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Attempts to fabricate micro injection molding tools and assemble molded micro parts on same EDM machine

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ABSTRACT

An EDM method for manufacturing plastic micro gear pumps is proposed. Micro gates and cavities for mating gears are machined by EDM in both sides of a stainless steel foil, respectively. The foil is then transferred to an injection molding machine, and fixed to a mold to form mating gears by injection molding. The mating gears formed on the foils are then re-positioned on the EDM machine, released from the foil, and placed in a second foil pre-machined by EDM for the pump housing, using an ejector pin fabricated by reshaping the tool electrode used to machine the two foils.

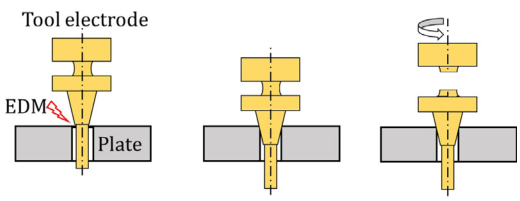
1. Introduction

In recent years, molded parts made of plastic materials are widely utilized in modern devices and optical elements. Among them, demands for micro size molding technology are growing to realize the downsizing of products.

The current research trend of micro injection molding is mainly directed to precision transfer printing technologies which replicate microstructures on the surface of relatively large plastic parts [1], such as micro lens arrays [2] and micro needle arrays [3].

However, little research has been conducted on molding microscale parts individually. Hopmann and Fischer [4] successfully controlled the amount of plastic precisely to mold micro parts. To minimize the waste and degradation of heated polymers, the units for the plasticization and injection were separated. On the other hand, Fujieda et al. [5] proposed a method to mass-produce separated micro parts using an injection molding machine which is widely used to produce parts of centimeter size. With their method, micro cavities and gates are machined on two stainless steel foils of 60 and 40 μm in thickness, respectively. Injection molding of a single micro lens is then carried out by laminating them and inserting them into a mold for molding a thin plate. When the plastic is injected in the cavity for the thin plate, the pressure in the cavity is increased to extrude the plastic from the micro gates into the micro cavities. Therefore, this method has advantages such as not requiring precise measurement of the amount of plastic and enabling large amounts of micro lens to be produced at one time. However, these previous researches did not consider how to handle and assemble the micro parts after injection molding to manufacture functional products. Since the micro parts are small and delicate, their handling and assembly are extremely difficult. Hence, in order to mass-produce micro machines composed of micro plastic parts, it is necessary to develop a system with which fabrication of micro mold inserts, micro injection molding, and micro assembly are continuously performed with minimum manual work.

In a previous research on micro assembly, Langen et al. [6] proposed an assembly method using an electrical discharge machining (EDM) machine as shown in Fig. 1. To assemble a micro pin and metal plate, the pin is first formed by EDM. In this step, taper and neck are also machined at the same time. Then, a hole is machined in the metal using the straight part of the pin as a tool electrode. Next, the tapered pin is press fitted into the hole. Finally, the pin is twisted to break it at the neck, thereby assembling the plate and pin. However, since holes are machined by EDM, all the parts need to be made of electrically conductive materials. Thus, in this research, in order to manufacture micro machines composed of plastic parts, we aim to develop an EDM micro production system which can automate all the processes from tool forming, mold insert fabrication, injection molding, handling, positioning and assembly.



(a) Micro-EDM (b) Insert (c) Twist

Fig. 1. Fabrication process of pin plate module.

2. Fabricated micro gear pump

For the demonstration test of the developed system, the micro gear pump shown in Fig. 2 was fabricated in the micro channel. The gears are made of plastic (polypropylene), and the micro channel is

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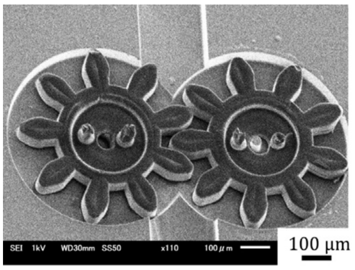

Fig. 2. Fabricated micro gear pump.

made of stainless steel. The right gear is driven by the left gear which is rotated by a shaft inserted into the chamfered hole made at the center of the driving gear.

3. EDM micro production system

3.1. Whole system

Fig. 3 shows the flow chart of the whole production system that was developed. First, a tool electrode is machined by EDM (a). Next, the stainless steel foil of 100 µm in thickness is fixed to the positioning jig on the EDM machine, and the cavities are machined by EDM (b) using the tool electrode machined in step (a). The foil is inserted into the mold (c) and injection molding is performed (d). Before the foil with the molded micro gears is detached from the mold and fixed again to the positioning jig on the EDM machine (e), another stainless steel foil, called base foil, is fixed on the same jig and pump cavities are fabricated on it by EDM (f). Finally, molded parts are released from the insert foil and assembled to the base foil using an ejector pin made from the same rod that had been used throughout the whole production process on the developed system, reshaped repeatedly for different purposes (g).

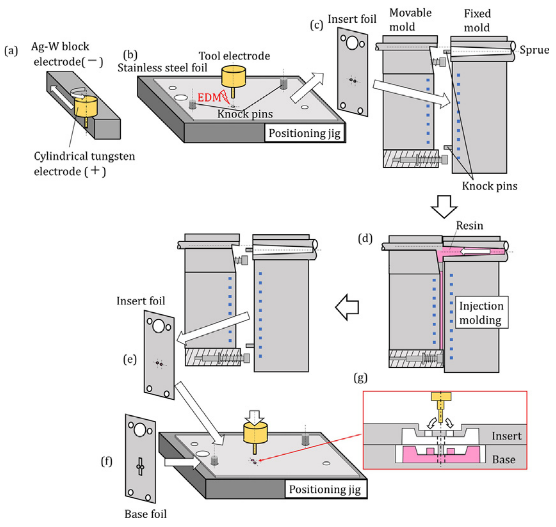

Fig. 3. Flow chart of EDM micro production system.

3.2. Machining of micro cavities

First, as shown in Fig. 3(a), a tungsten cylindrical rod of 500 µm in diameter is machined by EDM using a silver tungsten block electrode to obtain a tool electrode of 48 µm in diameter with the machining conditions shown in Table 1. The EDM machine used in this research was Sodick AE05 with a positioning accuracy of 0.5 nm. In step (b), the stainless steel foil, called insert foil, is positioned on the jig on the EDM machine using two knock pins. The repeatability of positioning the stainless steel foil is within ±2 µm. Table 2 shows the EDM conditions for the cavity machining. By setting the electrostatic capacitance as the stray capacitance, the discharge energy can be minimized to enable fine processing.

Table 1
Machining conditions used for shaping tool electrode.

Power supply voltage (V)	137
Servo reference voltage (V)	120
Capacitance (pF)	2200
Rotation speed of tool electrode (rpm)	3000
Workpiece	Tungsten

Table 2
Machining conditions used for fabricating cavity.

Power supply voltage (V)	137
Servo reference voltage (V)	120
Capacitance (pF)	Stray capacitance
Rotation speed of tool electrode (rpm)	3000
Workpiece	Stainless steel foil (SUS304)

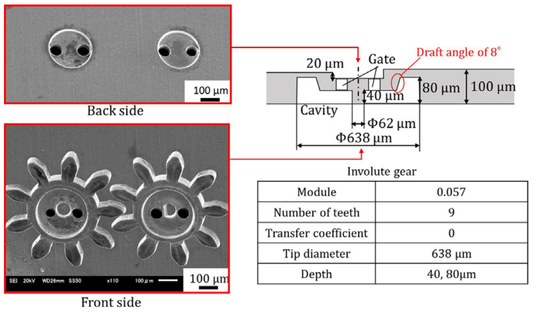

Fig. 4. Cavities of micro gears machined on insert foil.

Fig. 4 shows the cavities of the micro gears machined on the insert foil. It took about nine hours to finish all the machining. The cavities of two gears are machined so that they are meshed with each other. Two gate holes are prepared for each gear to facilitate the filling of the plastic and to release the gear from the insert foil evenly using the ejector pin as described later in Section 3.5. In addition, the periphery of the boss in the cavity has a draft angle of 8° to facilitate the release of the plastic gear after injection molding. Without the draft angle, the release resistance is large due to the shrinkage of the plastic, causing the deformation of gears at step (g) in Fig. 3.

3.3. Injection molding

Fig. 5(a) and (b) shows the schematic diagram of the mold used in this research and molded product, respectively. This mold was originally developed by Ogawa et al. [7] to produce thin light guide plates with a length of 50 mm, width of 40 mm, and thickness of 0.35 mm. The mold is made by diffusion bonding of laminated tool steel plates. For this reason, coolant channels are arranged at a depth of 2 mm from the molding surface, enabling the control of the mold surface temperature so that it is more or less constant and uniform over the entire surface. Taking advantage of the uniformity of the mold temperature, Fujieda et al. [5] performed micro injection molding by using the space originally made for the light guide plate as a sheet runner from which molten plastic is introduced to micro gates distributed over the insert foil attached on the mold. As a result, they were able to produce a considerable number of micro parts at one time on the large area. Since this method did not require precise measurement of the amount of injected plastic, micro injection molding could be performed using

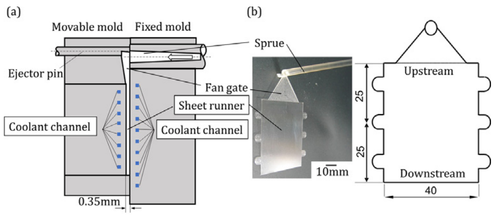

Fig. 5. Mold and molded plastic plate.