PLASMA NITRIDING OF FINE MICRO-PATTERNED MARTENSITIC STAINLESS STEEL MOLD FOR INJECTION MOLDING

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ABSTRACT The plasma printing had grown as an important means not only to make micro- and nano-texturing onto the surface of metallic products but also to fabricate the molds and dies for micro-stamping and macro-processing. This plasma printing consisted of three steps: 1) ink-jet printing to draw the initial two dimensional micro-pattern onto the metallic products or dies/molds, 2) high density plasma nitriding to transform the initial micro-pattern to the hardness depth profile distribution, and, 3) mechanical removal of the printed area to make three dimensional micro-textures. This plasma printing was successfully applied to micro-texturing onto the stainless steel molds for injection molding. In the present study, high resolution ink-jet printing is employed to investigate the effect of drawing accuracy in the micro-patterning on the geometric accuracy of micro-textures. This ink-jet printing has capability in micro-dot patterning down to 8 μm. The silver nano-particle ink is utilized to draw the micro-dot and micro-line patterns besides the usage of primer and carbon-black compound ink. High density plasma nitriding is performed to investigate the effect of nitrogen ion density on the selective nitriding and hardening behavior in this plasma printing. Both the SEM-EDX and three dimensional profilometer are employed not only to describe the selective nitriding process in micro-texturing but also to measure the geometry of micro-textures The surface contact angle measurement is also utilized to discuss the effect of the plasma nitriding and micro-texturing on the surface property.

INTRODUCTION

Micro- and nano-textures on the metal and polymer surfaces of parts and components have functions to reduce the friction and wear and to improve the joining strength (Denkena, 2012; Aizawa, 2014-1). As needed, the surface texturing is also employed to have the surface profile leather-touched or textile-patterned. In order to fabricate these micro- and nano-textured surface of products, the mold-die units for injection molding must have their original micro- and nano-textures on surface. When using the micro-milling or micro-EDM, huge amount of digital data has to be built in as CAM data before actual time-consuming micro-milling or micro-EDM (Estion, 2004; Jiang, 2011). A non-traditional micro-texturing method is demanded in market to fabricate the molds in much shorter processing time.

The authors (Aizawa, 2014-1, 2, 3; Santojojo, 2014) have proposed an alternative micro-texturing with aid of the high density plasma nitriding, or, the plasma printing method. This process consists of three steps: #1 Ink-jet printing to draw the initial two dimensional micro-pattern onto the metallic products or dies/molds, #2 High density plasma nitriding to transform the initial micro-pattern to the hardness depth profile distribution, and, #3 Mechanical removal of the printed area to make three dimensional micro-textures. Authors applied this plasma printing successfully to micro-texturing onto the stainless steel molds for injection molding (Katoh, 2014; Aizawa, 2015). This process has several preferable features: 1) Fine resolution of micro-textures on the mold, 2) Accurate alignment of micro-textures on the mold, 3) Significant reduction of leading time, 4) Micro-texturing onto the large surface area, and 5) Flexibility in micro-texturing. In the present study, high resolution ink-jet printing is employed to investigate the effect of drawing accuracy in the micro-patterning on the geometric accuracy of micro-textures. This ink-jet printing has capability in micro-dot patterning down to 8 μm. The silver nano-particle ink is utilized to draw the micro-dot and micro-line patterns besides the usage of primer and carbon-black compound ink. High density plasma nitriding is performed to investigate the effect of nitrogen ion density on the selective nitriding and hardening behavior in this plasma printing. Both the SEM-EDX and three dimensional profilometer are employed not only to describe the selective nitriding process in micro-texturing but also to measure the geometry of micro-textures The surface contact angle measurement is also utilized to discuss the effect of the plasma nitriding and micro-texturing on the surface property.

EXPERIMENTAL PROCEDURE

2.1 Experimental Apparatus

The present plasma printing process mainly consists of three steps, as illustrated in Fig. 1.

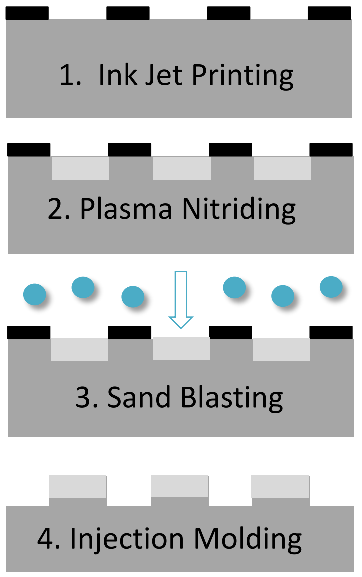

Fig. 1 Plasma printing process, assisted by the high density plasma nitriding.

The ink-jet printing method is first employed to print the initial two-dimensional micro-patterns directly on the surface of substrate materials. In second, the low temperature plasma nitriding is employed to transform this micro-pattern to hardness-profiled pattern. Since the ink-jet printed micro-pattern works as a mask for nitriding, the unprinted substrate surface is selectively nitrided and hardened. Finally, the sand-blasting is further used to mechanically remove the masked or printed area on the surface and to dig the micro-textures into substrate. Then, the original micro-patterns drawn on the substrate surface transforms to the three dimension micro-textures into the mold substrate; the top surface of unprinted or nitrided area has sufficiently high hardness to working as a mold. This micro-textured mold is used in the injection molding to duplicate the original micro-patterns onto the plastic products.

2.2 High Density Plasma Nitriding System

High density plasma nitriding system was set-up for solid-solution hardening of steels. Different from the DC- or RF-plasma generators, where the plasmas are ignited and generated in the frequency of 13. 56 MHZ or its multiples, the present high density nitriding system has no mechanical matching box with slow response time of 1 s to 10 s to adjust the applied power. Since input and out powers are automatically matched by frequency adjustment around 2 MHz, the matching response time is only limited to 1 ms at most. This prompt power control provides to make full use of meso-plasma pressure range over 50 Pa.

Different from the conventional processes, the vacuum chamber is electrically neutral so that RF-power and DC-bias should be controlled independently from each other. A dipole electrode is utilized to generate RF-plasma; DC bias is directly applied to the specimens. Heating unit is located under this DC-biased cathode plate. The emissive light spectroscopy (PMA-11, Hamamatsu, Co. Ltd.) as well as the Langmuir probe system (ALP System, Impedans, Co. Ltd.), are instrumented to the present plasma nitriding system to make quantitative diagnosis on the generated nitrogen plasmas. Through the preliminary studies, the nitriding conditions were optimized as listed in Table 1.

Table 1 Optimal nitriding conditions for solid solution hardening via the high density plasma nitriding processes.

Process	Parameters
Pre-sputtering	DC(500V) Nitrogen (75 Pa) at 693 K for 1.8 ks
Nitriding	RF(250V), DC(300V) Nitrogen (100 ml/min) Hydrogen (20 ml/min) 75 Pa at 693 K for 7.2 ks

In the following nitriding experiments, the specimens were located on the cathode table before evacuation down to the base pressure of 0.1 Pa. Then, nitrogen gas was first introduced as a carrier gas before heating. After heating to the specified holding temperature, nitrogen pre-sputtering was started at the constant pressure. After pre-sputtering, hydrogen gas was added to nitrogen gas with the specified partial pressure ratio. Both pressure (P) and temperature (T) controls were automatically performed with the tolerance of $\Delta P < 1$ Pa in deviation of partial pressure and $\Delta T < 1$ K in temperature fluctuation.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Micro-Dot Texturing by Plasma Printing

The square-shaped micro-patterns were printed onto the surface of AISI-SUS420 stainless steel mold-die unit by using the flat-bed type ink-jet printer (Mimaki-

Engineering, Co. Ltd.), as shown in Fig. 2. The edge length was varied from 100 μm to 500 μm; these square units are accurately printed to be in checker-board pattern onto the surface of mold substrate.

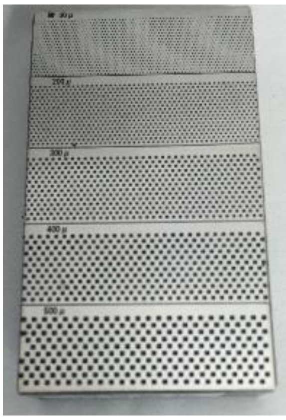

Fig. 2 Initial micro-dot pattern drawn by the ink-jet printing onto the surface of AISI420 mold.

No nitrogen atoms were permeable to the printed patterns since these printed patterns worked as a masking on the surface. Then, the hardness of this patterned regions remained to have the same as the matrix hardness. On the other hand, the bare surface of mold-unit other than the printed region were plasma-nitrided to have higher hardness. Figure 3 depicted the hardness profile across the square patterns. Higher hardness than 1000 HV was attained in the unmasked regions; the measured hardness in the masked or printed square patterns is nearly equal to the heat-treated AISI420 substrates.

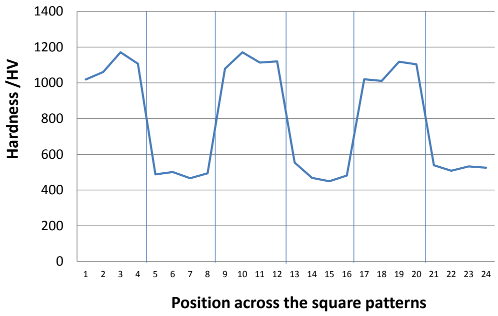

Fig. 3 Hardness profile of the plasma nitrided AISI420 mold substrate across the square dots.

The air-blasting system with the SFC-100 (Fuji-Seiki, Co. Ltd.) was utilized to make sand-blasting to eliminate the printed patterns and to dig the printed patterns. Among several candidate media, the glass powders with the diameter of 30 μm was employed in this blasting treatment. Figure 4 shows the blasted surface of plasma-nitrided AISI420 mold. The optical microscope was used to measure the square micro-textures with the edge length of 100 μm on the surface of specimen. As shown in Fig. 5, each square micro-texture was precisely dug into the mold-unit with the depth of 10 μm. To be noticed, each corner of square micro-pattern is regularly dug into the mold-unit as a sharp corner just in the similar manner to micro-milling or micro-EDM (electrically discharge-machining). This geometric accuracy as well as the flexibility in shaping characterize this plasma printing in practice.

Fig. 4 Micro-textures formed into the AISI420 mold unit after sand-blasting.

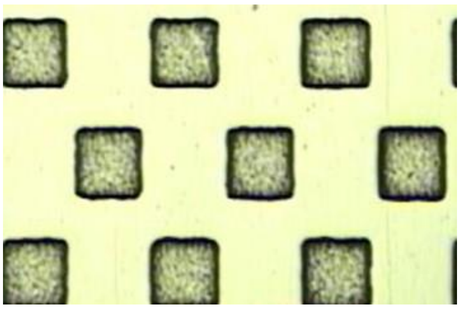

Fig. 5 Micro-textures with the square pattern, plasma-printed into the AISI420 mold unit.

3.2 Injection Molding

The micro-textured mold-unit was fixed into the cassette mold-die for injection molding. The injection molding system (Mitsubishi Electrics, Co., Ltd.) was employed to duplicate the micro-textures onto the plastic cover case of mobile phone (i-phone6). The polycarbonate was utilized as a work material. Figure 6 depicts the optical microscopic image of the PC cover case. The duplicated micro-textures are regularly aligned on the top surface with uniform and flat height of 10 μm.

CONCLUSION

New universal design of products like a mobile phone requires for innovative manufacturing to control the contact surface conditions and interfacial configuration. Micro-textures are ready to prevent from slipping the phones from hands and to improve the contact feeling between the hands or fingers and the mobile phones. Furthermore, slightly visible or nearly invisible micro-textures are useful to increase the high quality of products as well as their feeing in touch. The present micro-texturing provides an engineering solution to product-design oriented issues in manufacturing.

The plasma printing method provides a means to decorate the plastic product surface by various kinds of micro-textures only by improving the mold surface quality for injection molding. When using the conventional tooling such as micro-milling or micro-EDM, huge amount of production cost and leading time is needed to machine the designed micro-textured into molds with increasing the density and geometric complexity of micro-textures. The plasma printing process is commonly useful to micro-texturing the molds irrespective of the micro-texture density and its complexity in geometry. In particular, this method is expected to play a role in manufacturing of medical parts and sheets, which require for perforation of tailored unit-cells in the specified surfaces and interfaces.

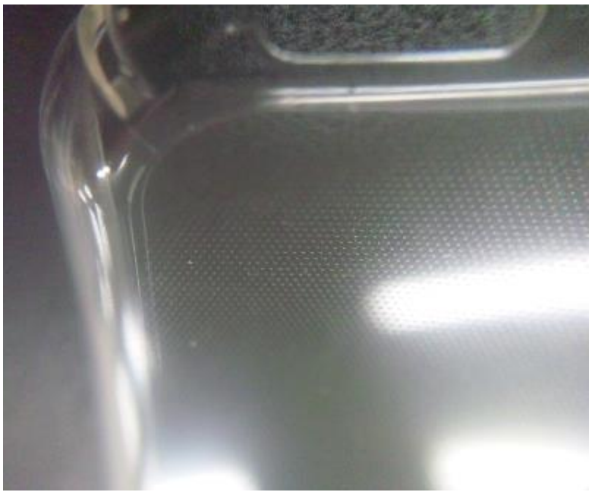

Fig. 6 Convex micro-textures on the plastic cover-case, duplicated by the injection molding with use of the concave micro-textures on the mold surface.

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REFERENCES

Aizawa, T., Satoh, S., Yamaguchi, T., 2014-1, Micro-texturing design for joining between polymer components. Proc. 7th ICOMM, 15, 1-9.

Aizawa, T., Yamaguchi, T., Sakayori, O., 2014-2, Japanese Patent of #2014-038436.

Aizawa, T., Yamaguchi, T., 2014-3, High-density plasma nitriding assisted micro-texturing onto martensitic stainless steel mold-die. Proc. IWMF2014, 31-37.

Aizawa, T., Yamaguchi, T., 2015, Plasma nitriding assisted micro-texturing into martensitic stainless steel molds for injection molding, Proc. 10th 4M/ICOMM, 460, 1-8.

Denkena, B., Koehler, J., Laestner, J., 2012, Efficient machining of micro-dimples for friction reduction. Proc. 7th ICOMM, 85-89.

Etsion, I., 2004, Improving tribological performance of mechanical components by laser surface texturing, Tribology Letters, 17: 733-737.

Jiang, Y., Zhao, W.S., Kang, X.M., Gu, L., 2011, Adaptive control for micro-hole EDM process with wavelet transform detecting method. Proc. 6th ICOMM, 207-211.

Katoh, T., Aizawa, T., Yamaguchi, T., 2015, Plasma assisted nitriding for micro-texturing onto martensitic stainless steels. Manufacturing Review, 2, 1-8.

Santojoyo, D., Aizawa, T., Muraishi, S., Morita, H., 2014, Micro-texturing of stainless steels via high density plasma nitriding. Proc. 9th ICOMM, 90, 1-8.

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