Development of On-The-Machine Robotic Mold-Maintenance System by Utilizing Electro Discharge Deposition Technology

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Abstract

Maintenance of mold in a regular schedule has emerged as powerful platforms for quality assurance of the product. One of the greatest challenges is it may cause a dangerous situation for workers in the process of repairing mold using manual operation. This study set out to investigate the usefulness of a robotic system based on the on-the-machine repair of the worn mold without detaching and attaching the mold. Specifically, an electrodeposition applicator for repairing is attached to the hand of the work conveying robot which is installed near the machine tool. This study employed a vertical articulated robot, which is equipped with various sensors. Fundamental electrodeposition experiments were performed using the constructed robot system. The results from the experiments showed the feasibility of the developed system.

1. Introduction

Manufacturing methods are fast becoming a key instrument in the manufacturing processes. Some processes are considered important in mass production, such as pressing, injection molding, and casting. In particular, regular maintenance of the mold is prerequisite to keep the product qualified. In the case of mass production, spare molds are usually prepared for the regular maintenance of mold. On the contrary, if the mass production is not needed, an immediate repairing of mold wear and defects and modification of the design of the mold in the correction of processing errors are required. There is an urgent need to address the safety problems caused by maintenance of the mold which is installed on the machine tool. For example, workers are risky to have a burn by touching hot parts, receive injuries by falling on heavy parts or having cramps (see Figure 1).

This study uses a robot system to make awareness of the use of the on-the-machine maintenance of molds. The process begins by installing the robot system near a machine tool in the production line because the robot is used to transfer a work piece. Its duties involve pressing, injection molding, and die casting. In this process, we only focus on the process which the robot transfers workpiece in front of a machine. Recently, Verl et. al. (2019) studied the effects of utilization of industrial robot [4]. Considering all of this evidence, it seems that the industrial robot can be not only applied for transferring of the workpiece but it can also be used in machining and tooling. Using this approach, researchers have been able to know the concept of robot repairing system.
The goal of the robot system is that the robot itself replaces the end effector, recognizes mold defects such as wear, and performs on-machine repair of the mold. In the study, the robotic hand finishing was proposed in the paper [4]. Over the past decade, most research in technology has emphasized the use of the robot in trimming, splaying, and polishing, and it evolves today’s technology. On the other hand, in recent years, laser, electron beam, and micro-welding that enable us to control material deposition with low heat input. The mold repair options have been paid more attention [3]. Therefore, using installed Electro Discharge Deposition (EDD) technology in the robot can help perform a function of transferring and repairing mold.

Figure 1. The instance of mold repairing done by an engineer [1]

To use the mentioned concept, the first step in this process was to develop a robotic system that can build up metal on scratches using EDD technology and use in the experiment. The feasibility of on-the-machine mold-maintenance will be also discussed in this paper.

2. On-the-machine robotic mold-maintenance system

2.1. System Outline

Figure 2 shows a set-up experiment of a metal build-up using the vertical articulated robot. The vertical articulated robot used in this study is RS20N and it was made by Kawasaki Heavy Industries. EDD device, so-called Micro-depo, that was made by Techno-Coat Co. Ltd. was selected for deposition of metal build-up and is installed on the robot arm as the end effector. Micro-depo is a coating device that was developed to repair the mold. The control parameter of the Micro-depo are voltage, capacitance, and frequency. The stage of assuming mending scratch on mold, the SD-01 type of electrode was selected in the experiment of the study. This electrode can provide deposition of metal that is used to build-up on various materials, such as SCM, SC, SUS. The material of electrode is made of tungsten carbide and cobalt, and it can be applied to the process of mold repair.

Figure 2. The process of system development
2.2. Method of Electro Discharge Deposition (EDD) Process

EDD is a process that has a composition of electrode and was melted by an electric spark generated between workpiece and electrode. It was also deposited on the surface of the workpiece.

The electrode material is heated to 8,000-25,000 [°C] at the contact portion. It functions by discharging the direct current for a very short time of $10^{-6}$ to $10^{-5}$ seconds in a cycle of $10^{-3}$ to $10^{-1}$ seconds. The heated electrode turns into a plasma and metallurgically transfers to the work surface. The transferred electrode material is alloyed and can be overlaid by depositing on the work surface (see Figure 3-a). In this stage, an appropriate gap is required because it can generate a spark between the workpiece and the electrode. This gap is called the discharge gap. Regarding the sparks, they do not occur when the workpiece and the electrode are in contact (the discharge gap is 0) [3]. When the method of Micro-depo EDD is used, the vertical position of the electrode is frequently moved up and down. Then, it continues to process. The electrodeposition is adjusted so that the discharge gap is suitable to generate a spark.

![Image](a)

**Figure 3.** Illustration of replicator unit and discharge cycle[1]

There are two advantages of utilizing of Micro-depo EDD method. One is to investigate a low input of heat. The mold surface is less affected by heat i.e. thermal strain, cracks, sinks, etc. Because the spark time is very short ($10^{-6}$ to $10^{-5}$ seconds) but the interval between discharges is ($10^{-3}$ to $10^{-1}$ seconds) is long for the spark time (see Figure 2-b). It was found that other show a high adhesion that does not peel off after the build-up. The reason is that the electrode is alloyed and deposited on the workpiece. At the same time, it forms a strong diffusion layer like grown-up root below the surface (see Figure 2-a). In addition, the materials of plastic (S55C, SCM445, SCM430, etc) are generally adopted [2]. Therefore, there is an advantage of using electric conductors including those steel materials because they can be utilized as a workpiece by proper choice of electrodes.

2.3. Motion programming for die repair

Micro-depo EDD equipment is applied to repair defects of mold. To utilize it as an end effector of the robotic system, it is necessary to program the tool move as a human operator does. Figure 3 provides the programmed motion of the basic built-up motion of the electrode. To begin this process of mold repair operations, the electrode is contacted with the surface of the work, and the electrode is moved in the horizontal direction by the designated distance of the move. When a spark is generated from the tip of the electrode, the melted electrode is transferred to the surface of the workpiece. Once, the electrode leaves for upward in the vertical direction and returns to the start point of this sequence, the cycle is completed. Following the next cycle, after positioning of shortened electrodes is compensated, the sequence is repeated until the height correction of the deposited is in the vertical direction. Table 1 presents the parameters that can affect mold repair processing.
3. Fundamental deposition experiment

To understand the mold repair cycle, the robotic system is used as a trial. Length error of deposition against to the programed length is investigated. In this process, it is assumed that there is one to repair a scratch of 10 mm length, 1 mm width, and about 0.5 mm depth on the surface of S35C, 10.0 [mm] of feed and this stage was programmed.

After the deposition experiment, the deposited line is obtained as shown in Figure 4. It is clear that the electrode material is deposited on the surface of the workpiece because it demonstrates the state of the weld bead.

The length of this deposited line was measured as shown in the red line (see Figure 5). As can be seen in Table 2, the length errors obtained under various conditions using tool feeding speed and capacitor capacity of EDD controller.

Table 1. Control element

| Control method                  | Control range |
|--------------------------------|---------------|
| Cycle count[Times]             | program       |
| Discharge gap[mm]              | program       |
| Feeding speed[mm/s]            | program       |
| Height correction[mm]          | program       |
| Base material and electrode angle[°] | program | 0 ~ 90 |
| POWER[V]                      | Microdepo     |
| Capacitor capacity[μF]         | Microdepo     |
| Spark frequency[Hz]            | Microdepo     |
| Electrode rotation number[RPM] | measurement   |
| Electrode diameter[mm]         | -             |
| Atmosphere                     | Argon gas=2~15[L/min] |

Figure 4. Illustration of repair sequence

Figure 5. obtained surface in deposition experiment
Table 2. Length error in various control parameters

| Feeding speed [mm/s] | Capacitor capacity [μF] | Length errors [mm] |
|---------------------|-------------------------|--------------------|
|                     | 10          | 50          | 100          |
| 1                   | +1.09       | +1.21       | +0.99        |
| 5                   | +1.01       | +1.09       | +1.11        |
| 10                  | +0.94       | +0.95       | +1.19        |

The results revealed that the feed rate and capacitor capacitance have less influence on the length of the obtained deposition length under this experimental condition. Meanwhile, the length was about 0.9 to 1.2 mm and was longer than the distance of the tool travel.

4. Cause of error in deposit length

To identify the error that affects factor of the deposit length, the generation of spark at the end of the electrode is observed by using a microscope. The results indicated that the melted electrode composition can transfer to the surface on the workpiece. The obtained microscope image is shown in Figure 6. It also shows that the sparks are generated inside from the acute angle side by the end of the electrode. A possible explanation for this might be that the length of deposition becomes longer than the length of the programmed tool feed in the X-direction. There are, however, other possible explanations. It can generate an extra spark of the electrode which can produce deposition of the melted droplet of the electrode.

![Figure 6. Spark generating point](image)

![Figure 7. Illustration of mechanism about Occurrence of error](image)
5. Conclusion
The aim of the present research was to examine the on-the-machine maintenance of molds. This study has shown that the robotic system can deposit metal on scratches by using the EDD device so-called Micro-Depo. The feasibility of the on-the-machine robotic mold-maintenance is also discussed. This study has found that generally, when moving the electrode in the horizontal direction by the specified value, the deposit length error is about 0.9 to 1.2 [mm]. It did not affect on the feeding speed and capacitor capacitance (1). The second major finding was that since the sparks are generated from the acute angle side of the tip of the electrode, extra spark is generated for the horizontal feed of the electrode resulting in the deposit length error (2). Further research could usefully explore how to build the on-the-machine maintenance of mold by developing of the mold-repair cycle made by repeating build-up deposition-processing of the straight beads. Further work could also be conducted using a deposition method to guarantee a sufficient hardness of deposited area in mold repairing.

Acknowledgments
The authors would like to acknowledge that some images and illustrations related to experimental equipment and molding technology were provided by Techno Coat Company Limited. We are thankful for the support from Mr. Takumi Tanaka, the 5th-year student in the department of mechanical engineering at NIT Ariake.

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