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Micro Cutting of Polycrystalline Alloys Using Carbide End Mill

THESES

According to my aims during my research activity the principles of machining of polycrystalline alloys (namely unalloyed and low-alloy tempering steels and brass) by two-flutes, carbide micro end mill of diameter less than 1 mm were analyzed theoretically and experimentally. The dimensions of machined structures falls in the size range of 1-999 microns. As a result of my work, following scientific theses were formulated:

1. Thesis

The thickness of the actual removed material layer mostly differs from the set value of feed rate per tooth at micro cutting by two-flute end mill. Firstly, it is confirmed directly by the deviation between the distance of the tool marks shown up at the bottom of the micro milled groove and the set value of the feed rate per tooth. Secondly, it is confirmed indirectly by both the alternately varied peaks of the force measuring graphs and the asymmetric wear of the tool edges. The two edges of the tool generally take part in the chip removal process differently (way, unlike). It also frequently occurs that only one or neither of the edges removes any material in the particular rotation of the tool. The uncut layers are accumulated accompanied by the elastic deformation of the tool and by the elastic and plastic deformation of the material being machined. I defined the sum of the accumulated feeds as actual feed rate per tooth (f_{zact}). It is influenced by the correlation among the minimal chip thickness, the relative large tool run-out and the set value of feed rate per tooth. The value of the actual feed rate per tooth can vary from one rotation to the other one.

2. Thesis

The surface roughness of the bottom of the grooves machined by micro sized end mill is always better on the down milling side than on the up milling side. The diagram of the average surface roughness of the micro milled grooves as a function of the set value of feed rate per tooth shows a characteristic form (pattern) in the investigated parameter ranges (v_c=30–150 m/min, f_z=0.1–8 µm, a_p=10–30 µm). Increasing the feed rate per tooth, the surface roughness will be considerably better. After reaching a characteristic minimum value, the roughness will be worse again by further increasing of the parameter, but in a slower rate as before. No valuable effect of cutting depth upon surface roughness was found. If set value of feed rate per tooth is smaller than minimal chip thickness valid under instantaneous machining circumstances then the measured surface roughness corresponds to the theoretical value calculated by Brammertz formula.

3. Thesis

The properly chosen cutting parameters at micro end milling and the grain size of the investigated, polycrystalline materials (copper: 20–40 µm, temper-grade steel: 5-15 µm) are from the same order of magnitude. Consequently, chip removal process and machined surface roughness are influenced by anisotropy of the workpiece material, too. Anisotropy means the different value and the different orientation of mechanical parameters (Young modulus, yield strength, active slip mechanism) of single grains the effect of grain boundaries.

4. Thesis

Burr occurrence lengthwise of the micro end milled groove will be definitely larger in the investigated parameter ranges (v_c=30–150 m/min, f_z=0.1–8 µm, a_p=10–30 µm) if both cutting depth and set value of feed rate per tooth decrease. Burr formation is characterized by burr height. No valuable effect of cutting speed upon burr occurrence was found. If feed rate per tooth is smaller than minimal chip thickness valid under instantaneous machining circumstances then burr height is definitely greater on the down milling side (10–640 µm) than on the up milling side (6–25 µm). If feed rate per tooth is larger than minimal chip thickness valid under instantaneous machining circumstances then burr occurrence is about in the same order on both side of the micro milled groove.

5. Thesis

Frequency of excitation resulted from the kinematics of the milling process (~1-2 kHz) and natural frequency of the tool (~100-300 kHz) differ by two order of magnitude at micro end milling. It follows that tool failure because of resonance can be neglected. Tool breakage does occur mostly for the reason of overload resulted from the force growth through continuous tool wear, which is confirmed also by the graphs of force measurement.

6. Thesis

It follows from the registered graphs originated from force measurement during the machining process that the rate of loading according to continuous wear of the tool is characteristically limited at micro end milling. Assumed optimal cutting parameters for the particular machining challenge, it was found that cutting force grows at least twofold till tool breakage does occur, and it was experienced that micro end mill can not resist larger force growth than threefold. This experimental result assures a predictable micro milling process and enables a change of the micro end mill in a technologically suitable moment.

7. Thesis

At micro end milling, the actual path of cutting edge of the tool is determined by both the curtate cycloid originated from the kinematics of milling process and overlying factors simultaneously, such as firstly the tool deflection through cutting force characteristic at micro milling, secondly tool vibration resulted from process dynamic. These factors effects a relative large shape distortion compared with conventional sized milling (it can be relative as large as 5% in size and geometric shape). According to my analytic and FEM analysis, the actual shape distortion determined by microscopic investigation can be explained by both the relative large tool deflection and tool vibration.

8. Thesis

According to the modified machining circumstances resulted from size reduction, the optimal cutting parameters of micro end milling differs from the values, which can be derivated the data normal at conventional milling. Feed rate per tooth and cutting depth are bounded from above by the stiffness of the relative more fragile tool, and are bounded from below by the thickness of the actual removable material layer. This lower bound is independent from the diameter of the cutting tool, because the original edge radius of every investigated tool was found to be the same (1-5 microns).