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Determination of material properties by evaluation of machinability in multi-scale precision turning

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Abstract

The determination of material properties of metals generally is a time- and resource-consuming process. Material characteristics are influenced by e.g. the composition of the alloy or heat treatment processes and take significant effect on the machinability. Therefore, in turn, machinability is expected to be suitable for providing easier-to-detect information about the material properties such as tensile strength, Young's modulus or hardness. The underlying objective of the work presented is to establish new ways of characterizing different steel alloys with different heat treatment conditions by relating the machinability to their material properties.

In this paper, a first attempt is taken to identify suitable test methods and cutting parameters for the steel alloys 100Cr6 (AISI 52100) and X46Cr13 (AISI 420) that allow for the correlation of cutting force with e.g. tensile strength and Young's modulus. In a multi-scale approach, microspheres with a diameter of 1 mm and macro-scale specimens are face-turned with sharp CBN tools at cutting depths of 0.2 mm. Additionally, macro-scale specimens are face-turned with conventional cutting parameters, i.e. cutting depths above 0.2 mm. The cutting process is analysed by high resolution cutting force measurements in order to relate the force increase and the overall cutting force value to the aforementioned properties. Additionally, the surface roughness is evaluated for its capability of determining the hardness of the material together with the cutting force. The integration of a multi-scale approach is supposed to contribute to the understanding of scale effects between conventional and micromachining.

Keywords: material properties, machinability, multi-scale precision turning, cutting force, surface roughness

1. Introduction

An increase in resource and time efficiency in the development of structural materials calls for novel high-throughput technologies. Innovative procedures capable of generating and characterizing large amounts of specimens with new alloy compositions in a reasonable time frame have to be developed to achieve this goal [1]. Recently, some advances have been made in the field of material prototyping, referred to as rapid alloy prototyping (RAP), which involves the fabrication of specimens with variable alloy compositions in one casting operation [2]. However, testing for mechanical, chemical and technological properties of metal-based materials still depends on time-consuming procedures, limiting speed and efficiency of the characterization. To further accelerate material development processes, new test methods have to be established.

Alloy composition and heat treatment, which determine mechanical material properties like Young's modulus, tensile strength, hardness and various others, also affect the machinability of a given material [3]. The indicators of machinability, such as the cutting force, surface characteristics and chip formation mechanisms therefore provide a range of measurands that are directly or indirectly related to the material properties. This paper deals with a concept to consider this alternative source of information about a material's state in face turning experiments. Furthermore, the possibilities of implementing a high-throughput processing of specimens are enlightened.

2. Multi-scale experimental approach

To uncover relations between indicators of machinability and material properties, suitable measurement techniques and process parameters have to be identified. The goal is to validate a new characterization method based on the analysis of turning experiments with common steel-based materials. Considering the necessity to handle large numbers of specimens when trying to establish a high-throughput characterization, a multi-scale approach is taken for the experimental program. Precision turning experiments with multiple spherical micro specimens (diameter 1 mm), which are mounted in cavities on a cylindrical support disk, allow for testing of larger numbers of specimens in one pass with a comparatively simple experimental setup (see Fig. 1). Depending on the disk size and the sample arrangement, numerous specimens can be evaluated with varying process parameters.

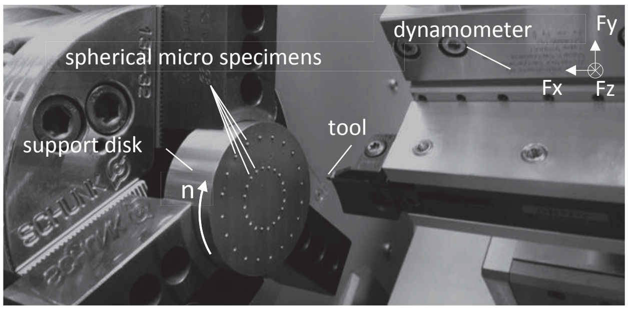

Figure 1. Experimental setup for microturning experiments

Regarding the materials' microstructure and the ratio of the tool edge radius to the depth of cut, size effects have to be taken into consideration when analysing micromachining processes [4-5]. Therefore, results will be verified on a limited number of macro specimens. This multi-scale-approach allows for establishing a link between the machinability of micro and macro specimens and general material properties, while also contributing to further describe size effects in machining. In this approach, the cutting force and surface roughness in micro and macro scale face-turning experiments are evaluated with a set of process parameters to formulate a starting point for further investigations. The main properties these indicators are expected to be related to are Young's modulus, tensile strength and hardness. Steel alloys 100Cr6 (AISI 52100) and X46Cr13 (AISI 420) are machined due to the commercial availability of microspheres from both materials (see Table 1 for material properties). Experiments were performed on a precision lathe (Benzinger Go-Future B2), utilising a multicomponent dynamometer (Kistler 9119AA1) mounted to the tool holder. The tools are made of fine grain CBN. For both materials, microspheres were machined with cutting depths of 0.2 mm and macro-specimens with cutting depths of 0.4 mm. Cutting velocity was held constant at 150 m/min.

Table 1: Properties of the examined materials according to manufacturer information

Sample material	**100Cr6**	**X46Cr13**
Tensile strength	1,570 N/mm^2	1,850 N/mm^2
Young's modulus	208,000 N/mm^2	215,000 N/mm^2
Hardness	60-62 HRC	52-55 HRC

3. Results

Figure 2 depicts a force measurement over multiple microspheres for the applied set of process parameters. Even though it is shown that the resolution allows for the distinction of a single specimen, a reliable cutting force measurement is difficult due to the extremely short, impulse-like contact of tool and specimen. The repetitive rise of the cutting force to values between 15 and 20 N for each specimen does not imply that the peak force resembles the actual force level. Force measurements for macro specimens resulted in similar cutting force levels even though the cutting depth was twice as high as in the micro specimens.

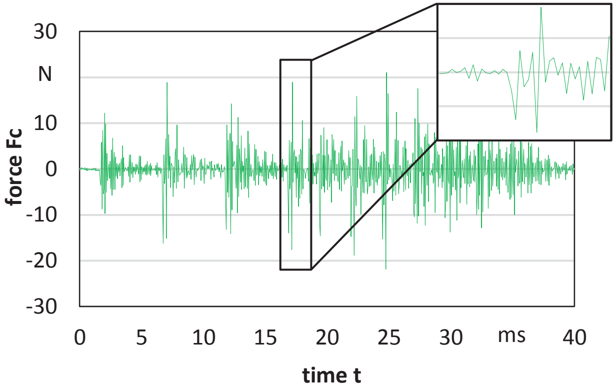

Figure 2: Force measurement while machining multiple microspheres

Figure 3 shows a comparison of the surface roughness of both micro and macro specimens for each of the examined alloys. The values are averaged over 6 measurements or 6 different micro specimens, respectively. For the microspheres, no significant differences can be seen as for both materials the average Sa values is about 100 nm. However, the standard deviation for both micro and macro specimens is comparatively low for the X46Cr13 alloy. This may indicate an alloy-specific characteristic that can possibly allow for a distinction. In general, the surface roughness Sa is at least two times higher for the macro-specimens and can be explained by the higher depth of cut and the continuous cutting conditions whereas the microspheres are machined with a discontinuous cut.

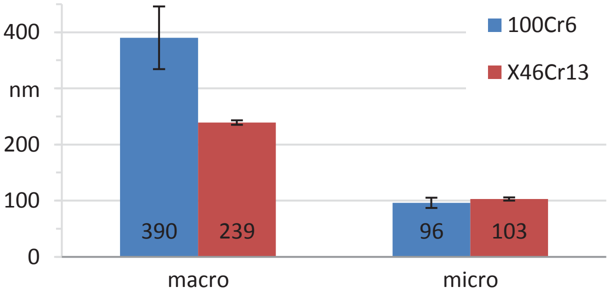

Figure 3. Surface roughness of micro and macro specimen

4. Summary and Conclusion

This study postulates the necessity for alternative characterization methods when trying to establish a high-throughput processing of specimens in structural material development. As a first approach and to formulate a starting point for further investigations, the face turning process was analysed on multiple scale levels regarding the cutting force and the surface roughness. It has been shown that the turning process is capable of handling larger numbers of samples when micro specimens come into use, depending on the tray size and arrangement of the samples. Furthermore, data acquisition from multiple points of view is possible in a single experiment; the measurement setup used for this study is easily extensible with further measurement equipment like acoustic emission sensors, heat sensors or others.

In general, a relation between indicators of machinability and material properties is proclaimed, which holds the potential for the development of alternative characterization methods for novel materials. The exemplary investigation of two common steel alloys shows that the cutting force and surface roughness varies along with the mechanical material properties. To detect reliable links between indicators of machinability and material properties and to quantify the latter by analysing data from the cutting process, further experiments have to be conducted. Future work on this topic will include the extension of both the measurement setup and the experimental programme in order to generate a database that allows an in-depth analysis of the proclaimed relation while also further investigating scale effects between conventional and micro-turning and influences of the microstructure of the material.

Acknowledgement

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