Data Article

Data for a simulation of metal cutting with cutting fluid using the Finite-Pointset-Method

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A B S T R A C T

The measurement and simulation data, their preparation and the simulation setup published in this co-submission are related to the article “Simulation of metal cutting with cutting fluid using the Finite-Pointset-Method” \cite{1}. Wet and dry turning experiments were conducted at the Institute for Machine Tools and Factory Management (IWF), Berlin, Germany. Required adaptations of the used software MESHFREE were performed at Fraunhofer ITWM, Kaiserslautern, Germany. Both institutes collaboratively developed and validated the orthogonal cutting simulation model using the Finite-Pointset-Method (FPM).

In this paper all measurement and simulation data and their preparation methods are presented in detail. This includes the preparation methods of process forces, analysis of chip morphology images as well as measured contact lengths on tool rake faces. Moreover, the experimental and simulation data are provided at the Mendeley Data repository \cite{2}. Hence the reader can use the data for own validations and analysis. Furthermore, the used simulation model files are completely published at the Mendeley Data repository. It allows the reader to retrace all settings. In addition, this enables to

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Specifications Tables

| Subject | Industrial and Manufacturing Engineering |
|---------|-----------------------------------------|
| Specific subject area | Modeling of a wet orthogonal cutting process with the Finite-Pointset-Method and experimental validation |
| Type of data | Table, Microscope Image, Graph |
| How data were acquired | Turning machine: VDF-180 C-U from Oerlikon Boehringer, Göppingen, Germany; Cutting fluid: Adrana A 401 from Shell Macron GmbH, Dortmund, Germany, in a 5% water-based emulsion; Force dynamometer: Z13764 from Kistler, Winterthur, Switzerland; Microscope: VHX 5000 from Keyence, Osaka, Japan; Simulation software: MESHFREE β2020.06 from Fraunhofer ITWM, Kaiserslautern, Germany; Analysis software: MATLAB R2019b from The MathWorks Inc., Natick, USA. |
| Data format | Raw, Filtered, Analysed, Simulation models |
| Parameters for data collection | Process: Orthogonal turning; Workpiece material: Inconel 718; Tool material: SPUN120312 H13A; Cutting condition: dry, wet; Process repetitions: 2; Cutting speed: \( v_c \) = 40, 70, 100 m/min; Feed: \( f \) = 0.05 mm; Rake angle: \( \gamma_0 \) = 0°; Clearance angle: \( \alpha_0 \) = 11°; Width of cut: \( b \) = 1 mm |
| Description of data collection | During the short time cutting experiments the forces were measured. Afterwards the collected workpiece chips were prepared in epoxy resin, subsequently ground and etched as well as photographed and measured under the microscope. The simulation results were analogically analysed. Detailed information is given below. |
| Data source location | Technische Universität Berlin; Institute for Machine Tools and Factory Management (IWF); Chair of Machine Tools and Manufacturing Technology; Pascalstraße 8–9; 10587 Berlin; Germany |
| Data accessibility | Data is hosted on Mendeley Data [2]. Data identification number: 10.17632/x2998wdc95.3. Direct URL to data: https://data.mendeley.com/datasets/x2998wdc95/3. For general accessibility, raw and filtered results contained in .mat-files are additionally exported in the open-source format .ods. |
| Related research article | Uhlmann E, Barth E, Seifarth T, Höchel M, Kuhnert J, Eisenträger A. Simulation of metal cutting with cutting fluid using the Finite-Pointset-Method. In: Curtis D, editor. Procedia CIRP 9th CIRP Conference on High Performance Cutting. Amsterdam: Elsevier B.V.; 2021:101 pp. 98–101. |
Value of the Data

- The provided data and its preparation allow the reader to identify strengths and weaknesses of the used measurement and preparation methods in the article [1]. Due to the upload of the simulation model all settings can be comprehended.
- All researchers and industrial users with the focus on cutting simulations can benefit from the provided data and simulation setup.
- The provided simulation models enable the reader to repeat the simulations and conduct own parameter studies. In addition, the measurement data can be used for the validation of numerical and experimental results in other research works.
- The provided model allows the reader to simulate dry and wet orthogonal cutting processes under variable conditions.

1. Data Description

1.1. Experimental data

In Table 1 the used process ID # are connected to the process settings and the process repetitions. In total twelve experiments are conducted including six different parameter settings. The parameter variation includes the cutting speeds \(v_c = 40, 70, 100\) m/min as well as dry and wet process conditions. Detailed descriptions of the experimental setup are presented in section 2.

The experimental process forces are saved in the file ‘Experimental_data.mat’ in the repository [2]. In this file the raw force signals, filtered forces and mean forces as well as the intervals of averaging are included. The file ‘Experimental_data.ods’ contains process forces in an open-source format to enable a general accessibility. The script for data preparation is published with the name ‘Analysis_of_Experiments.m’. This script filters the raw data and calculates the average over a specific time interval. The time interval of averaging for every process is determined by the subfunction ‘findConstantRange.m’. In addition, microscope images of contact lengths and chips morphologies are also provided in the repository in the files ‘Contact_lengths_experiment.pdf’ and ‘Chip_thicknesses_experiment.pdf’.

Table 2 summarizes measurement outcomes. In contrast to the article [1] Table 2 contains additional information such as mean contact lengths \(\bar{l}_c\) and all mean chip thicknesses \(h\).

| Process ID # | Cutting speed \(v_c\) m/min | Process condition | Repetition |
|--------------|-----------------------------|-------------------|------------|
| 1            | 70                          | dry               | 1          |
| 2            | 70                          | dry               | 2          |
| 3            | 70                          | wet               | 1          |
| 4            | 70                          | wet               | 2          |
| 5            | 40                          | dry               | 1          |
| 6            | 40                          | dry               | 2          |
| 7            | 40                          | wet               | 1          |
| 8            | 40                          | wet               | 2          |
| 9            | 100                         | dry               | 1          |
| 10           | 100                         | dry               | 2          |
| 11           | 100                         | wet               | 1          |
| 12           | 100                         | wet               | 2          |
Apart from that, differences between the process repetitions can be identified. In the following, percentage deviation between process repetitions as well as process parameters are mentioned. All calculated percentages are related to the larger value. The percentage deviation between process repetitions 1 and 2 of cutting forces $F_{c,1,2}$ is between 1.1% and 3.5% and for the feed forces $F_{f,1,2}$ between 0.7% and 6.4%. Percentage deviations between process repetitions of measured contact lengths $l_{c,1,2}$ are in range of 3.2% and 8.4%. In contrast to this, the measured chip thicknesses $h_{c,1,2}$ distinctively differ. The maximum deviation is 30.6% for process 7 and 8. The remaining chip thicknesses vary between 1.8% and 8.7%.

An increase between 1.9% and 11.2% in the mean cutting forces $\bar{F}_c$ can be identified with acting of cutting fluid in comparison to the dry processes. The developments in the mean feed forces $\bar{F}_f$ are not unambiguous. For a cutting speed of $v_c = 40$ m/min a decrease of the mean feed force $\bar{F}_f$ of 0.5% can be observed. In contrast to this, the cutting speeds $v_c = 70$ m/min and 100 m/min in wet processes lead to 7.3% and 3.1% increase in mean feed forces compared to the dry process. The mean contact lengths $\bar{l}_c$ decrease for wet processes in comparison to the dry process for $v_c = 40$ m/min by around 29.3% and for $v_c = 70$ m/min by around 1.7%. For $v_c = 100$ m/min changes between dry and wet processes can be observed with 0.7%. In the presence of cutting fluid, the mean chip thicknesses $\bar{h}$ decreases between 1.8% and 8.1% compared to the dry process.

### 1.2. Simulation model

In the Mendeley Data repository [2] the simulation model is provided. It consists of four text input files. The 'USER_common_variables.dat' is the main part in which most simulation settings are declared. Common process parameters are variable implemented and can be adapted. The files 'input_construction_geometry.dat' and 'KSS_nozzle_rectangle.msh' create the geometry of a wet orthogonal turning process. Additional settings for the numerical solver are determined by the file 'common_variables.dat'.

A parameter study of the reduced width of cut $b_{\text{sim}} = 0.05, 0.1, 0.2$ and 0.4 mm was conducted during the development of the simulation model. Fig. 1 shows the mean cutting force $\bar{F}_c$ and mean feed force $\bar{F}_f$ depending on the reduced width of cut $b_{\text{sim}}$. From $b_{\text{sim}} = 0.1$ mm to $b_{\text{sim}} = 0.2$ mm the mean cutting force $\bar{F}_c$ increased around 3.8% and the mean feed forces $\bar{F}_f$ around 17.9%. In contrast to this, from $b_{\text{sim}} = 0.2$ mm to $b_{\text{sim}} = 0.4$ mm a lower increase

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**Table 2**

Summarized results for the conducted experiments.

| Process ID # | 5, 6 | 1, 2 | 9, 10 | 7, 8 | 3, 4 | 11, 12 |
|--------------|------|------|-------|------|------|--------|
| $v_c$ m/min  | 40   | 70   | 100   | 40   | 70   | 100    |
| $f$ mm       | 0.05 | 0.05 | 0.05  | 0.05 | 0.05 | 0.05   |
| condition    | dry/wet | dry | dry | dry | wet | wet |
| $F_{c,1}$    | N    | 216  | 219  | 211  | 242  | 243    | 214   |
| $F_{c,2}$    | N    | 209  | 227  | 207  | 238  | 236    | 212   |
| $F_{c}$      | N    | 213 [1] | 223 [1] | 209 [1] | 240 [1] | 240 [1] | 213 [1] |
| $F_{f,1}$    | N    | 204  | 187  | 162  | 195  | 204    | 161   |
| $F_{f,2}$    | N    | 201  | 194  | 152  | 208  | 208    | 162   |
| $F_f$        | N    | 203 [1] | 191 [1] | 157 [1] | 202 [1] | 206 [1] | 162 [1] |
| $l_{c,1}$    | μm   | 543  | 414  | 292  | 414  | 393    | 274   |
| $l_{c,2}$    | μm   | 590  | 399  | 278  | 388  | 406    | 299   |
| $l_c$        | μm   | 567  | 407  | 285  | 401  | 400    | 287   |
| $a_1$        | μm   | 130  | 132  | 105  | 102  | 128    | 109   |
| $a_2$        | μm   | 142  | 139  | 115  | 147  | 132    | 107   |
| $F_r$        | μm   | 136  | 136 [1] | 110  | 125  | 130 [1] | 108   |
of mean feed force $F_f$ of around 1.7% was simulated and the mean cutting force $F_c$ decreases around 0.8%.

### 1.3. Simulation data

The simulation results are saved in the file ‘Simulation_data.mat’ [2]. It contains a file with the raw and filtered simulated forces, averaged forces and raw and filtered contact lengths. In the open-source format file ‘Simulation_data.ods’ the raw and filtered results are additionally saved. Images of the chip morphologies as well as measured chip thicknesses are provided by the file ‘Chip_morphology_simulations.pdf’. Due to the computational determinism of numerical simulations repetitions are not necessary. Therefore, just every second process ID # from Table 1 is included in the files.

The script ‘Analysis_of_Simulations.m’ uses the described analysis methods from section 2 to evaluate the representative simulation forces and contact lengths. Chip thicknesses are evaluated as described in section 2. Table 3 summarizes all simulation results. It can be seen that the mean cutting forces $F_c$ decrease in the presence of cutting fluid. A decrease in the mean cutting forces $F_c$ between 2.6% and 7.9% can be observed between simulations regarding dry and wet conditions. Analogical behaviour is detected for the simulated contact lengths $l_c$. The simulated contact lengths $l_c$ decrease between 1.2% and 10.3% between dry and wet simulations. For the
mean feed forces $F_f$ as well as the mean chip thicknesses $t_c'$ no clear trend can be identified. In comparison of the mean feed forces $F_f$ between dry and wet processes for $v_c = 40$ m/min and 70 m/min a decrease of 1.6% or rather 1.5% is simulated. For $v_c = 100$ m/min the mean feed forces $F_f$ increase by 2% in the wet process compared to the dry process. Compared to the dry simulation the wet simulations lead to 3.3% lower mean chip thicknesses $t_c'$ for $v_c = 40$ m/min and 6.4% lower for $v_c = 70$ m/min. In contrast to this, in the wet simulation with $v_c = 100$ m/min the simulated contact length $l_c$ increases around 3.3% compared to the dry simulation.

2. Experimental Design, Materials and Methods

Orthogonal dry and wet turning processes of the nickel-based alloy Inconel 718 are conducted as validation values for the FPM simulation model. This process kinematic was chosen as validation for the simulation models because of the simplified process kinematics in comparison to cylindrical turning.

Fig. 2 shows the experimental setup including process kinematic and orientation of the cutting fluid nozzle. Discs with a width of cut $b = 1$ mm were manufactured of a grooved shaft.

The turning machine VDF-180 C-U from Oerlikon-Boehringer, Göppingen, Germany, was used for this experiment. Tools of cemented carbide H13A from Sandvik, Sandviken, Sweden, in the ISO-geometry SPUN 120312 were utilized. Combined with the tool holder, the process kinematic resulted in a rake angle of $\gamma_0 = 0^\circ$, clearance angle of $\alpha_0 = 11^\circ$, tool cutting edge angle $\kappa_r = 90^\circ$ and tool cutting edge inclination $\lambda_r = 0^\circ$. An average cutting edge radius of $r_{\beta} \approx 5$ $\mu$m was measured on the tool cutting edge using the microscope MikroCADpico from LMI Technologies, Burnaby, Canada. In the experiment a variation of the cutting speed $v_c = 40$, 70 and 100 m/min was investigated by using a constant feed of $f = 0.05$ mm.

A 5% water-based emulsion out of the concentrate Adra A 401 from Shell Macron GmbH, Dortmund, Germany, was used for flood cooling. A viscosity of $\eta_{CF} = 10.6$ mPa·s and a surface tension of $\sigma_{y,CF} = 38.3$ mN/m were measured for this emulsion. The turning machine flushed the cutting fluid through a separate tube perpendicular to the rake face onto the tool. A distance between nozzle and tool was measured with $d_{IN} = 42.2$ mm and the nozzle diameter was $d_N = 7.3$ mm. Based on a measured cutting fluid volume flow of $V_{CF} = 20$ l/min, the cutting fluid velocity is calculated to $v_{CF} = 8$ m/s.
Inconel 718 is a difficult to cut material and damages the tool. To avoid the influence of wear these cutting processes were carried out only for a few seconds, until a constant force level was achieved, and each process parameter combination was performed twice. Additionally, all cutting edges were checked for intactness with the microscope VHX 5000, Keyence, Osaka, Japan.

For measuring the process forces a dynamometer of the type Z13764 from Kistler, Winterthur, Switzerland, was used. Subsequently, for repetitions 1 and 2 of all considered processes the forces were filtered using a bandpass filter. A lower frequency bound is necessary due to run in and run out sections in the force signals. Used cut off frequencies depend on the cutting velocity \( v_c \) and can be found in the related analysis script ‘Analysis_of_Experiments.m’ [2]. For the constant force level, the process forces were averaged. Fig. 3a) illustrates this approach for the dry cutting process with \( v_c = 100 \) m/min. The bold highlighted section of the curve emphasizes the constant force level in which the average was calculated. The cutting force \( F_c \) and feed force \( F_f \) are the mean values from both repetitions. In Table 2 the measured forces for every repetition \( F_{c,1,2} \) and \( F_{f,1,2} \) as well as the mean process forces \( F_c \) and \( F_f \) are listed.

Due to tribological interaction between tool and workpiece such as abrasion and adhesion on the tool rake face the contact lengths \( l_c \) were determined with a microscope after process completion. The accuracy of this approach has been demonstrated by the use of a thin copper layer on the tool rake face [3]. However, the contact length in an orthogonal process is not a constant
value over the width of cut b. Therefore, for every process repetition the minimum and maximum contact lengths were measured with the microscope VHX 5000, Keyence, Osaka, Japan, and the contact length of a repetition $l_{c1,2}$ was calculated by averaging minimum and maximum contact lengths. Examples of measured contact lengths are given in Fig. 3b) and Fig. 3c). The mean contact length $l_c$ is the mean value between both repetitions. All determined contact lengths are shown in Table 2.

To validate the chip morphology the chips for every process repetition were collected and subsequently prepared in epoxy resin. Afterwards they were ground and etched. The samples were examined with the microscope VHX 5000. Due to wavy morphologies the chip thicknesses in two peaks and valleys $h_p$ and $h_v$ were measured and by averaging those, the chip thickness $h'$ was determined for every process repetition. In accordance with the process forces and contact lengths, the mean chip thickness $\bar{h}$ for one process parameter combination is the mean value between both repetitions. This approach is demonstrated in Fig. 3d) and Fig. 3e) and Table 2 contains the summarized results.

The simulation outcomes were analogically post-processed as the experimental ones. In contrast to the experiments, repetitions were not needed because of the computational determinism of numerical calculations. All analysed results can be found in the Table 3. Fig. 4a) shows the simulated process forces. Due to the reduced width of cut $b_{sim} = 0.2$ mm, the simulated process forces were multiplied by $b/b_{sim} = 5$. Therefore, the measured and simulated process forces are comparable. The interval of averaging is highlighted in bold. The contact length $l_c$ was continuously determined by the simulation software. Fig. 4a) illustrates the time development of the contact length $l_c$. During the whole duration of the simulation the contact length was continuously increasing. Therefore, the maximum contact length in the range of the stationary process window was used as the simulated contact length $\bar{l}_c$. Thereby, no effects regarding the end of the simulation influenced the simulated contact lengths. Fig. 4b) illustrates the temperature field of the simulations in the middle plane of the chip. The mean chip thicknesses $\bar{h}$ were analogically determined as in the experiment.

| Process parameter | Material | Tool | Software |
|-------------------|----------|------|----------|
| Orthogonal turning | Inconel 718 | SPUN120312 H13A | MESHFREE |
| $v_c$ = 100 m/min | |
| $f$ = 0.05 mm | | | |
| $b_{sim}$ = 0.2 mm | | | |

**Fig. 4.** Illustration of analysis methods for simulations; a) process forces and contact length; b) temperature field with measured chip thicknesses.
Ethics Statement

The authors state to have no known conflict with ethics in publishing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have, or could be perceived to have, influenced the work reported in this article.

CRediT Author Statement

**Eckart Uhlmann:** Funding acquisition, Supervision; **Enrico Barth:** Conceptualization, Methodology, Validation, Resources, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition; **Tobias Seifarth:** Methodology, Software, Validation, Visualization; **Maximilian Höchel:** Investigation, Validation; **Jörg Kuhnert:** Conceptualization, Methodology, Software, Funding acquisition; **Almut Eisenträger:** Writing – original draft, Writing – review & editing.

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Supplementary Materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.dib.2021.107339.

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