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A Study On Phenomena Which Differentiate Micromachining From Macromachining.

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Abstract : *The research in micromachining has been started from last decade. The demand of microcomponent and microproduct is increasing progressively in electronics, optics, medical and automobile sectors. As machining dimensions diminishes from macro to micro, machining conditions varies which affect tool life, cutting forces and surface machined. Numerous efforts are in progress which attempts to enhance the tool performance. Cryotretment of cutting tools gives improved hardness, strength and wear resistance due to the precipitation of η (eta) carbide in metal matrix. In macromachining cryotreated tools performed well and ample of literature available while, the applications of cryotreatment for micro cutting tools, its characterization and performance is nascent. In present paper the opportunities for cryotreated tools in micro cutting and its expected performance while machining has been discussed.*
Keywords : *Cryotreatment, Micromachining, Tungsten Carbide, Size Effect, η carbide*

I. Introduction

The growing demand for miniaturization of electromechanical devices and systems for applications in automobile, biomedical, aerospace and defense industries is a key driver for the development of new micro manufacturing processes. Currently, photolithography-based processes and moulding techniques are using to micromanufacture parts, but for a limited range of materials like silicon, copper and Ni alloys and polymers. Unlike photolithography-based processes, mechanical micromachining processes such as micro milling, micro turning and micro drilling are capable of realizing three-dimensional free-form surfaces in a wide range of metals, ceramics and polymers for grooves, slots and cavities manufacturing [6].

Size effect, material homogeneity, minimum chip thickness these are the some concepts which differentiate micromachining from macromachining. In the study it has been found that, in micromachining the rapid tool wear generates higher cutting forces and this deteriorates surfaces. It is expected by improving tool life, the performance of micromachining can be improved. A few approaches have been proposed to overcome the tool failure and to make micromachining (preferably cutting) more suitable. The first approach involves the use of cutting fluids to provide cooling and lubrication. However, it is very difficult to transport the cutting fluid to the cutting zone and tool-workpiece interfaces due to the high cutting speeds and the small size of the contact zone. This limitation is also true to a great extent in macroscale machining.

The second approach involves the application of coatings on the micro tool surfaces to reduce wear. This approach is routinely adopted at the macroscale to enhance tool life. Although a few researchers have demonstrated that coatings prolong micro tool life to an extent but coatings become futile once it gets removed from the substrate. In the third approach; hybrid machining, for e.g. laser assisted micromachining, some researcher reported that poor surfaces while machining along with high set up cost. While studying above issue it have been found that, the unconventional tool life improvement approach is required to increase micro tool life.

II. Fundamental terms in micromachining and issues

In this section the definitions, basic terms and applications of micromachining have been discussed. Moreover; how micromachining differentiate from macromachining and various challenges and opportunity in micromachining have also been discussed.

Micromachining is the ability to produce features with the dimensions from 1 µm to 999 µm. Or when the volume of the material removed is at the micro level [14]. According to Albert Herrero the reasonably accepted limits for micro technologies are from 0.5 to 499 µm. Micromachining has applications in biomedical, aerospace, automotive and defence industries. Micro-robots, micro-motors, micro-sensors, micro-compressor and microscale fuel cell are typical example of micro product [13].

Micromachining is majorly classified as a mask based and tool based. It is found that, mask based micromachining is useful for selected material and has limitation to produce complex 3D component. So from last two decades tool based of micromanufacturing techniques have been developed. Tool based method overcomes the limitation of mask based process; it is applicable to metals, alloy, polymers composite and ceramics to form complex 3D components. Mechanical micro cutting consist of micro turning, micromilling, micro drilling etc. Size effects, homogeneity, minimum chip thickness these are some phenomenon which differentiate micromachining from macromachining [15].

Size effect is related with specific energy, specific energy is the energy needs per unit volume of material removed. The size effect is typically characterized in machining, as a non-linear increase in specific cutting energy (or specific cutting force) with decrease in undeformed chip thickness. The higher consumption of specific cutting energy shows material is difficult to machine. [16].

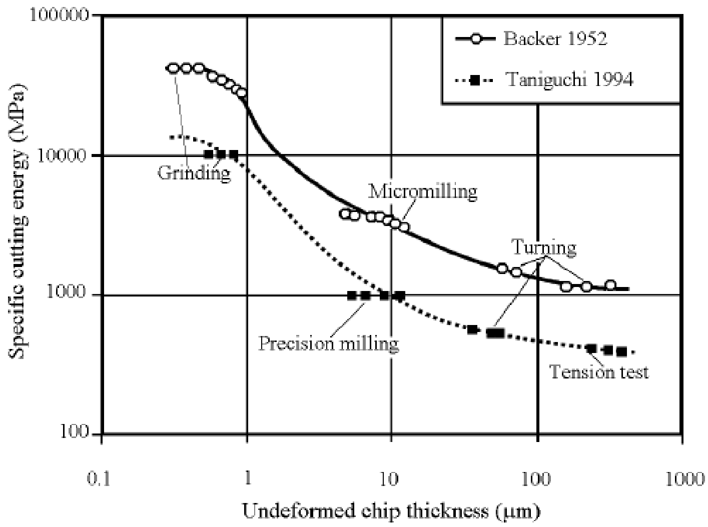

Figure 1: Variation in specific cutting energy for three major machining processes [16].

Figure 1 shows the relationship between the specific cutting energy consumption of SAE 1112 steel for three major machining processes, a more comprehensive trend which includes tensile test data. These trends suggest that decreasing undeformed chip thickness causes work-hardening of material surface [16]. It is found that, size effects originating when the thickness of material to be removed is of the same order of magnitude as the tool edge radius and microstructure of workpiece material has significant influence on the cutting mechanism. It is expected material microstructure, dislocation density/availability, crystallographic orientation, material strengthening effect due to strain, strain rate, strain gradient, subsurface plastic deformation, material separation effect, cutting speed and all inhomogeneities present in all commercial engineering metals may be affecting parameter for size effects [15].

In micromachining workpiece cannot be considered as homogeneous and isotropic due to the size effect caused by material microstructure. The average grain size of generally used engineering materials is between 100 nm to 100 μm. In addition to that, at present the achievable cutting radius (1~2 μm) is limited by tool grinding technology and carbide grain size (0.4-0.7 μm). The feature size of the micro-machined component is normally of a similar order, thus the role of material microstructure is ingrained in the micro-cutting process[16].

When the volume of material deformed at one time is relatively large, there is a uniform density of imperfections and strain (and strain hardening) may be considered to be uniform. While the volume deformed of material approaches the small volume, the probability of encountering a stress-reducing defect (grain boundaries, missing and impurity atoms, etc.) decreases. In that case the specific energy required and mean flow stress rises and the material shows obvious signs of the basic inhomogeneous character of strain [15].

Size effect is significant when the average grain size and uncut chip thickness approaches the same size. In such a case, chip formation takes place by breaking up of the individual grains of a polycrystalline material. While machining multiphase material the tool life get reduces due to change in phase hardness. Suppose initially, the cutting edge is in ferrtic phase and progressing in perlitic phase in that case the cutting forces and surfaces obtained will be different. Literature available for the material which are easy to cut so it so it is needed to explore micromachining of hard material such as hardened steel, nickel and titanium base alloy, heat resistant alloy.

It has been found that, the crystallographic orientation affects chip formation, subsurface crack generation and shear strength. The variation in shear strength affects in generating cutting forces causes' material induces vibration and ultimately surface morphology. Author suggested that, the effect of the crystallographic orientation can be minimize or eliminate by using ten times larger depth of cut than average grain size. Figure 2 shows the improving surface quality at higher depth of cut [15].

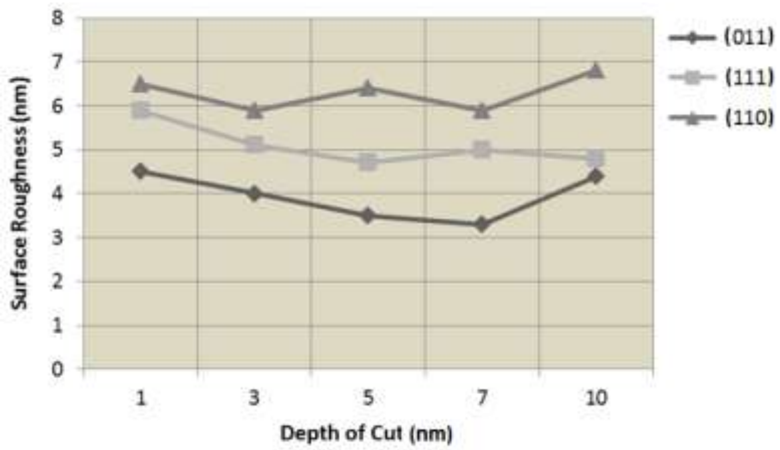

Figure 2: Effects of the crystallographic orientation and the depth of cut on the surface roughness conducted by the diamond turning of single-crystal aluminium roods [15].

Minimum chip thickness is the minimum undeformed chip thickness below which chips may not form [15]. The concept of minimum chip thickness is that the depth of cut or feed per tooth must be over a certain critical chip thickness before a chip will form. Its value is often between 5 % and 38 % of the tool edge radius. It is found that, in conventional machining shear takes place along shear plane, in micromachining shear stress rises continuously around the cutting edge and material seems to be pushed and deformed rather than sheared. Micromachining processes are greatly influenced by the ratio of the depth of cut to the cutting edge radius causing a significant influence to the cutting process by a small change in the depth of cut [15, 18].

The minimum chip thickness phenomenon leads to a rising of slipping forces and ploughing of the machined surface, contributing to the increase of cutting forces, burr formation and surface roughness. It is found that, estimation of the minimum chip thickness is one of the present challenges in micromachining.

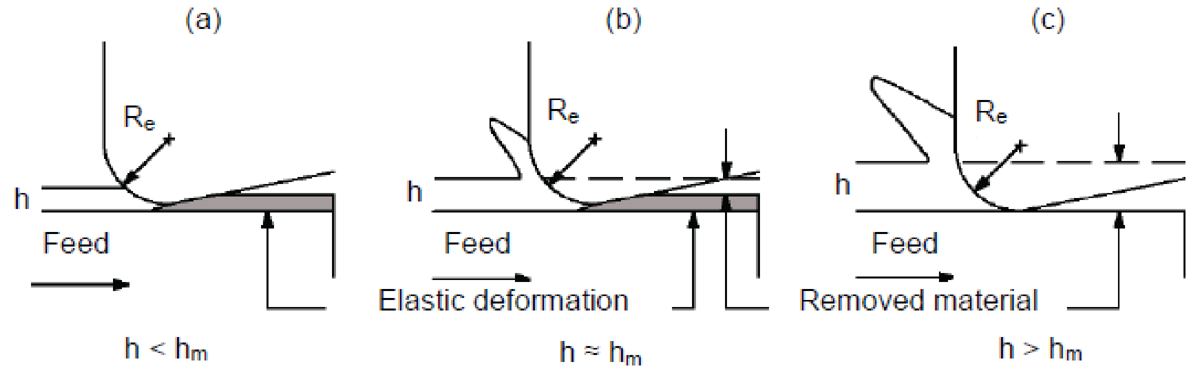

Figure 3: Schematic diagram of the effect of the minimum chip thickness [15, 18]

In figure 3 (a) the uncut chip thickness (h) is less than the minimum chip thickness (hm). The cutter (edge radius Re) deforms elastically the workpiece and no chip is formed, chips formed in a discontinuous way

In figure (b) the uncut chip thickness is almost equal to the minimum chip thickness. Although the workpiece slightly deforms, a chip is formed by material shearing. The elastic spring back of the work-piece leads to a removed depth of work-piece material smaller than the desired depth of cut.

In figure (c) the uncut chip thickness becomes greater than the minimum chip thickness. The elastic deformation of the work-piece decreases dramatically and the removed depth of material becomes equal to the desired depth of cut [15,18].

III. Conclusion

Based on the review of the published literature, following conclusions can be drawn,

1) Size effects, material inhomogeneity and minimum chip thickness are the phenomena which differentiate micromachining from macromachining.

2) The conventional approach of tool life and machining improvement are not that much useful for microcutting.

3) The new approach such as hybrid manufacturing or Cryotretment of cutting tools may improve performance of micro cutting.

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