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The influence of electrochemical assistance on the cutting forces in microturning process

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Abstract

In case of microcutting, the main problem occurring during machining is related to the size effect. This means that with a decrease of the depth-of-cut a nonlinear relation between the uncut chip thickness and the cutting forces is observed. The implication of such an effect is an increase in the specific cutting energy (the energy necessary to remove a unit of material volume). One of the solutions to overcome this problem and to achieve high performance of the microcutting process is to develop a hybrid machining process by introducing an additional energy source in the machining area. The role of the additional energy source is to change the machined material's properties (improve material machinability) or to change the material removal mechanism. In the paper, the concept of an electrochemically assisted microturning process will be presented. This is a hybrid machining process in which microcutting directly removes the material while electrochemical assistance changes the conditions of the cutting by changing the mechanical properties of the machined material. The experimental part includes a discussion of the research methodology and a comparison of the straight turning results in the case of machining 304 stainless steel without and with electrochemical assistance. The change of the main cutting force resulting from electrochemical assistance was selected as the main investigated technological factor.

Keywords: micromachining; microcutting, microturning; hybrid machining; electrochemical assistance.

1. Problem formulation

The production of microparts is a dynamically developing area in manufacturing technologies. The advanced materials play an increasingly important role in the shaping of microparts. Improved thermal, chemical and mechanical properties of a machined material give substantial benefits to product design and performance, however, they also make traditional machining processes inefficient economically or impossible to apply in general. Therefore, special attention is paid to the application unconventional processes in the group of methods dedicated to machining technological equipment, micro-electro-mechanical systems (MEMS) parts, functional prototypes and tools for micro-casting and micro-forming.

One of the research and development trends in today's micro-manufacturing technology is the integration of different manufacturing techniques into a single machine tool [1]. In this respect integration is defined as a combination of various manufacturing technologies in a single workstation to obtain a product of high and clearly defined features. Such a solution can be justified by economical or synergetic reasons. In the former this results in combined or complete machining, and in the latter it leads to the hybrid process.

According to the CIRP definition, hybrid manufacturing processes are based on simultaneous and controlled interaction of process mechanisms and/or energy sources/tools that have a significant effect on process performance [2]. Hybrid micro-machining processes enable to improve surface roughness, material removal rate, tool life and geometrical accuracy. In case of machining microparts made of hard-to-machine materials hybrid processes especially gives possibility to obtain higher machining efficiency. From the literature review

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presented in [1] results that hybrid micro-machining processes have great potential for fabricating 3D complex micro-components with high accuracy and good surface quality (as examples ECDM [3] or laser assisted machining can be indicated [4]).

In case of microcutting, the main problem occurring during machining is related to the size effect [5]. The implication of it is an increase in the specific cutting energy (the energy necessary to remove a unit of material volume) and it can be stated that the occurrence of size effect limits application of the microcutting process to machining parts made of soft materials [4]. One of the solutions to overcome this problem is to introduce an additional energy source in the machining area. The role of the additional energy source is to change the machined material's properties (improve material machinability) or to change the material removal mechanism. An example of successfully applying the first strategy in cutting is thermal-assisted machining [7]; the second strategy is the ultrasonic vibration-assisted cutting process [8]. In this paper the concept of the electrochemically-assisted microturning process will be presented. In this process microcutting directly removes the material, while electrochemical assistance changes the conditions of the cutting by changing the mechanical properties of the machined material. The investigated process is a typical hybrid machining process.

The idea of electrochemical assistance of the cutting process has been presented in Figure 1 and is based on the fact that metal has different mechanical properties than its oxide [9]. During the electrochemical process, a thin electrolytic passive film (oxide layer) grows on the workpiece surface for the appropriate range of material potential and electrolyte pH. This layer has properties that are different than the core material [10] and can be removed with the use of a relatively reduced cutting force.

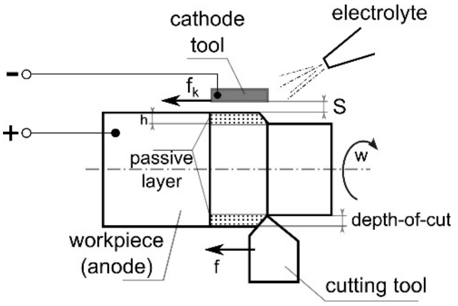

Fig. 1. Scheme of electrochemically assisted microturning: S - interelectrode gap, h - thickness of the passive layer, f, f_k - cutting tool and cathode feed rate ($f = f_k$), w – rotational speed

In order to verify this conclusion during cutting, experiments on straight turning were carried out. The assumptions and results of these are presented in the following paragraphs.

2. Research methodology

The research were carried out on the test stand designed in designed at the Institute of Production Engineering at Cracow University of Technology. Its detailed description has been presented in [11].

The data acquisition system for main cutting force measurement in microturning (Figure 2) consists of hardware components (force sensor CL 17pm, CL 10D amplifier and the NI USB-6351 data acquisition unit) and a LabView platform with developed software for data acquisition and storage. Registered with 1 kHz sampling rate force signals were analyzed with DIAdem and Matlab software. The force sensor was mounted on a tool holder (Figure 3), which allowed to measure the thrust of the holder on the force sensor in the direction of the main cutting force. The measured value is proportional to the main cutting force. It is worth underlining that the main research goal was to determine the difference between the traditional and the electrochemically assisted microturning process and, in this case, such a solution is sufficient.

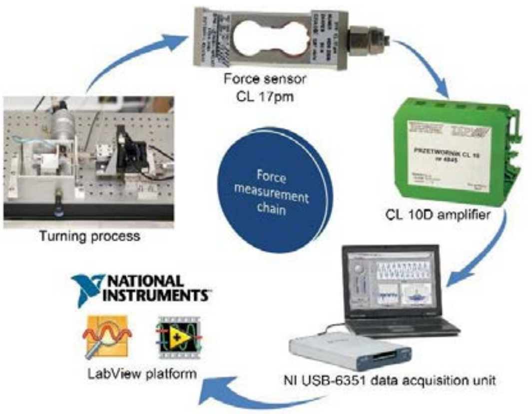

Fig. 2. Scheme showing the force chain measurement in microturning process.

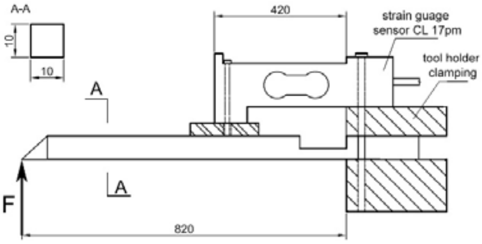

Fig. 3. Scheme showing the method of mounting the strain gauge force sensor CL 17pm

Verification of the described method of force measurement was carried out for straight turning with three different values of depth of cut a_p equal to 1 µm, 5 µm and 10 µm. It can be stated that the values of the sensor load are in the range of milinewtons. From a comparison of the force signals (Figure 4) it turns out that the sensor load decreases nonlinearly with the depth of cut a_p, which is in agreement with the cutting process scaling effects [5].

The measurement range of force sensor CL 17pm is from 0 -5 N with accuracy 2,5 mN. The measured values of force are very low, therefore measurement accuracy issues were also analyzed. Based on calculated from 5 repetitions the mean