The micromachining processes supported by electrochemical dissolution

Skoczypiec, S.; Ruszaj, A.

Institute of Production Engineering,
Cracow University of Technology,
Al. Jana Pawla II 37, 31-864, Krakow, Poland
Tel. +48123473743, Fax: +48123743202,
e-mail: skoczypiec@m6.mech.pk.edu.pl

Abstract

In the paper two examples of electrochemical dissolution application for improve technological factors in micromachining will be presented. First is connected with the possibility of decreasing forces in cutting processes by electrochemical intensification support. Second example presents application of electrochemical dissolution for increasing metal removal rate or surface quality in sequential machining process (with combination of electrodischarge micromachining).

1 Introduction

In group of methods worked out for machining of technological equipment, MEMS parts, functional prototypes and tools for micro-casting and micro-forming special attention is paid for application of microcutting and unconventional processes such as the laser beam, electrodischarge and electrochemical machining. The recent development is focused on 3D-shaped surfaces manufacturing. In case of microcutting the main problem during machining is connected with size effect [7, 13]. Significant forces in machining area limits its application to machine 3D parts made of soft materials and dimensions > 100 μm.

Because of this fact the special attention is paid for unconventional processes such as: electrochemical (ECMM) and electrodischarge (EDMM) micromachining, however its disadvantages such as low precision and low productivity also affect quality of machining [12].

One of effective methods to overcome these problems and achieves high performance for micromachining process consists in combining various physical and chemical processes into one machining process, defined as hybrid machining [9].

Below two examples of electrochemical dissolution application which gives the possibility to improve technological factors in micromachining will be presented. First one is a typical hybrid process, where microcutting processes directly removes the material while the electrochemical machining is changing the conditions of machining, by decreasing mechanical properties of machined material.

Second example presents application of electrochemical dissolution in micromachining process chain as a method for increasing metal removal rate or surface quality in sequential machining process (with combination of electrodischarge micromachining).

2 Electrochemically assisted microcutting

The size effect in metal cutting is understood as the non-linear increase of the specific cutting energy with decreasing the undeformed chip thickness (Figure 1) [7, 13]. It has strong influence on manufacturing process, because of the most important effect connected with this is the increase of the cutting force. In case of micromachinining it can be a reason of tool or workpiece bending, brake or damage. This effect increases with machined feature size decreases.

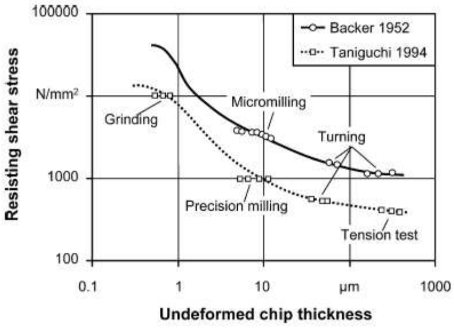


Figure. 1. Variation of shear stress on shear plane when cutting [7, 13].

Therefore, despite of development of tools and machine tools for the micro-cutting application is mainly limited to machine parts made of plastic, silicon and non-ferrous material. Machining of parts make make of steel is very difficult.

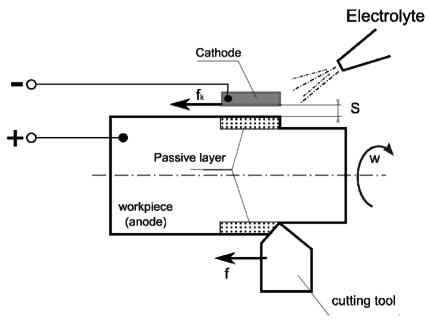
Because of high flexibility the microcutting operations are commonly used for machining small parts with 3D convex (microturning) and 3D concave (micromilling and microdrilling) shape. Taking into account rather low productivity of microcutting process its main area of application is fabrication of tooling for other mass-production microprocesses (micromolding, microforming and micro-die casting). The precision and life time of machined mold has to be high, because its defines the precision of the product, therefore such materials as tool steel or hard ferrous materials are preferred for the above mentioned tooling. Unfortunately, application of diamond tools for micromachining for this purpose is limited, because its affinity to ferrous material. Various efforts have been made to avoid such problems, such us cutting in a carbon saturated atmosphere, cooling the area of cutting process, modifying the chemical composition of the worked material and application of tool ultrasonic vibration during the cutting process [7]

One of the possibilities to decrease cutting forces is to decrease the mechanical properties by workpiece surface layer electrochemical passivation before the cutting (Figure 2). Between workpiece and additional electrode the electrolyte is supplied. When electrolyte pH and voltage are properly selected (according to Pourbaix diagram) on the workpiece surface the thin oxide layer occurs (thickness < 1 μm). This layer is fragile and softer than core material, so can be easily removed with relatively smaller decreased forces [1, 10], what increase tool life, decrease probability of tool damage, and increase accuracy of shaping by decreasing tool and workpiece deformation.

In aspect of discussed method the results of abrasive electrochemical grinding process research should be taken into account. Application of electrochemical dissolution in abrasive grinding changes properties of surface layer what results in significant process productivity increase, improved surface layer quality and tool wear decrease [9]. Presented conception can be effectively applied for:

- microcutting process with geometrically defined tool (i.e. microturning – Figure 2), where electrochemical intensification can solve the problem of tool and workpiece deformation;
- grinding of microstructures (Figure 3), where size of machined features depends on grinding tool dimensions (thickness/diameter ration) and tool wear

[2, 5]. These parameters are connected with forces in machining zone – its decrease can improve possibilities of micro-grinding process.



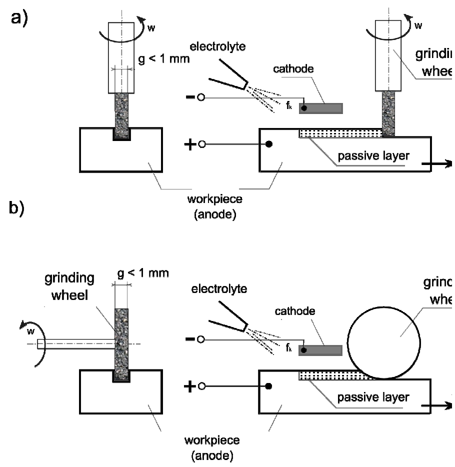


Figure 2. Scheme of electrochemically assisted microturning process; S – interelectrode gap, f, f_k – cathode and cutting tool feed rate, ($f = f_k$), w – workpiece rotational speed.

Figure 3. Scheme of electrochemically assisted microstructuring process with application of micro peripheral (a) and micro pin-type grinding wheel, f – workpiece feed rate, w – tool rotational speed.

Presented in [1, 10] results pointed that: cutting force decrease is possible when thickness of removed material is correlated with thickness of passivated oxide layer. Based on above presented consideration the special equipment has been designed in the Institute of Production Engineering of Cracow University of Technology.

3 3D-EC/EDMM sequential hybrid process

Electrochemical micromilling (3D-ECMM) gives possibility to machine parts without significant influence of workpiece mechanical properties on material removal rate, without tool wear, satisfactory surface quality and many times higher in comparison to electrodischarge machining material removal rate. On the other hand accuracy of electrochemical dissolution process is not satisfactory and irregularity of material structure has great influence on machining results [4, 6]. In electrodischarge milling (3D-EDMM) every current conducted material, despite of its mechanical properties can be shaped with satisfactory, higher than in ECMM accuracy. However, the 3D-EDMM process has two main disadvantages, such as electrode tool wear and low material removal rate, what significantly decrease its area of application [3, 8, 11].

Characteristics of both methods indicate a few essential complementary advantages. It is also worth to underline a lot of similarities in analysed processes (such as machining kinematics, tool shape and material, limitations of workpiece material etc.) what gives possibility to apply sort of identical technical solution in machine- tool design for ECMM and EDMM process.

From above presented considerations results that the idea of combination of 3D-ECMM and 3D-EDMM process into sequential hybrid machining method which will be carried on the same machine tool looks as the way to achieve efficient micromanufacturing method. Combination of EC/EDMM process gives possibility to minimize disadvantages and strengthen the advantages of electrochemical and electrodischarge micromachining. The 3D-EC/EDMM sequence process can be carried on in the following ways (Figure 4):

- ECMM→EDMM: about 80% of allowance is machined by electrochemical dissolution with accuracy about 20 μm. Remainder 20% of allowance thickness is removed with application of electrodischarge machining, what gives possibility to achieve final part with accuracy 1 to 5 μm and relative high material rate;
- EDMM→ECMM (or ECMM→EDMM→ECMM): sequence applied in case when a minimal change of surface layer quality is required (elimination of white layer after electrodischarge machining).

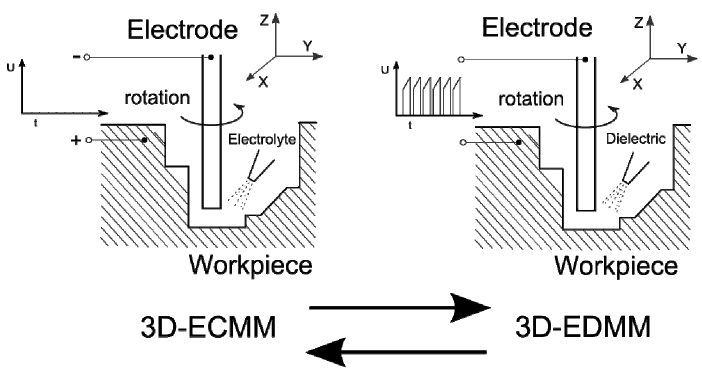


Figure 4. Scheme of the hybrid sequential technology with application of EC/EDMM sequence.

Presented conception gives possibility of essential reduction of both methods disadvantages what results in improvement of technological factors (especially decrease of machining time). Application of EC/EDMM sequence on single machine lead to efficient and accurate 3D surfaces micromachining method. However, it is worth to underline that integration of both technologies into single machine tool cause sort of technical problems connected with process realisation and lead to machine tool design complication.

Analysis of typical design of erosion machines gives possibility to identify similar functional units, what results in machine design simplify. Electrodischarge as well as electrochemical machines consist of similar units (see Figure 5). One can state that main problem of both technologies integration on single machine tool is to achieve EC and ED machining with the same workpiece and tool handling. Therefore, the main technical problems which have to be solved are as follows:

- exchange of working fluid (electrolyte to dielectric and backwards),
- integration of the technology with the CAD/CAM system to realise the machining sequence with single control programme (the same coordinates for both sequences).

Based on this assumption the hybrid machine -tool has been designed in the Institute of Production Engineering (Cracow University of Technology). Solution of the above presented problems gives possibility to take advantage from profs of ED and ECMM technologies.

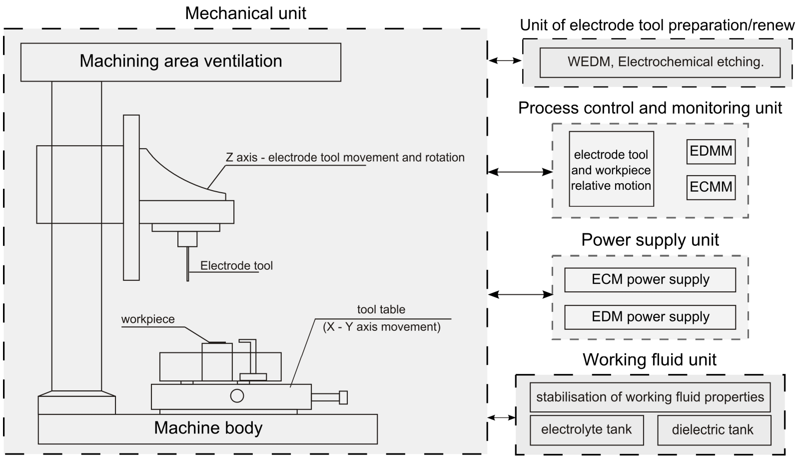


Figure 5. Functional scheme of hybrid sequence EC/EDMM machine-tool.

During conference meeting the description of equipment and results of primary investigations of above described processes (micro-cutting assisted by electrochemical passivation and sequential 3D-EC/EDMM processes) will be presented.

4 Recapitulation

The problem of microdetils made of metals and its alloys manufacturing is very important and industry looks for mew more efficient and more accurate method. In the paper the two ways of improving processes of microdetails manufacturing have been presented. The first one is connected with application of electrochemical assistance in microcutting processes. The second presents the attempt to apply the combine successive ECM/EDM processes and try to increase accuracy and metal removal rate in comparison too those reached separately in ECM or EDM microfabrication. In Production Technology Institute (Cracow University of Technology) the special equipment for experimental investigations of above mentioned processes have been built. The description of this equipment and result of primary investigations will be presented during Conference.

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