Micro mould fabrication by thermo-mechanical-chemical friction polishing

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Abstract

The paper discusses the possibilities and limitations to shape synthetic single crystalline diamond micro forming dies by friction polishing. The manuscript presents experimental results with varied process parameters as contact temperature, process time and pressure force between diamond and friction rod. Based on the results and with respect to the theoretical background, possibilities and limitations of the thermo-mechanical-chemical shaping process are discussed.

1. Introduction

One of the most important requirements for a micro forming die is to ensure a high durability with high dimensional and shape accuracy. Due to outstanding mechanical properties of single crystalline diamond such as high hardness, high wear resistance and low friction in contact with the most non-ferrous metals, it appears to be a highly attractive material for micro-forming tools. These prominent properties hamper the machinability of diamond and thus, to fulfil the high requirements regarding the high dimensional accuracy micro moulds. In addition to a high wear resistant tool material, the die edge radius plays a dominant role in micro deep drawing processes and strongly influences the deep drawing result. To overcome the restrictions and to improve the geometrical properties by means of a defined edge radius of diamond dies for deep drawing, a thermo-mechanical-chemical material removal of diamond as finishing process called friction polishing is proposed.

The basic idea of friction polishing is the application of a metal counterpart in frictional contact and additional external heating to enforce material removal on the diamond. The metal is used as catalyst to transform the carbon of the diamond lattice into amorphous carbon. Then, the weak-binding amorphous carbon diffuses into the metal to form carbides or reacts with oxygen to form CO or CO_2, or forms graphite at the diamond surface, which is easily removed [1, 2].

2. Experimental procedure

The synthetic single crystalline diamond with a dimension of 3.5 x 3.5 x 1.7 mm³ was premachined by laser ablation to generate a defined clearance hole with a diameter of Ø = 1.06 mm (Figure 1b). In a second step, the sharp edge is friction polished with shouldered stainless steel rods (1.4301) as showed in Figure 1c. To ensure that the friction rod is in the right position, a guide pin on top of the friction rod with a length of l = 0.5 mm and a diameter of Ø = 1 mm was used. The guide pin is followed by a transition radius of r = 100 µm to generate a die edge radius on the diamond. Experiments were conducted on a set-up displayed in Figure 1a.

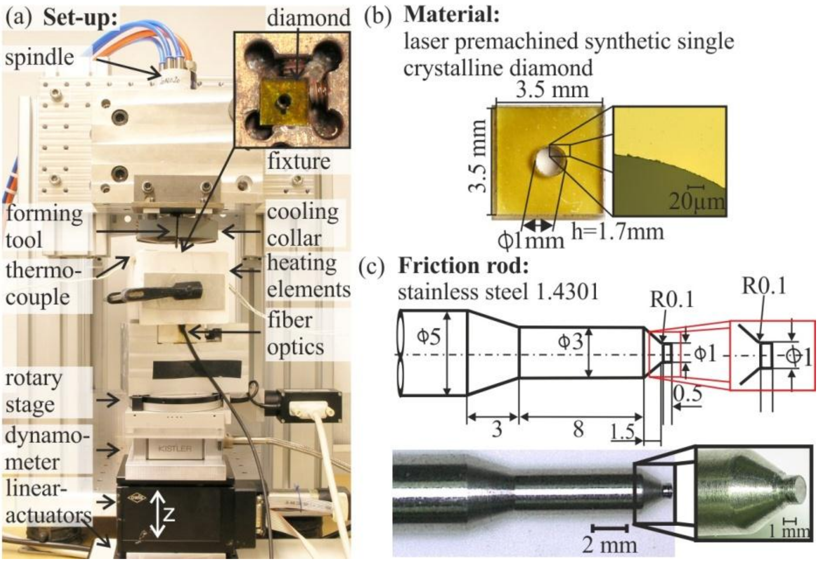


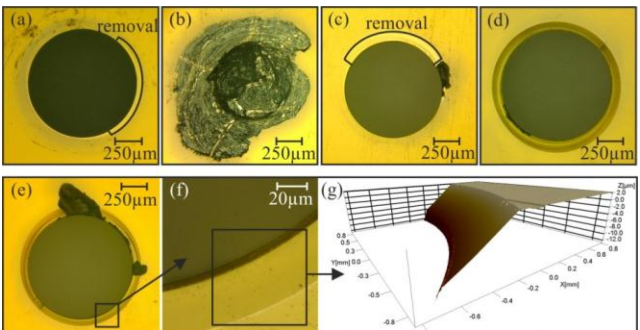
Figure 1: Experimental set-up for friction polishing (a), laser premachined single crystalline diamond (b) and friction rod (c)

The diamond was fixed in a holder and heated to 450 respectively 350 °C controlled by a pyrometer MI16 (Sensotherm) with fiber optic. The rotational speed of the frictional rod for each experiment was 35.000 rpm, the polishing forces were set to 1 respectively 4 N applied by linear actuators and controlled by a dynamometer

(Kistler). Experiments were carried out in different sets of experiments for 5, 15 and 25 min. Each experiment is followed by cleaning the diamond surface from metal residues by etching with warmed aqua regia for several minutes. The evaluation of the machined diamond surface was carried out by WLI (Taylor Hobson; Tailorsurf CCI HD) and a digital microscope (Keyence; VHX-500K).

3. Results and Discussion

The experimental results exhibit a huge range of process influences. The contact temperature in combination with the pressure force between friction rod and diamond plays a prominent role. The combination of low contact temperature (350 °C) and low pressure of 1 N leads to a barely visible diamond removal (Figure 2a). On the other hand, at higher temperatures (450 °C) and higher loads (4 N) the diamond removal is increasing (2c) but also at the risk that the process has to be aborted due to breakage of the weakend friction rod (2c). Thus, higher contact temperature causes higher tool wear. Additionally, tool material is smeared on the diamond surface and acts as barrier layer in the removal process. To prevent a partial contact on the rim of the clearance hole (2c), a rotary stage was implemented into the set-up. The diamond was rotated at a speed of about 1 min^{-1} to receive a uniform removal at the entire perimeter of the diamond edge. Best surface results could be achieved by lower contact temperature and higher loads. The machined area showed a smooth surface without major faults (2f + g) with a surface roughness of Ra = 6.9 nm and Rq = 8.2 nm



parameter:					
	temperature:	350 °C (a)	450 °C (b);	350 °C (d)	350 °C (e);
	polishing force:	1 N	4 N (c)	4 N	4 N (f);
	duration:	15 min	5 min	15 min	25 min (g)
	rotational speed:	35.000 min^{-1}	35.000 min^{-1}	35.000 min^{-1}	35.000 min^{-1}

Figure 2: Single crystalline diamonds after friction polishing by 450 °C and 350 °C

(average of 5 measured points). Nevertheless, some bursts on the diamond were observed (2e). Thus could be attributed to higher load, the dynamic machining process of the rotating friction rod or thermal subsurface damage caused by the laser processing. Furthermore, the geometry of the friction rod could not shape the diamond in the desired geometry. This is due to the wear of tool material and deformation of the friction rod (Figure 3).

Further studies aim to rise the lifetime of the friction rod by using other materials such as hot work steel or stellite. Another approach is to apply friction rods with adapted contouring geometries to approximate the die edge radius incrementally.

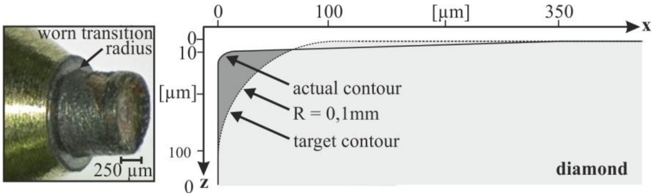


Figure 3: Worn friction rod and die edge contour.

4. Conclusion

The presented paper shows the general possibility to machine laser premachined single crystalline diamonds by friction polishing. To generate a die edge radius by friction polishing, some limitations have to be overcome: i) the stability of the friction rod geometry especially at high temperatures; ii) prevention of spalling on the diamond edge; iii) amplification of the diamond removal. Appropriate tool materials and varied tool geometries and process parameter could solve these challenges.

5. Acknowledge

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