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Investigation of the influence of cooling lubricants on workpiece topography

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Model-based prediction is becoming increasingly important to meet the ever-increasing demands on manufacturing. In grinding, the prediction of the process forces and the generated surface by physical models are particularly important.

Since cooling lubricants are almost always used on an industrial scale, the grinding model, developed at our institut, must be extended to include this component. Therefore, in order to implement cooling lubricants into the FEM-based model, it is first necessary to investigate the behaviors and effects of cooling lubricants in real experiments. Various influencing factors such as the scratching speed of individual abrasive grains in interaction with cooling lubricants need to be investigated. However, the existing physical grinding model is not limited exclusively to the prediction of the resulting forces. It is also supposed to be able to qualitatively predict the expected resulting surface of the workpiece. Hence, this paper will focus on the topographic characteristics that can occur in the scratch test due to different cooling lubricants and scratching speeds.

Based on real experiments on a test rig for such scratch tests, it has been shown that different scratch speeds have a negligible influence on the topographical nature and expression of a scratch. In contrast, however, there is a direct influence of cooling lubricants on the topographic properties. This effect is additionally influenced by the viscosity of the cooling lubricant used.

1 Introduction

According to estimates of the World Energy Council, it can be assumed that the global primary energy demand will increase by 32% in the next 20 years [1,2]. According to this estimate, the largest increase will be in the developing and newly industrializing countries, whereas the OECD countries will keep their energy consumption more or less constant. This assumption is based, among other things, on the fact that the western industrialized nations increase their energy efficiency. Therefore, industries, as one of the largest consumers of energy, are increasingly focusing on energy efficiency. [1,2]

However, the implementation of energy-efficient production is also significantly dependent on the industrial sector. According to this, the design of efficient energy use also depends on it. The chemical industry, for example, inevitably needs high temperatures for many processes to run, in the metal processing industry high temperatures are usually a concern. Temperature development in metal processing is a result of contact between a tool and a workpiece. In the resulting contact zone, heat is generated by friction. Tribological effects, which include friction between materials, cause a high energy loss in many areas [3].

Therefore, it is a challenging task, especially in metal processing, to minimize process-related energy losses. In addition, different manufacturing methods also involve different initial situations. Tribological effects in forming processes have different effects than in cutting processes. An important representative in the field of cutting processes is grinding. Grinding is an important element in the production of high-precision components, which in turn enable more energy-efficient machines. Due to the process, grinding is associated with high energy losses. In order to make the grinding process itself more energy efficient, it is essential to have a better understanding of the process itself. However, the grinding process is very complex, not only because of the large number of geometrically undefined cutting edges that are continuously in contact with the workpiece [4]. It is therefore necessary to identify and understand the processes during grinding at each individual abrasive grain in order to capture the friction losses better.

In order to gain a better understanding of these processes, at our institute Sridhar et al. [5] developed a physical force model that is capable of mapping such a grinding process in its entirety. The focus of this model is on the precise interactions and processes between the abrasive grain and the workpiece. In doing so, it should be possible to precisely determine the occurring process forces of individual but also of multiple abrasive grains. However, many already existing approaches only use models to capture the total forces during grinding [6,7]. Besides the approaches based on total forces, there are other attempts. Nie et al. [8] have mathematically mapped an abrasive grain statistically and used it to describe the influence of cutting speed and cutting depth on the process forces. In addition, most models do not include cooling lubricants [8,9]. This is also the case for the model of Sridhar et al. [5]. Since cooling lubricants are indispensable in industrial grinding processes, it is also necessary to consider them in simulations. Previous studies have already shown that cooling lubricants have an influence on the process forces [10,11]. In order to incorporate the real effects into the FEM model, we carried out investigations on a single-grain test rig. Here, the influence of cooling lubricants and varying scratch speed on the workpiece surface are investigated. The focus

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is on possible characteristic marks on the workpiece surface, which are important for the grinding model. In particular we analysed the scrtach profile and related scratch depth and scratch width to the measured forces.

2 Materials and Methods

In order to qualitatively evaluate the influence of cooling lubricants in relation to different scratch speeds, appropriate scratch tests must be carried out first. The test rig shown in Figure 2 is used to perform such scratch tests. For scratch tests, this test rig allows various parameters to be varied or adjusted. The most important parameters here are scratch speed, scratch depth and indenter geometry. Additionally, the scratching environment can be changed from dry to lubricated by applying cooling lubricants from a dispensing unit (specifically reference oils).

2.1 Conducting the experiments

To simplify the investigation and to 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 from Weber Reference Oils) because they do not contain any additives, which could cause additional effects on the force signal. A dynamometer (type 9109AA from Kistler) integrated into the test rig measures and records the resulting tangential and normal forces during a scratch test. A confocal distance laser (CL-3000 series from Keyecne) is used to set the targeted scratch depth. To perform an actual scratch test, the sample (here aluminum) must first be freed of any production residues or other contaminations. For this purpose, it has proven effective to clean the aluminum workpiece, by using acetone in an ultrasonic bath. After the cleaning process, the specimen is then fixed in the test rig by using a clamping device. After the scratch depth is set by using the confocal distance laser, the sample can be moved through the previously installed indenter. Here, any speeds can be set for the scratch process.

2.2 Proceeding after the scratch tests

After running the scratch test and cleaning the workpiece, the surface of this workpiece is then optically investigated under a digital microscope (VHX-7000 series from Keyence). The primary focus is on the width d and depth t of the scratch. The topography of the scratch represents the imprint of the indenter used. For the tests carried out here, a cone-shaped indenter with an angle of 105° is used. Figure 1 shows such an indenter. When looking at the profile of such an indenter, the ratios of the perimeter u to the height h, also shown in Figure 1, are always the same. Only directly at the indenter tip is this ratio distorted by the rounding of the tip. The perimeter u and the height h represent the width d and the depth t transferred to the workpiece surface.

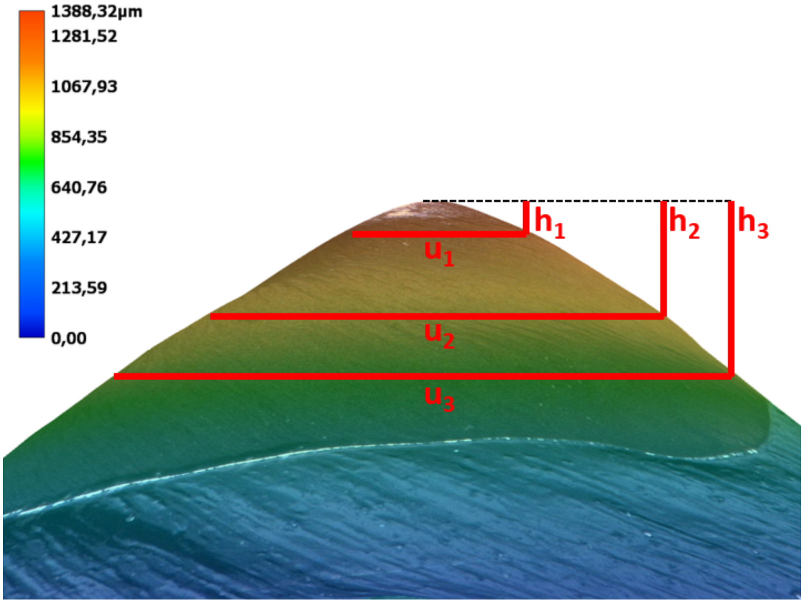

Fig. 1: Profile of a cone indenter with an angle of 105°.

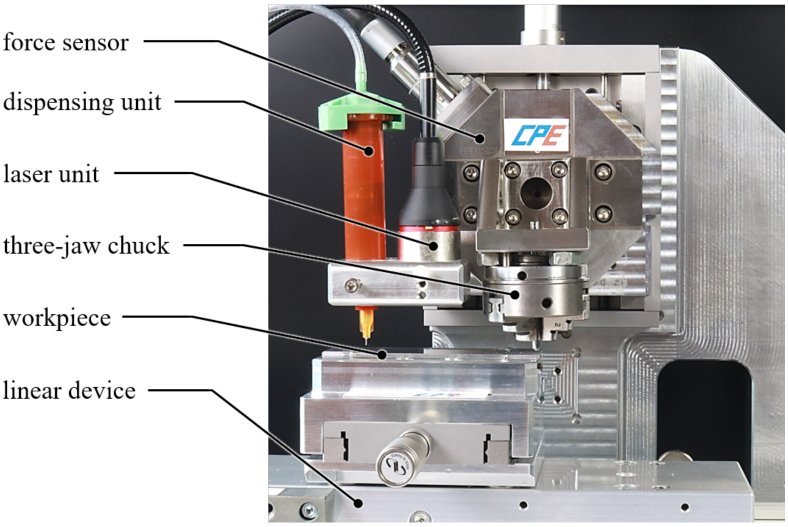

Fig. 2: Test rig used for the scratch tests in dry and lubricated conditions.

3 Results

Target depth of 80 µm and 250 µm are investigated as well as scratch speeds of 50 mm/s, 400 mm/s and 750 mm/s. Furthermore, the previously mentioned reference oils FVA2 and FVA3 are used as cooling lubricants. The reference oil FVA2 with ν = 85 mm^2/s at 20°C has a significantly lower viscosity than the reference oil FVA3 with ν = 300 mm^2/s at 20°C. In total, this results in 3 samples per scratch depth with one of the three conditions (dry, FVA3, FVA2) and 9 repetitions each per scratch speed. Optically recorded images of the workpiece surface serve as the source material for the investigation. Using the implemented software within the digital microscope, relief images are acquired for this analysis. Figure 3 shows a relief obtained by further processing of the raw data by the microscope software, which is more suitable for analysis purposes. The relief shown here is considerably reduced in its data density in order to minimize the amount of data and computational effort. Using an algorithm, a large number of cross-sections are generated on the basis of such relief images. This in turn produces profiles as shown in Figure 4. Figure 4 also shows, in simplified form, how the quotient d/t of scratch width d and scratch depth t is determined for evaluation. In this study, the main focus is on the influence of cooling lubricants and scratching speed on the scratch geometry. Figure 5 shows the influence of the reference oils for various samples at speeds of 50 mm/s, 400 mm/s and 750 mm/s. It can be seen that both reference oils FVA3 and FVA2 have a lower ratio of d/t compared to the unlubricated scratches. In this illustration, the reference oil FVA3 is particularly conspicuous. It has the lowest ratio of d/t in all tests. As the reference oil FVA3 has a higher viscosity than the reference oil FVA2, this effect can be explained by the different flowability. To clearly identify this correlation, further investigations with oils or liquids of different viscosities need to be carried out. Therefore, both the lower ratios d/t of the two reference oils compared to those of the unlubricated ones and the conspicuously lower value for the reference oil FVA3 can be aligned with practical experience. According to Nadolny et al. [12], low-viscosity cooling lubricants are primarily used for the removal of high temperatures, while cooling lubricants

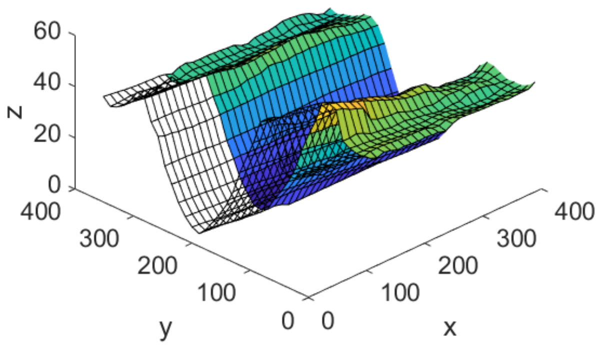

Fig. 3: Relief image generated from the data of the digital microscope.

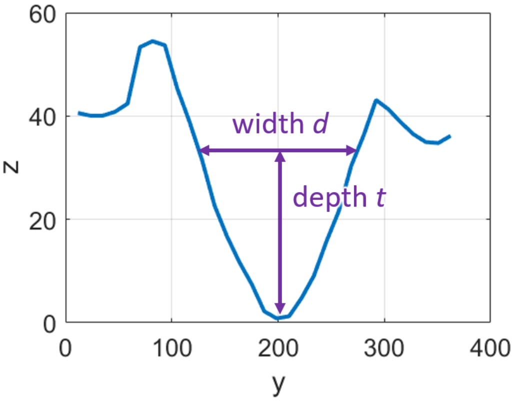

Fig. 4: Profile of a scratch resulting from a cross-section cut.

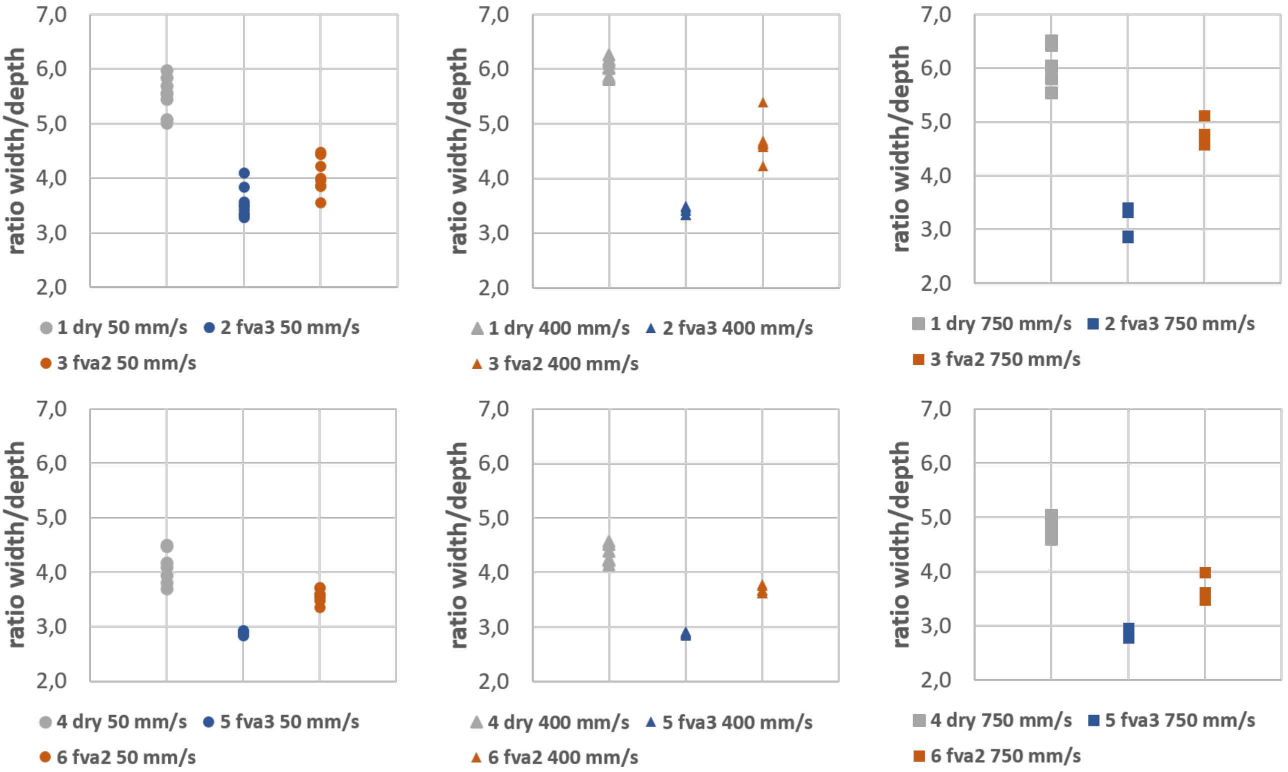

Fig. 5: Ratio of scratch width b to scratch depth t for velocities 50 mm/s, 400 mm/s and 750 mm/s in dry and lubricated environments. Samples 1 - 3 are performed with set scratch depth of 80 µm, samples 4 - 5 are performed with set scratch depth of 250 µm.

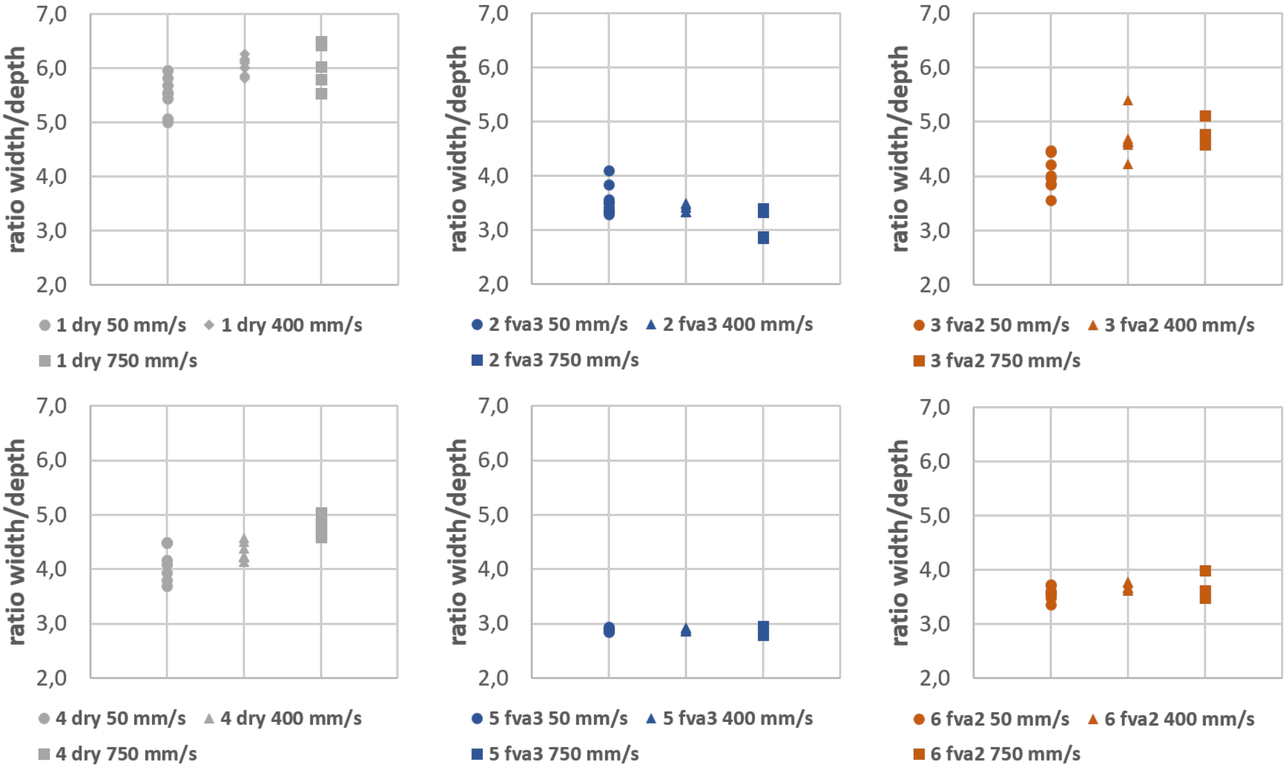

Fig. 6: Ratio of scratch width b to scratch depth t for dry and FVA3 and FVA2 lubricated scratch tests for different scratch speeds. Samples 1 - 3 are performed with set scratch depth of 80 µm, samples 4 - 5 are performed with set scratch depth of 250 µm.

or oils with high viscosities are used to yield a better surface finish. The lower ratio d/t when using the reference oil FVA3 also represents a reduction in the scratch width. One possible explanation for this effect is that the reference oils improve the removal of metal chips and reduce the metal thrust in front of the indenter tip. A buildup of material in front of the indenter tip in the unlubricated condition, on the other hand, can lead to an effective widening of the actual indenter perimeter. This temporary widening itself ultimately leads to greater material removal over the entire scratch. This is also consistent with the findings of Nie et al. [12] that lubrication in general and specifically higher viscosity oils are used to produce a better surface finish. Figure 6 shows the influence of different scratching speeds for the conditions unlubricated, reference oil FVA2 and reference oil FVA3. Based on this figure, it can be seen that varying scratch velocities have no significant effect on the topographic characteristics of the workpiece surface in this velocity range. Nevertheless, it can be seen that the deviation of the ratio d/t is lower with a deeper target scratch depth. One reason for this is that deeper indents are less susceptible to interference in scratch initiation. Particularly with low indentation depths, it is important to consider that there is a risk of not indenting deeply enough into the workpiece with the corresponding indenter. In this case, the less ideal, more rounded, part of the indenter tip contributes to scratch initiation. This defect in the ratio u/h at the indenter tip also produces a significant effect in the detection of the ratio d/t in the workpiece surface. In contrast, at deeper indentation depths, more of the actual cross-section of the indenter is engaged. Consequently, it is advisable to use the maximum possible indenter cross-section for scratch tests.

4 Conclusion

To investigate the influence of cooling lubricants on the surface of the workpiece, several scratch tests are first carried out. A cone-shaped indenter with an angle of 105° is used. The scratch tests are carried out at different scratching speeds with and without reference oils on an aluminum workpiece. In summary, different scratching velocities have no obvious influence on the topogarfic character of the material surface. Accordingly, with regard to the ratio of scratch width d to scratch depth t, no significant change is to be expected within a scratch profile. However, it has been shown that within a selected scratch speed, a trend can be identified between the unlubricated and the lubricated scratches with respect to their topographical structure. For instance, the scratches produced in a lubricated environment have a smaller scratch width according to the ratio d/t than those scratches from an unlubricated test environment. Specifically, the reference oil FVA3 generally shows the narrowest width within several test series. Both effects can be plausibly explained based on common empirical values.

In addition, it has proven advisable to carry out the scratch tests in such a way that as large a part as possible of the cross-sectional area of the indenter used is allowed to penetrate the surface of the workpiece. This results in lower defects and scratches that are more susceptible to interference, which can also be better detected by the optical measuring device which is used here.

For the further development of the physical force model, the findings obtained here show important implementation approaches. Under the influence of the cooling lubricant, an increase in the generated scratch width is to be expected. This is also directly related to the viscosity of the reference oil or cooling lubricant used. However, different velocities do not show any factor to be considered for the force model with respect to the topography of a scratch.

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