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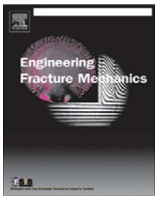

Fracture phenomena of microdrills in static and dynamic conditions

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ABSTRACT

The mechanical drilling of microholes with diameters below 0.5 mm is executed using miniature drills, which are exposed to loads of relatively large cutting forces, frequently causing the failure of the fragile tools. This paper describes the experimental investigations into the deformation, strength, and fracture of the cutting parts of microdrills in static and dynamic conditions. Firstly, microdrill behaviour owing to bending, compression, and torsion was investigated separately in static tests. In addition, torsion was applied together with compression. The values of deflections, forces, and torque were measured and the formation of microcracks and their propagation observed. The tests indicated the characteristic forms of the fracture sections for the kinds of microdrills and loads investigated. In dynamic conditions, the start of the drilling plays an important part. The surface irregularities on the work part cause the drill tip to be pushed aside and changes of its axial position. A typical reason for tool destruction during drilling is excessive stress from cutting forces. The cases of microdrill failure in dynamic conditions collated with various drilling trials. The results show distinctions in the behaviour of microdrills in both circumstances as well as the similarities and differences in the forms of fracture sections.

1. Introduction

The continuous trend towards the miniaturisation of many products involves extensive investigations in various fields of technology aimed at the development of new technical solutions. The use of microproducts and microcomponents has increased greatly during the past decade. They are produced for the electronics, optics, biomedicine, automotive, aerospace, and other industries. In their manufacture, various machining techniques are used; among others, microcutting techniques such as downscaled realisations of turning, milling, drilling, and so on are applied in the shaping of miniaturised components [1,2]. The major drawback of some mechanical micromachining processes is that the forces generated can easily deform the very small tools. This also concerns the drilling of microholes with diameters below 0.5 mm.

In the drilling of microholes, miniaturised twist, spade, or D-shaped drills are used. Microdrilling is a process executed with little strength reserve of fragile tools. Therefore, analysis and investigation into the strength properties of microdrills are of great importance. The general description might be deduced from material strength theory [3]. In the case of twist drills, stress–strain analysis is complicated because of the complex drill geometry, so simplified models are used. As a consequence, theoretical and experimental values of strength indices differ. Practical research is carried out rarely only to verify theoretical calculations [4]. A need for special and sensitive testing equipment might be the next reason for the lack of experimental investigation into the strength properties of the smallest tools [5]. For microdrills it is possible to assign various strength indicators. A suitable parameter is the value of the torsion moment causing the breakage, because it can be directly compared with the torque arising during drilling [6]. But the detection of axial thrust is easier and in this regard often used

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for the selection of optimal microdrilling conditions [7]. Even a slight increase in-process forces could cause the failure of the microdrill. Damaging the tool also often means a loss of the valuable work part. Therefore, every possible way to limit the load, such as the application of lubricants, use of an intermittent drilling cycle, and so forth, is utilised. In some cases, a meaningful role is played by the correct machining of the additional pilot hole, which enables a proper start for the microdrilling to follow [8]. The damage to range drills can be predicted and prevented by using special monitoring systems [9]. Unfortunately, in microdrilling the values of measured signals are very small and the signal-to-noise ratio is too low. Thus, the effective prevention of the destruction of microdrills is possible only under selected conditions [10,11]. In general, the issue is still open for investigation and development.

The fracture mechanics of components and tools in a regular range of dimensions have been the subject of many theoretical and experimental works. The theoretical risk of failure can be expressed by numerous formulas using probability calculus [12]. Special attention has been paid to the fracture of brittle materials such as glass, alumina, or silicon nitride. A well known relation is dependence of crack extension behaviour on the grain size of the material microstructure. The determination of the fracture toughness of such materials is often carried out by indentation cracks made by Vickers or Knoop indentors [13,14]. These are believed to behave like natural cracks, but it is necessary to bear in mind their imitative characteristics and particular morphologies. Fracture problems similar to those of rotating tools have been investigated for cylindrical shafts with much larger diameters. To identify the depth and location of the crack, and likewise its evolution, a vibration response has been used [15]. The application of that method to microdrills seems to be difficult. The other approach has been described directly for drills with diameters of a few millimetres but its usefulness for microdrills is also problematic [16]. The evident factor influencing the strength and fracture toughness of examined objects is their surface microgeometry. Experimental investigations of other microtools have confirmed expectations that the reduction in roughness increases strength [17]. A natural explanation of these relationships is that microgrooves are potential notches for stress concentration and make seeds that generate cracks.

To summarise, the strength properties and fracture behaviour of microdrills are poorly recognised partly because of the novelty of microtechnology and partly as a result of research difficulties. An interesting question is whether it is possible to identify kinds of destructive stresses based on the shape of the fracture section. For this it is necessary to state the characteristic forms of fracture sections for various loads separately and for some combinations. The next problem is whether destruction is comparable between static and dynamic conditions and whether the deformations and fracture form found in drilling might indicate stress, causing the failure of the microdrill.

2. Basic cutting phenomena and forces present in microdrilling

During drilling the following basic phenomena appear. Cutting comprises the plastic deformation and shearing of machined material, followed by chip formation and removal. The chisel edge, as a consequence of its geometry, presses and pushes the material aside, partly under the major cutting edges. The friction of the drill surfaces and edges against the bottom and wall of the drilled hole accompanies the cutting. In addition, the chips clog the flutes and enlarge the friction against their surfaces and the hole wall. The shearing, chip formation, and friction generate pressure acting on the cutting edges, chisel edge, and side surfaces, and in the flutes. After superposition they are detected as the resultant cutting forces. Generally, in a simplified model, it is taken for granted that the tool is exposed to the action of torque *M* (torsion moment), thrust *F* (axial feed force), and, in particular cases, radial (passive) force *R* (Fig. 1). The torque *M* generates shearing stress in the drill body. The thrust *F* causes compression and buckling, whereas the radial force *R* causes bending of the microdrill. While the drill is being retracted from the hole, the axial force turns direction and generates tensile stress.

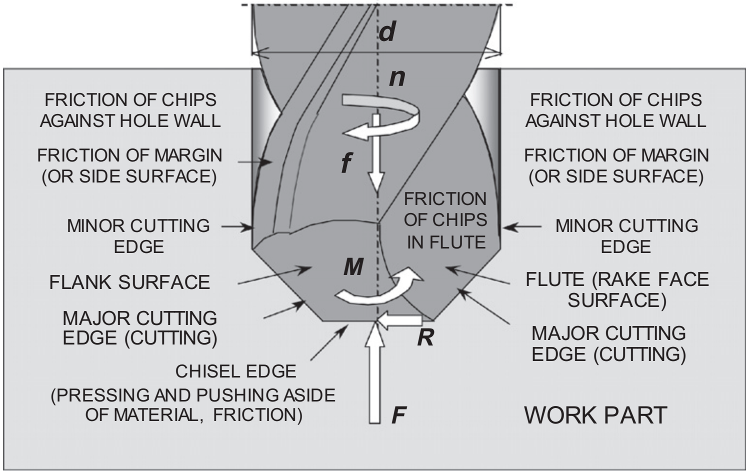

Fig. 1. Motions, basic phenomena, and resultant cutting forces in the drilling process.