

Chapter 11

3D Finite Element Modeling of High Speed Machining

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ABSTRACT

This paper presents simulation of High Speed Machining of steel with coated carbide tools. More specifically, Third Wave Systems AdvantEdge commercial Finite Element Method code is employed in order to present turning models, under various machining conditions. As a novelty, the proposed models for High Speed Machining of steel are three-dimensional and are able to provide predictions on cutting forces, tool and workpiece temperatures, chip formation, and chip morphology. Model validation is achieved through experimental work carried out under the same conditions as the ones used in modeling. For the experimental work, the principles for design of experiment were used in order to minimize the required amount of experiments and obtain useful results at the same time. Furthermore, a Taguchi analysis is carried out based on the results. The analysis indicates that there is a good agreement between experiment and modeling, and the proposed models can be further employed for the prediction of a range of machining parameters, under similar conditions.

INTRODUCTION

High Speed Machining (HSM) is of special interest to the industry and the academia in the last few years due to the advantages it exhibits in comparison to conventional machining. The boundary between conventional machining and HSM depends on factors such as the workpiece material and the process. Most commonly, definitions of HSM make use of cutting speeds pertaining to turning, separately for ferrous and non-ferrous materials; the limit above which an operation is characterized as HSM for some non-ferrous materials can be higher at about one order of magnitude to that of alloyed steel. However, the highest cutting speeds can be achieved for non-ferrous materials that exhibit good machinability, such as aluminum, but they are limited by the attained cutting speeds of the machine tools. On the other hand, machining speeds of materials with poor machinability, such as titanium, are limited by the available cutting tools. Furthermore, operations such as turning, milling and grinding are more suitable for performing HSM than other operations, based on the achievable cutting speeds of each type of machining operation (Byrne, Dornfeld, & Denkena, 2003). Thus, definitions that account only for cutting speed or only one cutting operation or wide material groups tend to have a lot of exceptions and to soon be outdated due to the ongoing research regarding machine tools and cutting tools for HSM.

Considering the above, a global definition of HSM operations is rather difficult to be provided since a number of factors need to be accounted for; cutting speed, spindle speed, feed, the cutting operation, workpiece material, cutting tool and cutting forces are the features included in some definitions (Byrne, Dornfeld, & Denkena, 2003; Erdel, 2003; Grzesik, 2008), while a definition including the cutting tool and spindle dynamics has been proposed (Smith & Tlustý, 1997). A definition by Tlustý (1993) states that HSM refers to processes with cutting speed or spindle

rotational speed substantially higher than some years before or also than the still common and general practice. The definition, even though is very general, avoids to give a spectrum of speeds or a lower value above which a machining process is characterized as HSM and can be applied to various materials and processes.

Although the rate of tool wear increases at high speeds (List, Sutter, & Bi, 2009), thus reducing tool life, several features of HSM can be considered as advantageous. A very important advantage of HSM is the high material removal rate achieved, which is a function of the cutting speed as well as the undeformed chip cross-section, and leads to higher productivity, especially in the case of light metal alloys.

Besides the increase in the material removal rate an increase in surface quality is achieved with HSM, thus making these processes suitable for precision machining and micromachining; high speed milling is used for the fabrication of tools e.g., EDM electrodes and dies, while high speed drilling is used for micro-drills on printed circuits. The excellent surface finish reported in HSM operations, further reduces machining time and cost as it makes subsequent finishing operations, such as grinding, redundant.

It is understood that when cutting speed is increased, a subsequent increase in cutting temperatures takes place and no decrease is observed with further increase in speed, despite the predictions of the opposite phenomenon by some researchers. On the other hand with increased speed, a decrease in cutting forces is observed (Schulz & Moriwaki, 1992). As experimental work has shown, cutting forces tend to reduce, in some cases by 10-15%, as the speed is increased to high values (Trent & Wright, 2000; Schulz, 2001; Grzesik, 2002; Erdel, 2003). This force reduction may be attributed to the reduced strength of the workpiece material due to the elevated temperatures of the process (Trent & Wright, 2000). High temperatures in HSM may be observed when cutting fluids are reduced or even omitted and so is their cooling

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