Experimental Research of Cutting Forces in Microdrilling

L. Kudla
Division for Precision and Electronic Products Technology, Warsaw University of Technology, Poland
kudla@mchtr.pw.edu.pl

Abstract

Drilling of microholes with diameters below 0.5 mm is widely used in precision and electronic product technology. This paper presents an investigation into the cutting forces generated during microdrilling. Based on the results obtained, specific cutting forces for various materials have been evaluated. Finally, discussion of the results and concluding remarks are provided.

1 Introduction

In works reporting investigations into the microdrilling process, very different values of recorded cutting forces are published [1-4]. Therefore, the main objective of presenting this research was the practical verification of the data acquired. Generally, it is taken for granted that the drill is exposed to the action of thrust F (feed force), torque M (torsion moment) and in particular cases also to a radial (passive) force R. Simplified equations connecting the basic loads F and M with the parameters are:

$$F = k_{sF} \cdot r \cdot f \cdot C_F \quad \text{and} \quad M = k_{sM} \cdot r \cdot f \cdot C_M$$

where: k_{sF} , k_{sM} = specific cutting forces respectively for thrust and torque, r = drill radius (d=2r), f = feed, the product $r \cdot f$ represents cross-section area of the cutting layer, and C_F, C_M = correction factors. Resulting from the above equations, the drilling forces depends first on the material properties of the workpiece, represented by k_{sF} and k_{sM}, and second on the feed because the drilling radius is fixed in certain operations. The cutting forces are also affected in some way by the cutting speed υ_c (or rotation n), various modifications of the drill geometry (chisel edge length, edge geometry), microgeometry of the tool surfaces and drilling technology (roughness, sharpness of the edges, hole length, presence of coolants, number of hits, etc.), which may be expressed by correction factors. Nevertheless, the major question is how the mechanical properties of a machined material influences the specific cutting forces k_{cF} and k_{cM}, generally characterised by a certain process.

2 Experimental conditions

The first objective of the investigations was the measurement of load values acting on a drill throughout the process of cutting. The measurements of the force and the torque were undertaken at an experimental setup composed of a drilling unit (spindle and feed device), measuring strain gauge dynamometer, amplification equipment and recorder. To achieve speed n = 24…72 krpm, a high frequency spindle was applied. In the case of lower speeds n<12 krpm, a drilling unit of a precision desk drilling machine was used. In both cases there were possibilities for changes in the feed rate in a wide range. Specimen materials represented various groups, such as plastics, metal alloys and selected composites. Before the drilling tests their properties were checked. Table 1 shows collated values of microhardness $\mu HV_{0.1}$ and of tensile strength σ_{tu} with uncertainty u of the measured results.

Table 1: Mechanical properties of basic specimen materials used in the research

Symbol	Material description	$\mu HV_{0.1}$ [MPa]	$u\mu HV_{0.1}$ [MPa]	σ_{tu} [MPa]	$u\sigma_{tu}$ [MPa]
PTFE	Teflon	42	± 6	15	± 2
PMMA	Plexiglass	242	± 56	61	± 11
FR4	Glass-epoxide laminate (without Cu)	312	± 87	312	± 87
Bak	Paper-phenol laminate	345	± 86	149	± 34
Txt	Textile-phenol laminate	394	± 89	67	± 14
DAl	Duralumin AlCu4MgMn	772	± 152	406	± 41
StC	Deep drawing steel C<0.2%	1449	± 349	354	± 63
Brass	CuZn39Pb1	1614	± 222	441	± 126
StAR	Acid resistive steel 1Cr18Ni9Ti	1837	± 289	684	± 8
Bronze	CuSi3Mn1	1906	± 667	799	± 33

Commercial twist microdrills with conventional geometry have been used in drilling tests (made of HSS-E steel or of tungsten carbides). The measurements of the rounding radius r_β of their cutting edges showed a distinct difference for both material executions [5]. The cutting edges of carbide drills were sharper (r_β<0.5 µm) than those of steel drills (0.1<r_β<2.8 µm). Therefore, an uncut chip thickness smaller than approximately 1 µm may not secure proper chip formation.

3 Results of the investigation

In Fig. 1 presents an example of the torque and thrust recorded during continuous drilling with f=0.1 mm/rev by υ_c=5 m/min. From the diagrams maximal values F_{max} and M_{max} were evaluated. However, sometimes they only correspond with an incidental increase of the cutting forces. Therefore, the average values F_{av} and M_{av} were also taken into account.

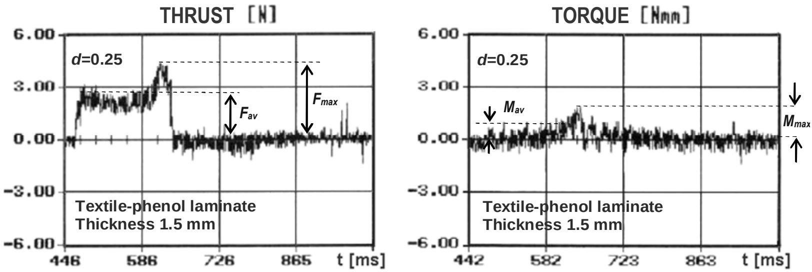

Figure 1: Evaluation of maximal F_{max}, M_{max} and average F_{av}, M_{av} values of thrust and torque from diagrams recorded

The measured values of F and M were used to estimate specific cutting forces k_{cF} and k_{cM} (Fig. 2). Their values were obtained by dividing the maximal thrust and the torque by the nominal cross-sectional area of cutting. The drilling experiments were carried out by continuous feed motion f=0.7-1.6 µm/rev and υ_c=9.5 m/min.

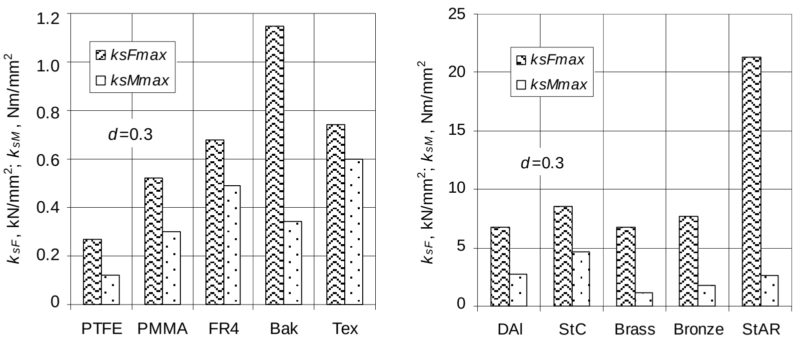

Figure 2: Mean values of specific cutting forces k_{sFmax} and k_{sMmax} evaluated for maximal values of F and M and for various materials

The scatter of evaluated k_{sFmax} and k_{sMmax} values were (in percent) ±(7...18) k_{sF}, ±(4...57) k_{sM} for metal alloys, and ±(31...69) k_{sF}, ±(47...97) k_{sM} for plastics and laminates. The values of k_{sF} and k_{sM} were also evaluated using peck drilling in acid resistive steel with constant stroke length s_i. The results illustrated in Fig. 3 show larger values of specific cutting forces in comparison with continuous drilling. It is probably caused by a relatively small feed, applied in peck drilling (size effect [3]).

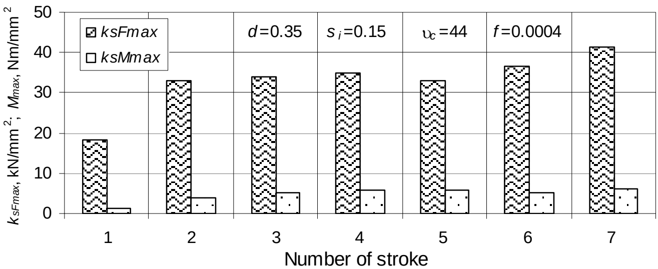

Figure 3: Values of specific cutting forces in succeeding strokes by drilling in acid resistive steel of thickness 1.0 mm

Additional evaluation of k_{sF} (in kN/mm^2) and k_{sM} (in Nm/mm^2), done for the other materials, gave the following results: for titanium alloy Ti6Al4V k_{sF}=9.5-12.0, k_{sM}=1.4-2.7, for soda lime glass k_{sF}=50.9-108.8; k_{sM}=4.0-7.8, and for mono-crystalline silicon k_{sF}=61.2...225.5; k_{sM}=4.3-6.0 [6].

4 Concluding remarks

The cutting forces generated during microdrilling and thus the specific drilling forces vary on a large scale. More precise evaluation, requiring further research and standardisation of measurement devices and procedures, is needed.

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