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Experimental Analyses of the Effects of Cooling Lubricants to Expand an FEM-Based Physical Grinding Force Model

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An FEM-based physical force model is an important step to obtain a full understanding of the grinding process itself. Such a physical force model is already under development and is based on Abaqus-FEM. In order to examine basic material behavior and material parameters for such a physical force model and to validate it, scratch tests have been carried out with single grains. However, the current physical force model is only designed for grinding processes that do not require cooling lubricants. Therefore, the aim of this work is to extend this physical force model in such a way that grinding processes with cooling lubricants can also be considered. In order to include the cooling lubricants in the FEM model, it is essential to carry out scratch tests with cooling lubricants in addition to the scratch tests in a dry environment. The aim is to identify basic mechanisms in connection with cooling lubricants, which are needed to expand the FEM model and to create a data basis for subsequent validation.

1 Introduction

Grinding is an important industrial manufacturing process. In addition to the production of high surface qualities in various areas, many tools, such as drills or milling cutters, are also manufactured by grinding. Even if the grinding process is optimized over time, it remains a highly complex process the mechanics of which are still not fully understood. This complexity is, among other things, due to a cutting process with many geometrically undefined cutting edges. Although it is possible to measure the process forces and statistically reduce them to individual grains, it is not possible to measure the individual reaction forces for a single grain itself.
An important step towards a better understanding of the grinding process is the development of a physical force model by Sridhar et al. [1], which makes it possible to map and even predict forces or to observe the interaction in the contact zone between indenter and workpiece e.g. plastic deformation due to the piling up of material while scratching.
However, since cooling lubricants are usually and necessarily used in grinding, they must also be considered in the force prediction. In order to include a general influence of cooling lubricants during grinding in such a physical force model, we define basic assumptions on the basis of scratch tests using a single grain with various cooling lubricants.

2 Materials and Methods

To investigate the influence of cooling lubricants on the force development during scratch tests, those tests are first carried out with and without cooling lubricants. In Fig. 1 the test rig, which is used to investigate the tangential and normal forces during scratch tests, is schematically shown. This scratch test rig can be used to preform tests in lubricated and dry conditions. In order to measure the forces during scratching, a dynamometer (type 9119AA1 from Kistler) is used. To perform a scratch test, the workpiece and dynamometer are mounted on a linear device, as seen in Fig. 1. They are moved horizontally underneath the indenter, which scratches the surface of the workpiece with a predefined cutting depth and cutting speed. To apply the cooling lubricant in front of the indenter and thus immediately before scratching, a dispensing unit (type DC1000 from Vieweg) is used. To simplify the investigation and focus on the main interaction between workpiece, cooling lubricant and indenter, the cooling lubricant is represented by reference oils (FVA2 and FVA3 differ in terms of their viscosity) because they do not contain any additives which could cause additional effects on the force signal.

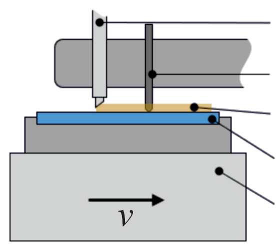

Fig. 1: Schematic illustration of the scratch test rig

3 Results

All forces recorded here and the associated results refer to scratch tests with a scratch depth of $50\,\mu\mathrm{m}$. The scratching speed is a varying parameter, whereby only $200\,\mathrm{mm/s}$, $400\,\mathrm{mm/s}$ and $600\,\mathrm{mm/s}$ are considered here. Fig. 2 shows the tangential

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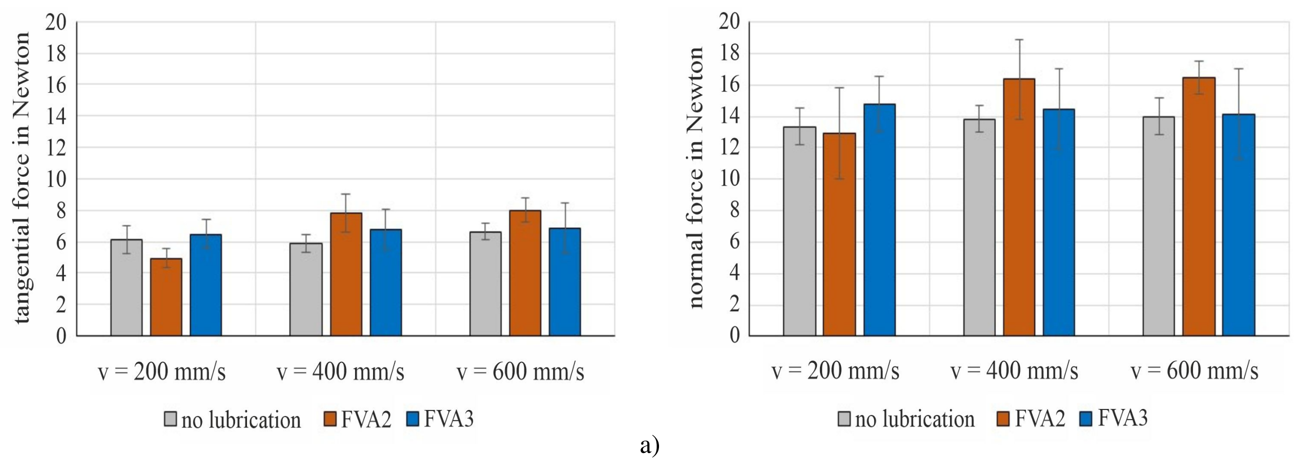
(a) and normal forces (b) during tests at the above-mentioned scratching speeds.
In fact, it can be observed that the use of a cooling lubricant has a noticeable influence on the tangential and normal forces during a scratch test. Furthermore, there is an obvious difference between the cooling lubricants FVA2 and FVA3, which only differ in their viscosity. The reference oil FVA2 with $85\,\mathrm{mm}^2/\mathrm{s}$ at $20\,^\circ\mathrm{C}$ has a significantly lower viscosity than the reference oil FVA3 with $300\,\mathrm{mm}^2/\mathrm{s}$ at $20\,^\circ\mathrm{C}$. The reference oil FVA3 usually shows only a very slight deviation with regard to the tangential and normal forces in direct comparison with the unlubricated scratch tests. This also shows that the viscosity of cooling lubricants is a decisive factor in the simulation.
Looking at the results in relation to the scratching speed, it can be seen that the reference oil FVA3 tends to increase tangential forces and decrease normal forces. If, on the other hand, the reference oil FVA2 is considered, it is noticeable that at the scratching speeds of $400\,\mathrm{mm/s}$ and $600\,\mathrm{mm/s}$ almost no difference can be seen with respect to the forces. Its behavior at $200\,\mathrm{mm/s}$, on the other hand, is very striking, because here the tangential and normal forces are smaller than those of the unlubricated scratch tests. This contrasts the findings of [2]. However, the standard deviation for the reference oil FVA2 is particularly large for the normal forces.



a) b)

Fig. 2: Diagramm of measured **a** tangential forces and **b** normal forces while preforming a scratch test with a scratch depth of $50\,\mu\mathrm{m}$ and various scratch speeds.

4 Conclusion

In summary, the use of oils as cooling lubricants has a detectable effect on the tangential and normal forces in scratch tests. However, viscosity plays an important role here. The results suggest that, as the viscosity of a coolant increases, the influence on the tangential and normal forces during a scratch test decreases. This may be explained by the low flow rate of a higher viscous lubricant, which may reduce its ability to wet the contact surfaces.
Based on the results, it can be concluded that the viscosity of a cooling lubricant is an important parameter for the extension of the physical force model. The cooling lubricants must, therefore, be fully modeled and cannot be modeled by variation of existing parameters or variables. For example, an adjustment or change of the friction values of the material would not be sufficient for an adequate representation the effects of the cooling lubricants on the process forces.

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