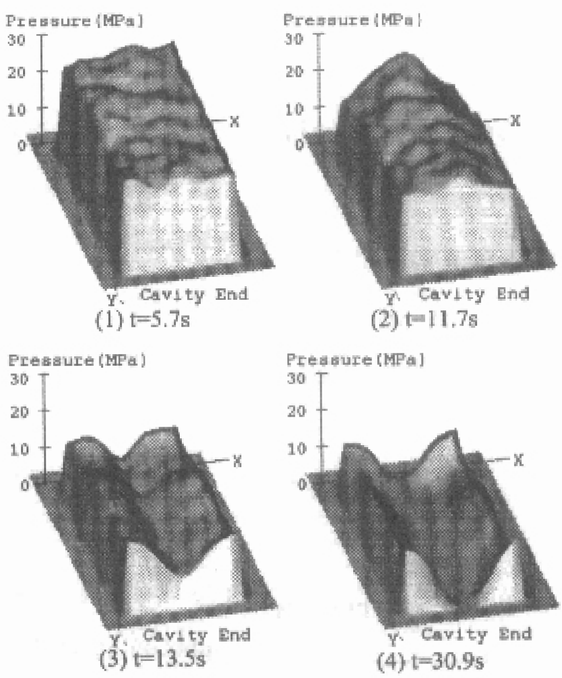


Figure 13 Melt pressure distribution profiles inside rib-cavity

Conclusion

Recently, in order to produce molded parts with high added value and high performance, new molding technologies, such as in-mold assembling molding, ultra high speed injection molding, and micro-molding etc., were developed. Many unknown molding phenomena and undesirable molding phenomena are expected to be faced. The visualization and in-process measurement technologies are thus desired.

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