Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 58 (2017) 73 – 78

www.elsevier.com/locate/procedia

16th CIRP Conference on Modelling of Machining Operations

Cutting simulations using a commercially available 2D/3D FEM software for forming.

Eric Segebade[a,]*, Michael Gerstenmeyer[a], Frederik Zanger[a], Volker Schulze[a]

[a]*wbk – Institute of Production Science, Karlsruhe Institute of Technology (KIT), Kaiserstr. 12, 76131 Karlsruhe, Germany*

* Corresponding author. Tel.: +49-721-608-45906 ; fax: +49-751-608-45004. E-mail address: eric.segebade@kit.edu

Abstract

Chip formation simulations require either sophisticated material based element removal or deactivation routines, or a powerful remeshing procedure. Therefore the accuracy of all chip formation simulations significantly depends on the FEM-software as well as the material data. Over the course of the past years, a few select commercial programs became the pre-eminent choice for chip formation simulations. In this work, the software simufact.forming, which is not one of those few programs widely in use, has been employed for 2D and 3D chip formation simulations. Orthogonal cutting experiments with AISI4140 were conducted and subsequently modeled, including the cutting edge radius. The results were analyzed with regard to how well chip formation and the resulting process forces in 2D and 3D can be depicted.

Peer-review under responsibility of the scientific committee of The 16th CIRP Conference on Modelling of Machining Operations

Keywords: Finite element methid (FEM); Cutting, Chip formation

1. Introduction

The modeling and simulation of cutting operations is steadily gaining momentum in terms of its utility for predicting macroscopic part performance. Various models from various scientific institutes and companies can already predict the cutting forces, temperatures, microstructural and phase changes, residual stresses, tool wear, tool life, and even chip type for machining operations [1-6].

Several software applications are most widely used for FEM- simulations of cutting operations (alphabetical order):

- Abaqus
- Advantedge
- Ansys/LS-Dyna
- Deform
- Forge

There are also some non-commercial custom programs and program modifications in use.

In addition to FEM-simulations, meshless techniques [7] and smooth particle hydrodynamics (SPH) [8] can also be used to depict the cutting processes of various materials. Chip formation can be simulated within FEM via different strategies, such as element deletion, node separation, continuous or discontinuous re-meshing, or by a combination of these. As shown in [9], the friction models and coefficients chosen profoundly influence the quality of simulations (regardless of software) and remain a critical factor for depicting cutting in simulations. Many of these methods have been evaluated by [10], who conclude that the simulation predictions vary widely depending on the software package, the modeling strategy, and (using the same software) the user. An even more detailed benchmark of simulation software for cutting processes is planned over the next few years within the scope of a CIRP collaborative work.

Future refinements in the FEM-simulations of cutting operations will focus on the incorporation of: physics-based material models (e.g., those considering microstructure), friction models obtained with cutting-relevant experimental data, thermal conductivity models, workpiece state data that accounts for upstream processing, cutting edge microgeometries, tool roughness, and wear data. Improvements in 3D simulations and computation speed – particularly when simulating complete parts – are also areas of interest.

Peer-review under responsibility of the scientific committee of The 16th CIRP Conference on Modelling of Machining Operations
doi:10.1016/j.procir.2017.03.195

Even though advanced cutting simulations usually focus on the resulting surface integrity details, such as residual stresses and microstructural changes, the first step in model validation is to predict the cutting forces for a range of process parameters. Without realistic cutting forces, the resulting predicted surface integrity can hardly be considered physically correct – barring the possibility of fitting prediction models to experimental data using incorrectly calculated forces (and, in turn, incorrectly calculated stress, deformation and possibly temperature fields). The asymmetry of the cutting edge should also be considered, since experience shows that edge asymmetry not only influences process forces [11] but also the resulting surface integrity of parts [12]. According to the literature, a change in the edge segment length at the flank face S_α will likely impact the process forces more severely than a change in the edge segment length of the rake face S_γ [13].

In this work, a 2D and 3D orthogonal cutting model is set up using the commercial FEM-software *simufact.forming*. The software specializes in forming and joining operations and has not previously been used for chip formation simulation. Following a brief analysis of the system's sensitivity to cutting edge asymmetry, an investigation of friction parameters is conducted. Finally, the model is tested against experimental cutting force data obtained for different process parameters with AISI 4140 considering the real cutting edge microgeometries.

2. Experiments

2.1. Experimental setup

Orthogonal cutting experiments with AISI 4140 QT were carried out on a Karl Klink vertical broaching machine. Workpieces with dimensions of 80*x*4*x*20 *mm* with the depth of cut applied to the height of 20 *mm* were used. While the workpiece is moved vertically, the tool is fixed on a three component dynamometer Type Z 3393 by Kistler. A rake angle of -7° was used for all experiments. All experiments were repeated three times. Additionally a new characterized cutting edge was used for each set of parameters. The three sets of process parameters are listed in Table 1.

Table 1. Orthogonal cutting experiments with AISI 4140 QT

set no.	cutting velocity v_c in m/min	uncut chip thickness h in µm		
1	80	25	50	100
2	100	25	50	100
3	150	25	50	100

2.2. Cutting tools and cutting edge characterization

Uncoated Walter Tools cutting inserts type WKM P8TN 6028833 with a cutting wedge angle of 90° and thus a flank angle of 7°. The inserts were shipped with a nominal cutting edge radius of 40 ± 10 *µm*. Each edge was analyzed using a confocal light microscope of the NanoFocus AG and subsequently characterized by the form-factor method [14]. The form-factor K is the ratio of edge segment lengths S_γ at the rake face and S_α at the flank face. The mean size of the radius $\overline{S}$ is the arithmetic mean of S_γ and S_α. Table 2 shows the combinations of tool microgeometry and experiment. It is notable, that none of the cutting edges features a K equal to or smaller than 1. All edges exhibit a S_γ that is at least 10% longer than the respective S_α.

Table 2. Cutting edge radii of the WKM P8TN 6028833

cutting velocity v_c in m/min	uncut chip thickness h in µm	mean cutting edge radius $\overline{S}$ in µm	form-factor K
80	25	35.0	1.8
80	50	35.0	1.1
80	100	41.0	1.2
100	25	44.0	1.3
100	50	38.5	1.6
100	100	39.5	1.5
150	25	33.5	1.2
150	50	44.0	1.4
150	100	39.0	1.7

3. FE-Simulations

3.1. 2D-FE-Model

2D-FE-simulations were set up with two different accuracy settings henceforth referred to as "basic" and "normal". The basic setup features approximately three times bigger elements than the normal setup. The basic setup was used for the comprehensive friction coefficient study. The normal setup as shown in Fig. 1 was compared with the experimental data as well as the sensitivity analysis regarding cutting edge asymmetry. In all cases the length of cut was set as 1 *mm*. The workpiece was modeled with a length of 4 *mm* and a thickness of 1 *mm*.

The mesh type "Quadtree" in plane strain condition with continuous remeshing depending on refinement boxes was used. The number of elements varied with uncut chip thickness with the highest number of elements necessary for 100 *µm* of uncut chip thickness. In the example shown in Fig. 1 (uncut chip thickness of 100 *µm*) the number of elements increased with length of cut from 15000 to up to 85000 elements.

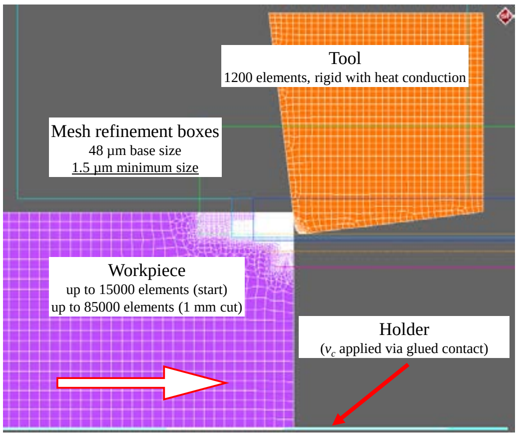

Fig. 1. 2D-cutting model (normal accuracy)