Limitations of Mechanical Micro-Drilling in Difficult-to-Machine Materials

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Abstract

Microholes with diameters below 0.5 mm are typical structures of various miniaturised components. The simplest technique for machining such microholes is mechanical microdrilling. However, some materials are difficult to machine because of their high hardness and brittleness: examples are various kinds of glass and ceramics, monocrystalline silicon, and selected polycrystals and composites. The limitations of mechanical micromachining in the mentioned materials are attributed to the high values of cutting forces in relation to the tool strength properties, rapid wear of cutting edges, chipping at the hole edges, and generation of cracks in workpiece.

1 Introduction

The demand for machining of high quality microholes in various difficult-to-machine materials has been increasing for a number of applications. In microsystem technology, examples are optical parts, chemical microreactors, substrates of micro-sensors, and parts of manufacturing equipment. Different methods are used for making microholes but the simplest machining technique is mechanical micro-drilling [1-4]. However, it is often difficult to perform high quality drilling of microholes. Mechanical microdrilling has inherent limitations which arise from the hardness and brittleness of the machined materials, insufficient strength of miniature drills, rapid wear of their cutting edges, and excessive stress concentrated in the cutting zone. The stress causes damage of various kinds, such as chipping of the hole edges and cracks surrounding the hole, at the exit side, and sometimes even between the holes. To overcome the problem, microdrilling in the ductile mode of cutting is widely used. It means a very small chip load, e.g. the application of a feed much smaller than 1 μm/rev. Obviously the hardness, wear resistance, and strength properties of the tool material should adequately exceed the corresponding properties of the machined material. Therefore, for such purposes only microdrills made of sintered carbides or in special executions of diamond may be considered. In reported experiments, commercial twist microdrills made of tungsten carbides (WC+Co) with conventional geometry have been used.

2 Cutting forces versus tool strength

The measurement of microhardness and specific cutting forces k_{sF} (specific feed force) and k_{sM} (specific torque) for the materials investigated gave the results collated in Table 1. Then, the values of breaking torque for microdrills are presented in Table 2. The estimated uncertainty of values is a few tens of percentage points.

Table 1: Microhardness and specific cutting forces for selected materials

Material	$\mu HV_{0.1}$ [GPa]	k_{sF} [kN/mm^2]	k_{sM} [Nm/mm^2]
Soda-lime glass	4–5.1	50.9–108.8	4–7.8
Borosilicate glass	4.6–6.7	111.6–127.6	12.8–14.7
Monocrystalline Si	8.3–8.5	61.2–225.5*	4.3–6*

* During a very short life time and by small feed rate

Table 2: Average values of maximal breaking torque for WC+Co twist microdrills

d [mm]	0.1	0.2	0.3	0.4	0.5	0.6
M_{max} [N·mm]	0.48	0.99	2.0	4.45	11.0	16.4

Taking into account the process parameters and values presented in Table 1 it is possible to evaluate the torsion load acting on the microdrill. For example, by drilling in soda-lime glass with feed $f = 1$ μm/rev and drill diameter $d = 0.2$ mm, the torsion load will be in the range of $M \approx 0.4$–0.78 N·mm, which is very close to the maximal breaking torque of 0.99 N·mm, as shown in Table 2. Moreover, it is necessary to include in the reckoning the fluctuations of load and strength properties of the microdrill. Therefore, the probability of breakage of the fragile tools is high, and damage to microdrills often occurs during microdrilling experiments [5].

3 Wear of cutting edges

When drilling in difficult-to-machine materials the wear of cutting edges is so rapid that by using a new drill it is possible, in typical conditions, to machine holes with combined lengths of several millimetres in soda-lime glass or even below 1 mm in monocrystalline Si. The worn edges increase the cutting forces and generate intensive heat, which is sometimes observed as a light radiation from the cutting zone and through characteristic changes of the machined surface. The decreased sharpness of the cutting edges also reduces the possibility of ductile forming of chips. Only the bottom surfaces of the first holes are smooth and show concentric trenches made by the cutting edges in ductile-regime cutting – Figure 1(a) and (c). Figure 1(b) shows a hole bottom deformed by thermal effects. The exemplary results of investigation into wear of cutting edges are shown in Figures 2 and 3.

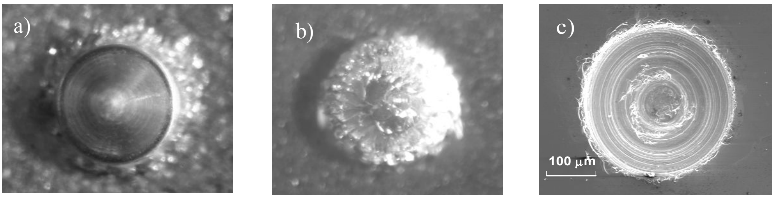

Figure 1: Different surfaces of the bottoms of holes of $\phi = 0.5$ mm drilled in borosilicate glass (Pyrex) (a) and (b), and of spot drilling of $\phi = 0.3$ mm in monocrystalline Si (c)

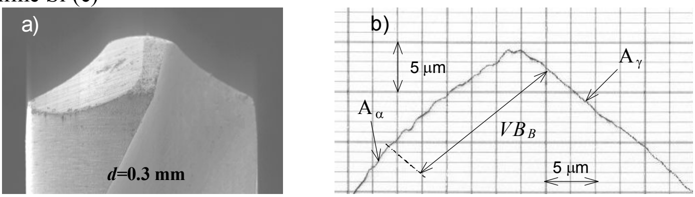

Figure 2: Wear of cutting edge of microdrill made of sintered carbides after machining of spot holes with a total depth of ~1 mm in monocrystalline Si. View of the drill tip (a) and profile of edge surfaces (b): A_α, A_γ – clearance and face surfaces

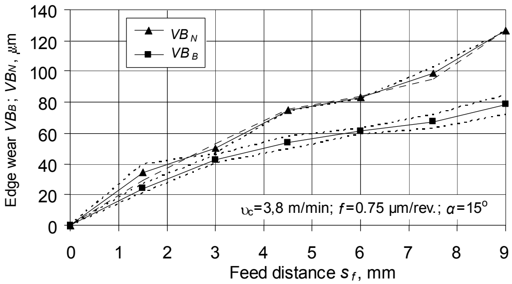

Figure 3: Average wear of cutting edge on clearance surface by the corner VB_N and in the middle of cutting edge VB_B for a carbide drill with d = 0.4 mm by drilling in soda-lime glass

4 Cracks and chipping

The stress caused by the cutting edges in the brittle material typically leads to chipping of the hole edges, which is greater at the outlet side (Figures 4 and 5). Another problem is the cracks surrounding the hole. They may be so large that damage to the specimen occurs during machining. Besides the application of ductile mode cutting, the other method used to prevent chipping of the edges and to obtain crack-free surfaces is the use of entry and backup covers (Figure 6). During drilling, covers made of the same material as the specimen should be pressed against the workpiece.

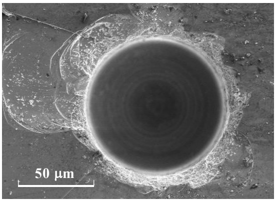

Figure 4: Chipping on inlet edge of microhole ϕ=0.1 mm drilled in monocrystalline Si

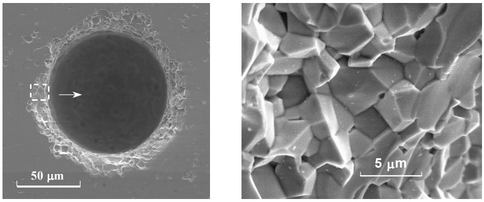

Figure 5: Uniform chipping on the edge of microhole ϕ = 100 µm drilled in polycrystalline Mn-Zn ferrite and an enlarged view of the edge

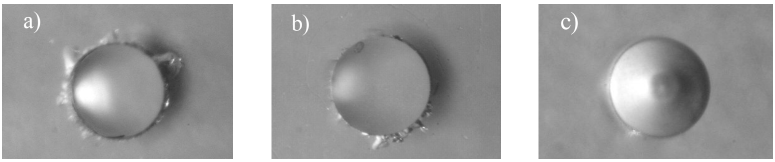

Figure 6: Edges of holes of ϕ = 0.5 mm drilled in soda-lime glass at the inlet (a), and outlet (b), and in the backup plate (c)

Concluding remarks

Despite essential limitations, mechanical microdrilling has potential benefits in the machining of microholes in difficult-to-machine materials. More detailed observation of the process enabled drilling results to be improved by using pre-selected process conditions and additional technical measures.

References

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