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Research Paper

Magnetic fixtures for enhancement of smoothing effect by electron beam melting

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ABSTRACT

In large-area electron beam (EB) irradiation method developed recently, high energy density EB can be obtained without focusing the beam. Therefore, large-area EB of 60 mm in diameter can be used for instant melting and evaporation of the wide area material surface, and high efficient surface finishing is possible. However, if the workpiece has a hole shape, the EB concentrates in the entrance edge or inside wall of the hole. Thus, it is difficult to smooth the hole bottom surface. Previous study showed that the surface smoothing and micro-deburring effects for non-magnetic workpiece could be improved by setting a magnetic block under the workpiece, since the electrons tend to concentrate the magnetic block along magnetic lines. In this study, smoothing of hole bottom surface was experimentally investigated by setting a magnetic block under a workpiece in large-area EB irradiation. Expansion of smoothing area of the bottom surface was also tried by setting a through hole at the center of the magnetic block. It was clarified that wide area of hole bottom surface could be smoothed by large- area EB irradiation by setting the magnetic block under workpiece. The surface roughness decreased to less than 3.0 μmRz at the area of hole bottom surface. When the hole diameter was 20 mm and hole depth was less than 40 mm, smoothing area of 10 mm in diameter was obtained by using the magnetic block. Moreover, the smoothing area was sufficiently expanded by setting a through hole with an appropriate diameter in magnetic block.

1. Introduction

Surface finishing of metal molds is generally done by hand lapping after milling or electric discharge machining (EDM), in order to obtain high quality and precise products. However, this process takes a long time and needs special technical skills. Ultrasonic polishing has been conducted for surface finishing on metal mold steel (Hocheng and Kuo, 2002; Jones and Hull, 1998), although this process requires abrasive fluids and there is a limitation of the workpiece size. Pulsed laser polishing (Pfefferkorn et al., 2014), CO_2 laser polishing (Ukar et al., 2010), and laser sintering (Ramos-Grez and Bourell, 2004; Lamikiz et al., 2007) have also been done for surface roughness reduction on metals. However, these techniques need adjustment of laser focusing point and large heat affected zone is generally generated. Therefore, a highly efficient surface finishing technique is still required.

In a large-area electron beam (EB) irradiation method developed recently, high energy density of EB can be obtained on workpiece surface without focusing the beam (Proskurovsky et al., 1997; Uno et al., 2005). Then, the large-area EB of about 60 mm in diameter can be used for melting and evaporating metal surface instantly. Therefore, highly efficient surface finishing is possible by preferential melting of convex rough surface with the surface roughness of several μmRz. Our previous study showed that reducing surface roughness with large-area EB was possible for the various materials, such as metal molds made of tool steels (NAK80 and SKD11 in JIS specifications) (Daichi et al., 2007), cemented carbide (Okada et al., 2011) and aluminum oxide (Ishida et al., 2008). The experimental results clarified that the surface roughness of metal mold steel decreased from 6.0 μmRz to less than 1.0 μmRz in a few minutes under appropriate conditions. In the cases of cemented carbide and aluminum oxide, the surface roughness also reduced. The releasability of the molded resin could be improved since the surface structure of cemented carbide was changed after EB irradiation. Moreover, we recently revealed that surface functions such as corrosion resistance and water repellency of the metal molds were improved by the large-area EB irradiation (Okada et al., 2014). Selada et al. (2011) also showed that corrosion and oxidation resistance of micro-injection molds were improved by combination techniques of laser beam and large-area EB irradiation. Furthermore, high corrosion resistance was even obtained on titanium alloys after the large-area EB irradiation (Okada et al., 2004; Walker et al., 2014). This large-area EB

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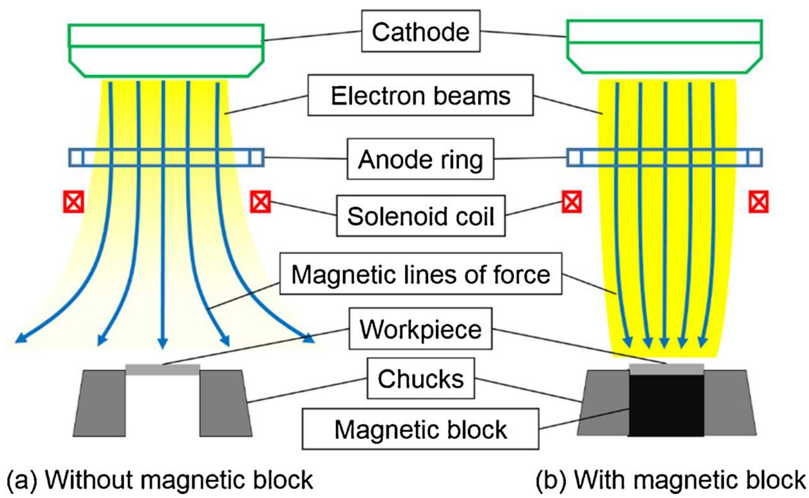

Fig. 1. Schematic illustration of a large-area EB irradiation with and without magnetic block.

irradiation method can be applied to complex shape. Murray et al. (2013) reported that surface roughness of micro rods was enhanced from an initial Ra = 126 nm to 22 nm, and edge of the micro rods surface was slightly rounded after large-area EB irradiation. Our experimental and simulation results suggested that this rounding phenomenon was caused by EB concentration on the tip due to concentration of magnetic fields, which was generated by solenoid coils set on the outside of the chamber in large-area EB equipment, near the tip (Shinonaga et al., 2016a).

However, if the workpiece has hole shape, the EB concentrates on the entrance edge or upper inside wall of the hole. Therefore, it is expected that smoothing of the hole bottom surface is difficult for large-area EB irradiation. Previous study showed that the surface smoothing and micro-deburring effects on non-magnetic workpiece of copper (Cu) could be improved by setting a magnetic block under the workpiece (Shinonaga et al., 2016b). As described before, during large-area EB irradiation, the lines of magnetic force are generated by solenoid coils set on the outside of the chamber. If the workpiece is magnetic material, the lines of magnetic force are directed towards the workpiece as shown in Fig. 1. Thus, EB with high energy density is irradiated to the non-magnetic materials by setting a magnetic block under the workpiece. The results suggest that the EB concentrates on the hole bottom surface by setting the magnetic block under the workpiece.

In this study, the influence of magnetic block on smoothing of hole bottom surface in large-area EB irradiation was experimentally investigated. Expansion of the smoothing area of the hole bottom surface was also tried by creating a through hole in the magnetic block. To the best of our knowledge, this is the first report for smoothing of hole bottom surface by large-area EB irradiation.

2. Experimental procedure

2.1. Large-area EB irradiation method

Fig. 2 schematically illustrates large-area EB irradiation equipment. In this method, ambience inside the chamber is argon (Ar) gas of about 10^{-2}Pa. At first, a magnetic field is generated by the solenoid coils set on the outer side of the chamber. When the magnetic field takes a maximum intensity, pulse voltage is loaded to the anode. Then, Ar plasma is generated in the operating chamber by rapid changes in magnetic and electric fields. Next, a pulse voltage is applied to the cathode, and the electrons are explosively emitted from the cathode by high electric field near the cathode. Therefore, large-area EB with uniformly high energy density sufficient to melt and evaporate the workpiece surface can be obtained. As shown in Table 1, pulse duration T_d, pulse frequency F_p were fixed to 2.0 µs, 0.125 Hz, respectively. Energy density E_d was varied from 7.5 to 15J/cm^2 and shot number of N was varied up to 40 shots.

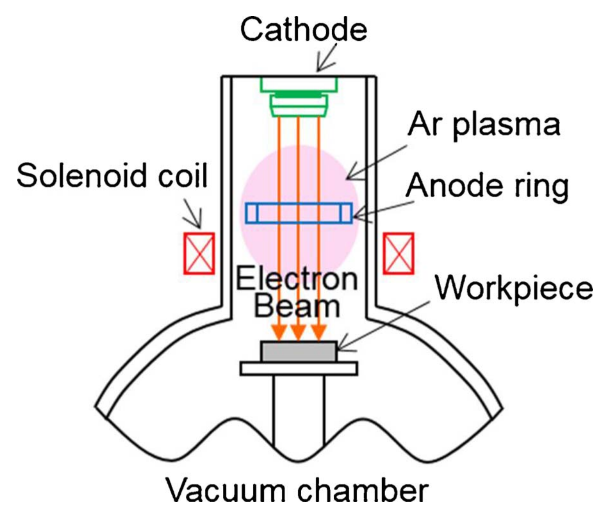

Fig. 2. Schematic illustration of a large-area EB irradiation equipment.

Table 1
Large-area EB conditions.

Pulse duration	T_d	[µs]	2.0
Pulse frequency	F_p	[Hz]	0.125
Energy density	E_d	[J/cm^2]	7.5–15
Shot number	N	[shot]	1–40

2.2. Workpiece and definition of smoothing area

Pure aluminum (Al) was used for workpiece in this study, and a hole shape was obtained by combining a bottom plate and a cubic block with a through hole as shown in Fig. 3 in order to make it easy to measure bottom surface roughness. Diameter of the through hole in workpiece was fixed to 20 mm. A uniform surface roughness of 12.0 µmRz on the Al plate surface was obtained by using wire EDM. Fig. 4 shows scanning electron microscope (SEM) images and surface profiles of Al plate before and after large-area EB irradiation. After EB irradiation under appropriate EB conditions of E_d = 10J/cm^2 and N = 30shots, sufficiently smooth surface could be obtained on the Al plate, and surface roughness of the plate was reduced from 12.0 µmRz to 2.6 µmRz. These results suggested that the limit values for reducing surface roughness on Al plate were about 2.6 µmRz. Therefore, if the roughness on hole