Electron Beam Micromachining of Plastics

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INTRODUCTION

The electron beam is often used to drilling and machining of various kinds of materials, both metals and non-metals [1]. The plastics were often neglected, mainly because they are insulators and contain a lot of gasses that get released when heated. The aim of this work was to find out some basics about machining of the plastics by the electron beam

EXPERIMENTAL SETUP

The presented experiments were performed on the desktop electron beam welder MEBW-60/2 (Fig. 1), developed at the Institute of Scientific Instruments AS CR, v.v.i. at Brno [2, 3]. It is also manufactured and sold by the Focus GmbH company under licence [4]. Our EB welder operates with accelerating voltage of up to 60 kV. The maximum power is 2 kW (33 mA at 60 kV or 40 mA at 50 kV).

For study of the surface structuring a testing pattern was used (Fig.2). It consisted of 6 lines of 10 squares of different color. The intensity of the color determined the speed of the beam movement, thus the melted volume. The brighter the color, the faster the speed. Each square was 1x1 mm in size, so the size of the final structure was 10×6 mm. The squares were engraved line by line with pitch of 0.083 mm (i.e. 12 lines/mm). Beam parameters used for the engraving of the patterns shown here were: HV: 50 kV, BC: 0.3 mA, engraving speed about 3000 mm/s.

Polytetrafluorethylen (PTFE)

Teflon is easily melted by EB without apparent degradation or color change. Created lines and relief were uniform without too much of spilled melted material, even at the higher beam power.

The engraved testing pattern is shown Fig. 3. The stepped structure is not apparent, however, each brightness step resulted in 9 µm step, so the deepest step was 45 µm.

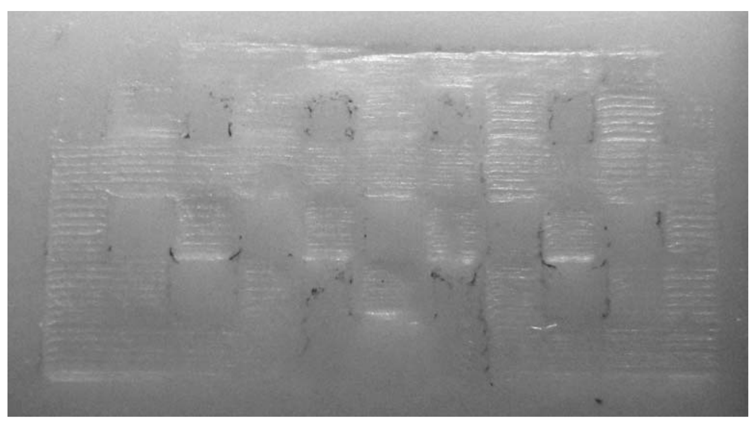

Fig. 3 Engraved pattern in PTFE

Polyvinylchloride (PVC)

Heating PVC with an electron beam change the original color to white and light brown. At the same time the material expanded and small hump grew. After that, it melted and evaporated. It further darkened and solidified as a sponge-like ridge. With rising beam power the ridge grew bigger.

However, it is possible to engrave it with labels and images. Engraved pattern (Fig.4) could even have stepped structure with some places above and below original surface.

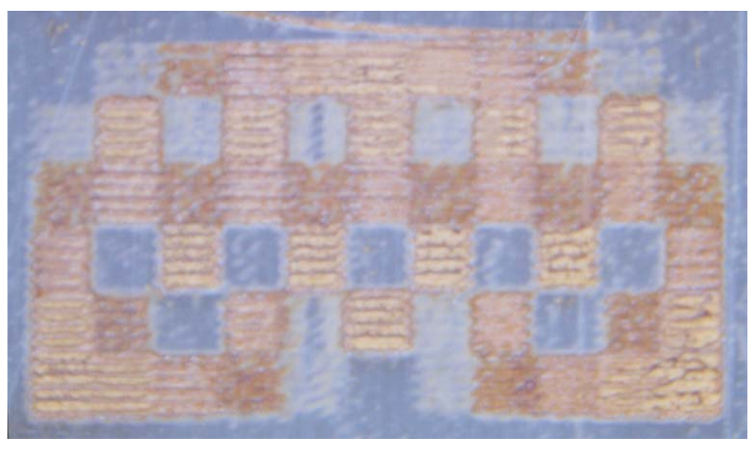

Fig. 4 Engraved pattern in PVC

Polymethylmethacrylate (PMMA)

Electron beam penetrated PMMA very easily and quickly melted it without color change . Fastest scanning of the electron beam during engraving damaged only the surface layer creating rougher matte surface.

Slightly slower beam melted more material and created stepped relief (Fig. 5). Its surface was smooth and stayed transparent. Each brightness step (but the 2 brightest) resulted in 20 µm step, so the deepest step was 90 µm.

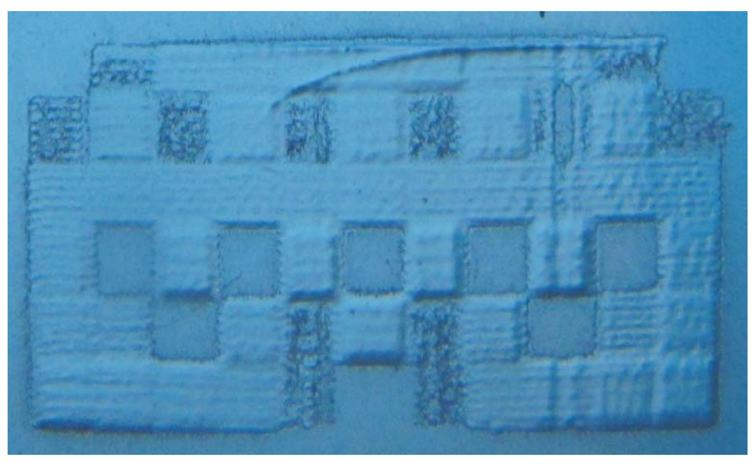

Fig. 5 Engraved pattern in PMMA

Polyethylene (PE)

For lower beam power and higher beam speeds the created lines were uniform without significant ridge. The material also kept its original color or just turned white.

Low power, high speed beam only slightly whitened the surface. With lower speed and higher power, more material was melted and evaporated, creating a stepped structure (Fig. 6). Each brightness step resulted in 30 µm step, so the deepest step was 150 µm.

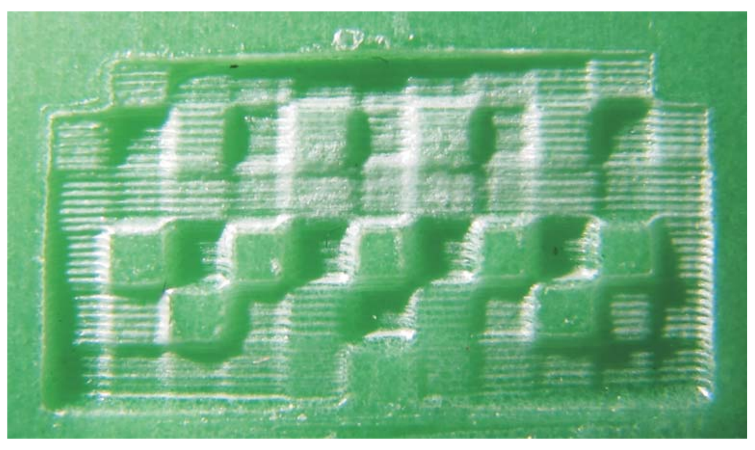

Fig. 6 Engraved pattern in PE

RESULTS

Plastics are usually very porous and are able to absorb high volume of gases. After heating by the electron beam, the gas is released and chamber pressure is rising. If the amount of released gas is low, vacuum system can pump it out. However, if the rise is high, there is a risk of discharges in HV part that interrupts the machining. Due to these reasons, only a small amount of material should be heated at the same moment.

The escaping gasses causes bubbles and bursts of the molten material. As it solidified, it create surface texture that is specific for the each plastic and for used beam parameters. Periodic linear ridges in shown images were caused by particular scan lines.

Fig. 1 Electron beam welder MEBW-60/2

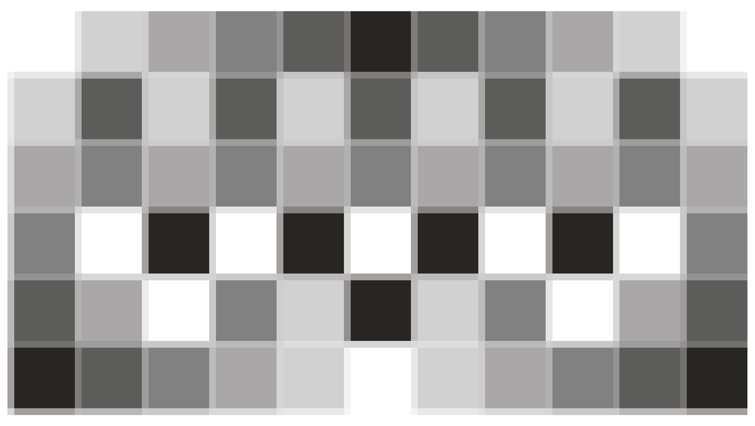

Fig. 2 Test pattern for engraving

Polycarbonate (PC)

Polycarbonate melted very easily when it was heated by the electron beam. With higher beam power, the material also degraded and changed color to brown and black.

The fast engraving only "scratched" the surface. No relief structure was engraved and the surface was matte and gray, even slightly brown (Fig.7).

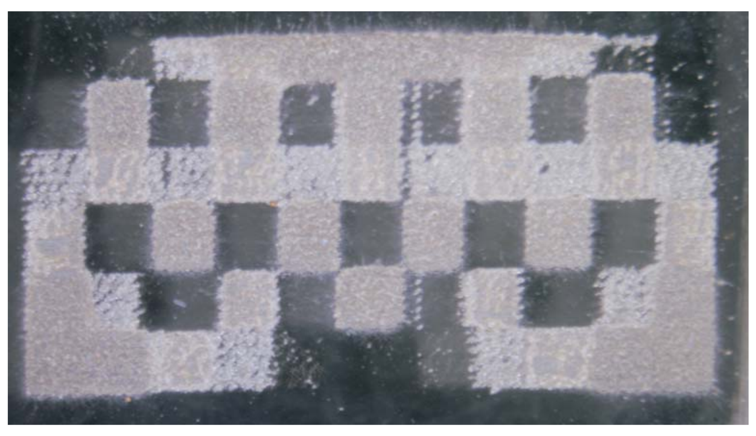

Fig. 7 Engraved pattern in PC

Fig. 9 ISI logo on PP

Polypropylene (PP)

PP melted very easily by the electron beam while keeping its color and the melt flowed onto surroundings.The result of engraving depended very much on the beam speed and power (Fig. 8). Low power and high speed created a white, raised, sponge-like structure that can be used for inscriptions (Fig. 9). Slower engraving melted more material without creating the sponge-like structure. However, the details of the engraved pattern vanished and large holes were formed because of the burst bubbles. The remelted spot also kept its grey color.

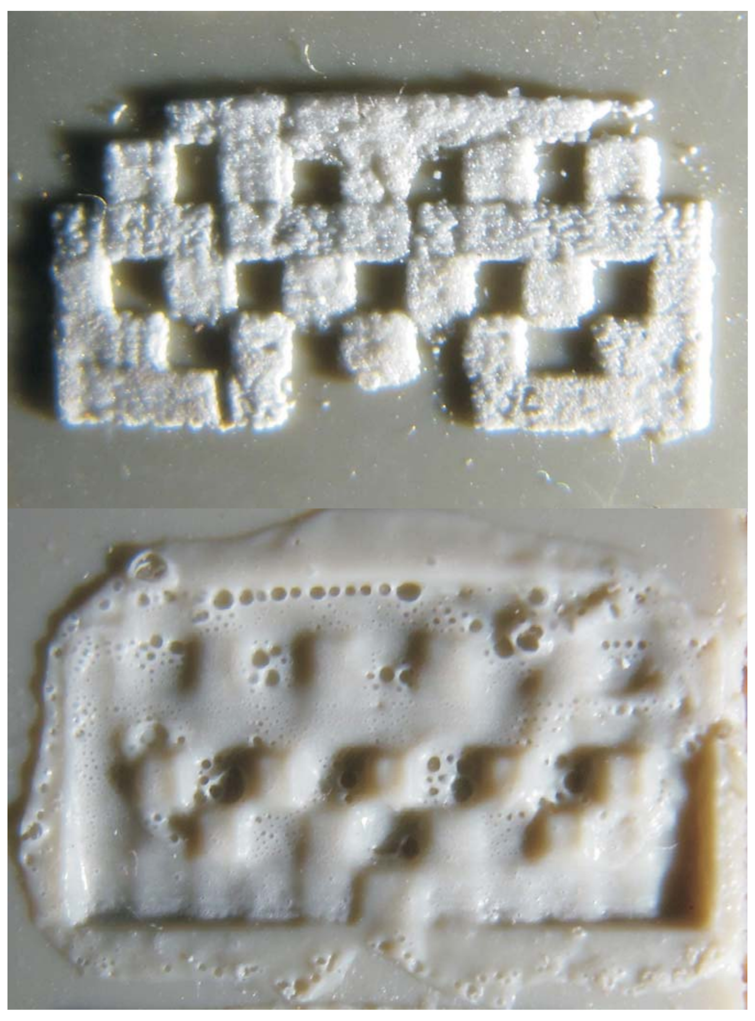

Fig. 8 Engraved pattern in PP; upper - fast beam, lower - slow beam

CONCLUSION

The possibilities of using the electron beam to machine and engrave plastics were demonstrated. Thanks to their thermal properties plastics are easy to melt and evaporated by the electron beam. As plastics contain a lot of gasses, only a small spot should be heated at the same time to prevent vacuum issues. Some plastics like PE, PTFE and PMMA can be machined by electron beam to create a relief structure. Other plastics like PP, PC and PVC can be engraved with contrast pattern that can be used e.g. as labels.

References

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Acknowledgment

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