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Multi-station molding machine for attaining high productivity in small-lot productions

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ABSTRACT

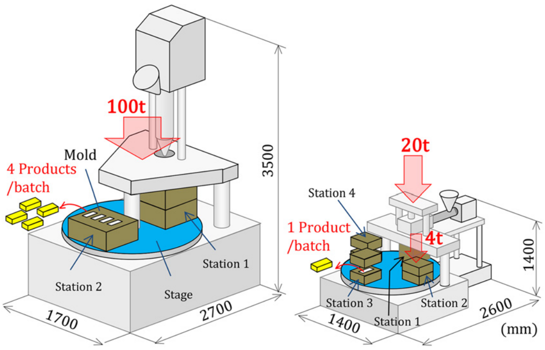
In typical resin molding, multi-cavity molds are generally used to reduce cycle time and increase productivity. However, these types of molds are large, which also increase the size of the facility. The newly developed compact multi-station resin molding machine features single-cavity molds and split process which are conducted in parallel in four stations to cut down on cycle time. To realize this method, small molds with self-clamping is required. This paper reports the results of the method for obtaining the optimum conditions for suppressing the generation of flashes and the degradation of dimensional accuracy in a short time using CAE.

1. Introduction

Economic globalization has been intensifying the competition between companies. Locating production bases near the customers is important for timely response to environmental changes and market demands [1,2]. Conventional automobile parts production has maintained competitiveness by mass production, which uses large facilities to machine large lots at high speeds [3]. However, in distributed small-lot production of automobile parts, it is hard to obtain cost advantages with this method, which has been hindering the localization of production nearby customers. Moreover, with the ongoing enhancement of product functionality, the shapes and accuracy of components have been sophisticated, and as a result, current components are manufactured through many processes including cutting and heat treatment [4]. Therefore, a single production line consists of multiple processes with different production speeds, which results in a large amount of excess stock between processes. A synchronization consistency line, in which the production speed is synchronized between processes, is effective for resolving these issues [5]. With the aim of simultaneously realizing 'cost-effective small-lot production' and 'synchronized production line with minimal stock between each process', the concept of '1/N machine' was proposed, and compact equipment with optimal production quantity, product quality and processing speed which realizes a truly efficient production system was developed [6].

Nowadays, the fuel efficiency enhancement and electrification of vehicles demand small and light-weight parts [7,8]. Plastics are drawing attention as the materials for vehicle parts because they are lighter than metals. Small plastic parts that cover metal terminals and IC packages are manufactured by injection molding of thermoplastic resin. In their production, the molding process requires longer cycle time compared to the neighbouring (upstream and downstream) processes, which is why multi-cavity type molds have been used [9]. However, the multi-cavity type molds has some disadvantages: multi-cavity molds necessitates the large molds, which requires the gigantic injection molding machine. To cope with these problems, a compact machine for manufacturing small-lot parts by injection molding under the concept of '1/N machine' was developed (Fig. 1), which is called a '1/N Multi-Station Injection Molding Machine (hereinafter referred to 'Multi-Station Machine')' [10]. The conventional injection molding machine consists of two stations: The first station performs injection, packing and the second station handles ejection and setting. In contrast, the Multi-Station Machine has a four station configuration (Fig. 2), and the segmented work operations are allocated to each station. When one step is completed, the stage rotates 90°, so that the processes are executed synchronously in all stations.

In order to realize the Multi-Station Machine, extensive development of injection molding should be made. The first is a



(a) Conventional machine (b) Multi-Station Machine

Fig. 1. Comparison of injection molding machine.

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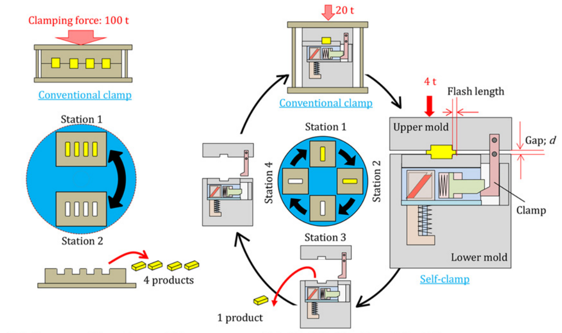
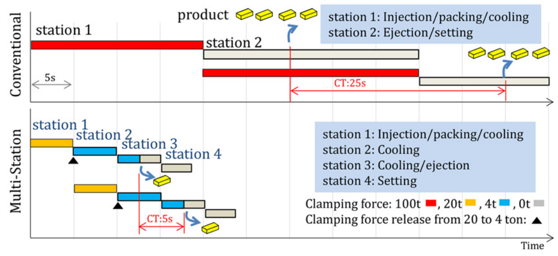


(a) Conventional machine (b) Multi-Station Machine



(c) Time chart of two batches

Fig. 2. Station structure and cross section of mold.

clamping of molds. In the conventional molding machine, the molds have been clamped with large clamping force so that they are not opened by resin pressure during injection. This clamping mechanism by hydraulic system or servo-controlled motor is one cause of making the machine heavy and large, but it is indispensable to ensure the dimensional accuracy of products. Such heavy clamping system could not be used for the Multi- Station Machine with a rotating stage, therefore it was necessary to develop a simple clamping apparatus, such as the self-clamping mold, shown in Fig. 2. The clamp bar of the upper mold is kept hammering into the wedge of the lower mold and maintains closing the mold on the station 2.

The Multi-Station Machine should be capable of minimizing the time to stay at each station. Especially, at the injection molding stage, minimizing the time necessary for the solidification without degrading the product geometry is extremely important. The challenge is to clarify the timing of moving the products from the station 1 to the station 2, or when the large clamping force should be released, which is the second key issue of realizing the Multi-Station Machine. If the time to release the large clamping force is not adequate so that the amount of gap is too large at station 2, the dimensional accuracy of products is degraded. Thus, defining the gap that yields the dimensional accuracy, or product quality, required for vehicle parts are extremely important. The time of releasing the large clamping force in Multi-Station Machine depends on the types of products and product geometries. The optimization of the molding conditions for varied products should be completed accurately and quickly, and CAE has an advantage for realizing the fast and accurate design of the molding conditions by using Multi-Station Machine.

This investigations aims at establishing CAE for designing the molding conditions for Multi-Station Machine, especially focusing on the timing of releasing the large clamping force and the allowable amount of the gap between the upper and the lower molds. A series of experiments are conducted to validate the CAE and to establish the forming strategies by using the Multi-Station Machine.

2. Experimental and simulation conditions

2.1. Allowable amount of the gap between the molds

Allowable amount of the gap between the molds was evaluated by roundness of a test product which was a cylinder with a diameter of 15 mm and a length of 30 mm. The material was polyphenylene sulfide containing 30% of glass filler (TORELINA- PPS, TORAY). The molding conditions in the experiment of evaluation are shown in Table 1.

Table 1
Injection molding condition of cylindrical test product.

Parameter	Value
Mold temp. (°C)	130
Injection plastic temp. (°C)	310
Set-up injection rate (mm/s)	50
Packing pressure; p (MPa)	60
Packing time (s)	4
Period from the end of packing to the release of the large clamping force; t_H(s)	0

2.2. Timing of releasing the large clamping force

The timing of releasing the large clamping force was evaluated by the length of a flash [11]. Fig. 3 shows a mold and a test product. The test product was a rectangular parallelepiped with an area of 20 × 80 mm and a thickness of 10 mm. The mold was configured to obtain temperature and pressure of the resin, in-situ [12–14]. The resin temperature was measured with a film sensor with a φ50 μm K-thermocouple wire affixed to polyimide film (ST-51S, RKC Instruments) sandwiched between the upper and the lower molds, so that the temperature during molding at any position within the cavity could be measured.

The resin pressure during injection molding was measured by converting the changes in the electric resistance of the strain gauge placed on the rear side of the ejector pin, which was indicated as 'A' in Fig. 3, into the changes in resin pressure (Mold Marshalling system, FUTABA). The molding conditions in this experiment are listed in Table 2. Assuming the period from the end of packing to the release of the large clamping force being t_H, t_H was changed from 0 to 6 s. The test product was left in the molds for 15 s, and then it was ejected. The gap between the upper and the lower molds; d in Fig. 2, when the clamping force was released, is fixed to 0.15 mm.

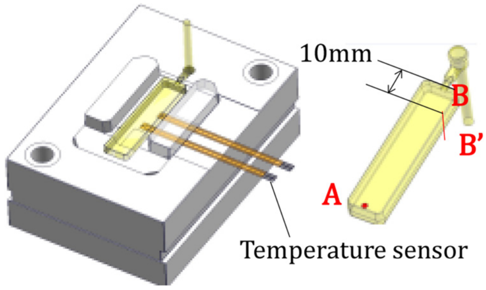


Fig. 3. Mold and test product.

Table 2
Injection molding condition of the product in Fig. 3.

Parameter	Value
Mold temp. (°C)	60
Injection plastic temp. (°C)	210
Set-up injection rate (mm/s)	50
Packing pressure; p (MPa)	30/50
Packing time (s)	3
Period from the end of packing to the release of the large clamping force; t_H(s)	0–6

The material was polypropylene (NOVATEC-PP, Japan Polypropylene). The length of flash was obtained by measuring the parting line above B–B′ in Fig. 3 with 3D Optical Surface Profilers (NewView8000, Zygo). The temperature distribution of resin was calculated using injection molding CAE software (3D-TIMON, TORAY Engineering). The material properties and boundary conditions for CAE are indicated in Tables 3 and 4. The heat transfer coefficient of the air had been adjusted based on the results of an experiment conducted in advance, but for the heat transfer coefficient of the metal die, a temporary value was used. For the purpose of modelling the cooling at a minute gap between molds, for temperature analysis after the large clamping force is released, assumed that the heat transfer coefficient of the element of the gap between the upper and

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