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Modeling the motion of the cooling lubricant in drilling processes using the finite volume and the smoothed particle hydrodynamics methods

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Abstract

The process of single-lip deep hole drilling is used in various industrial applications for the production of small bores with a high length to diameter ratio. Especially the cooling and the lubrication of the machining zone have a great influence on the tool life, on the transport of chips, as well as on the quality of the resulting bore. In this paper, two approaches for the modeling and simulation of drilling processes are presented. On the one hand, the Finite Volume Method is used for the stationary simulation of the flow field. Assuming the entire bore to be filled with coolant, the focus is laid on a precise description of important fluid mechanical quantities along the cutting edges. The results show that the mass exchange of the cooling lubricant close to the cutting edge is far too low in order to guarantee the required cooling effect. On the other hand, a coupled meshless approach for the transient simulation is presented. The cooling lubricant is there modeled by the Smoothed Particle Hydrodynamics method and the Discrete Element Method is used for the description of chips. In contrast to the Finite Volume simulation, the main focus is laid on the evolution of the free surfaces and the transport of particles. The results show that the transport of chips by the cooling lubricant can be described well. Furthermore, also the transient Smoothed Particle Hydrodynamics simulations show an insufficient mass exchange behind the cutting edges matching the steady-state results from the Finite Volume simulation with a bore completely filled with coolant.

Keywords: deep-hole drilling, chips transport, cooling lubricant, lubrication, machining, CFD

1. Introduction and background

As the industrial need for bores with a high ratio of hole-depth to hole-diameter is continuously increasing, simulation tools for an efficient and accurate process layout at low costs become more and more important. However, due to the large variety of phenomena occurring in the process of deep hole drilling, e.g., chips transport, thermal conduction, lubrication and turbulence, a single simulation tool for the investigation of all relevant aspects is hardly realizable. Hence, the choice of a suitable simulation method is strongly depending on the specific issue. In this work, the Finite Volume Method (FVM) is used for the stationary description of the flow field, with and without randomly placed chips at fixed locations. Smoothed Particle Hydrodynamics (SPH) coupled with the Discrete Element Method (DEM) on the other hand, is used for the transient simulation of the drilling process, including the transport of chips. Despite the well-known challenges of SPH regarding boundary conditions, convergence/stability analysis and spurious numerical density oscillations, see Section 2.7, it is well-suited for the transient simulation of the cooling-lubricant supply for drilling processes due to its ability of automaticaly describing the dynamic evolution of arbitrarily shaped free surfaces, respectively interfaces.

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1.1. Deep hole drilling

Deep hole drilling is an important process to produce small diameters with a high length to diameter ratio, and is widely used in various industrial applications, for example in the automotive and electronic industry, or in medical and biomedical technology. For the production of deep holes different methods such as laser drilling, electro discharge machining, electron beam machining, electro chemical machining, and the single-lip deep hole drilling (SLD) are used [11, 79]. One of the main advantages of the SLD is the high bore hole quality. However, the smaller the diameters which are limited by the feed rates, the higher the mechanical loads during the cutting process [15]. Generally, the SDL is successfully used for Ni-based alloys but for machined materials such as Inconel 718, the geometry of the SDL is not yet sufficiently understood [19, 50]. Compared to twist drilling the flow cross-section for the cooling lubricant of the SDL is larger. To increase the process stability, especially when machining ductile materials, the velocity of the cooling lubricant needs to be higher [12]. Detailed understanding of the coolant flow is very important for a sufficient cooling. Furthermore, detailed information may also help optimizing the arrangements of the internal coolant channels and the geometry of the tool [9]. Hence, the meshbased Computational Fluid Dynamics (CFD) and modern meshless methods like SPH are important research tools for the future of machining technology, especially when metrological methods reach their limits [62].