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SIMULATIVE INVESTIGATION OF THE INFLUENCE OF DIFFERENT ABRASIVE COATING STRUCTURES IN DOUBLE FACE GRINDING

The double face grinding process is a manufacturing process that is used when machining plane-parallel surfaces, for example during the production of bearing rings, wafers, seal and regulator disks. However, there are challenges when machining extremely hard and large components in terms of the required workpiece quality and cost-efficiency. Although the ecological disadvantages of the lapping process are present, it is often used to industrially machine such components. One approach to address these challenges is to structure the abrasive coating to enlarge the chip space in order to support cooling lubricant supply and chip removal. Therefore, the influence of different abrasive coating structures on the cooling lubricant flow was examined using Computational Fluid Dynamics (CFD) simulations. The simulation approach and the results of the simulation studies are presented in this article. By choosing a suitable abrasive coating structure that ensures an even distribution of the cooling lubricant, the supply of cooling lubricant and chip removal during the grinding process can be improved. The results of the simulation studies show that radial grooves are unsuitable because the flow of cooling lubricant is not evenly distributed in the inner area of the grinding wheel. This can be optimized by selecting involute grooves. By improving the supply of cooling lubricant, the application range of the double face grinding process can be expanded and enables the environmentally friendly machining of extremely hard and large components with plane-parallel functional surfaces.

1. INTRODUCTION

The increasing demand on workpiece quality and cost-effectiveness of machining processes as well as the increasing importance of their sustainability and resource efficiency lead to a constant development of tools and the corresponding manufacturing processes. Lapping and double face grinding are used for the fine machining of plane-parallel functional surfaces with high requirements regarding shape and dimensional accuracy during the application in spacer rings, sealing plates and control discs [1, 2, 3]. By using these processes, a very good surface quality and a high degree of plane parallelism can be achieved on the

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component. Due to the low material removal rate and increased environmental impact, double-sided lapping is increasingly being replaced by double face grinding. The advantages are based on the increase in productivity through higher cutting speeds and in the significantly lower environmental impact through the use of grinding wheels with bonded diamond or CBN abrasive grains in conjunction with a cooling lubricant cycle [4, 5]. The bonded abrasive grains take part in the cutting process until they are completely broken out of the grinding wheel bond. In addition to the primary tasks of the coolant lubricant, such as reducing friction and cooling the contact zone, secondary tasks such as cleaning the grinding wheel and removing chips are among the benefits. By using cooling lubricant and bonded abrasive grains, significantly higher cutting speeds and material removal rates can be achieved compared to lapping. Nevertheless, the cutting speeds and the resulting processing temperature are lower compared to other grinding processes [6, 7].

The machine structure of the double face grinding machine consists of two horizontally arranged grinding wheels while the workpieces are placed unclamped in between, Figure 1. The workpiece holders are guided by a driven inner pin ring and a mostly stationary outer pin ring. During machining, the workpieces perform cycloidal movements in relation to the grinding wheel surface which result from the superimposition of the driven grinding wheels, the rotation of the inner pin ring and the resulting workpiece holder rotation. For the machining process, several workpieces are placed in externally toothed workpiece holders. Due to the areal contact of the grinding wheels, the surfaces of the workpieces are evenly loaded. The kinematics are similar to those of a planetary gear, from which the name of the process is derived. Due to the process-specific kinematics, the ground components have non-directional, intersecting machining marks [8–10].

Besides the beforementioned advantages of double face grinding, there are currently challenges when machining extremely hard and large workpieces in terms of achieving the required workpiece quality and cost-effectiveness when machining knives and scrapers made of ceramic in paper processing. The effect of aquaplaning in the contact zone impairs the application of the required process force. After machining, the workpieces can also stick to the upper grinding wheel and increase the secondary process time during loading and unloading. In addition, due to the large contact zone between the grinding wheel and the workpiece, the cooling lubricant supply is often too low to ensure sufficient chip removal. Thus, separated material as well as grain and bond residues cause clogging of the grinding wheel. The resulting short tool life and frequent dressing of the grinding tools lead to reduced productivity. For these reasons, the processing of extremely hard and large workpieces is still performed using the lapping process despite the enormous environmental impact.

One approach to address these challenges is to structure the abrasive coating. For this purpose, grooves can be included into the coating to enlarge the chip space in order to support cooling lubricant supply and chip removal. The grooves also counteract aquaplaning and sticking of the workpieces. The structuring can be achieved using radial or involute grooves as well as grinding pellets of any shape and spacing. Research projects on peripheral grinding have shown that structured grinding wheels can positively influence the process behavior with regard to the achievable workpiece quality, the cooling lubricant supply into the grinding gap and the chip removal [11, 12]. The influence of structured grinding wheels on the process behavior during double face grinding has not yet been scientifically investigated.

The structuring of the abrasive coating is mainly based on experience. A targeted, application-specific design of a grinding tool concept for double face grinding of large and extremely hard workpieces is subject to ongoing research. For this purpose, a CFD-based simulation approach was developed to evaluate the influence of different abrasive coating structures on the cooling lubricant flow in the grinding gab. The simulation approach and the results of the simulation studies are presented in this paper.

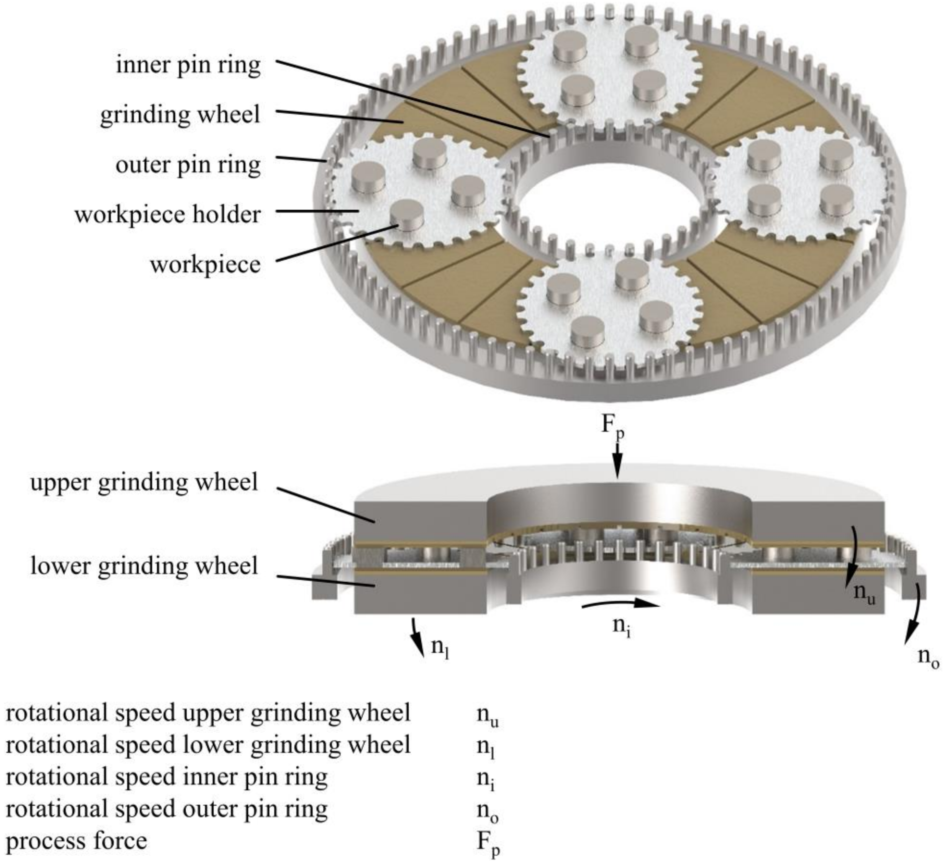

Fig. 1. Main components of the machine system for double face grinding with planetary kinematics

2. SIMULATION MODEL AND BOUNDARY CONDITIONS

The influence of radial and involute grooves on the cooling lubricant distribution was investigated as part of the simulative tests using the CFD software ANSYS FLUENT from Ansys INC, Canonsburg, Pennsylvania, USA. In order to evaluate the influence of the groove geometry, the area of the grooves was kept constant. The model development and the definition of the boundary conditions are based on the existing grinding machine DLM 505 HS from STÄHLI AG, Pieterlen, Switzerland at IWF, Technical University Berlin. The grinding wheels used on the machine have an outer diameter of d_o = 530 mm and an inner diameter of d_i = 265 mm, Fig. 2a. There are 20 coolant holes on the base body of the upper grinding wheel to supply the cooling lubricant. To reduce the simulation effort, only a partial section with one coolant hole was considered. Figure 2b illustrates the two simulation models with the different groove geometries. The distance of upper and lower grinding wheels was z_g = 1 mm. Due to the small distance between the grinding wheels, a high mesh resolution was necessary which resulted in an element number of approximately n_e = 20,000,000. The meshing of the geometry is shown in Fig. 2c.

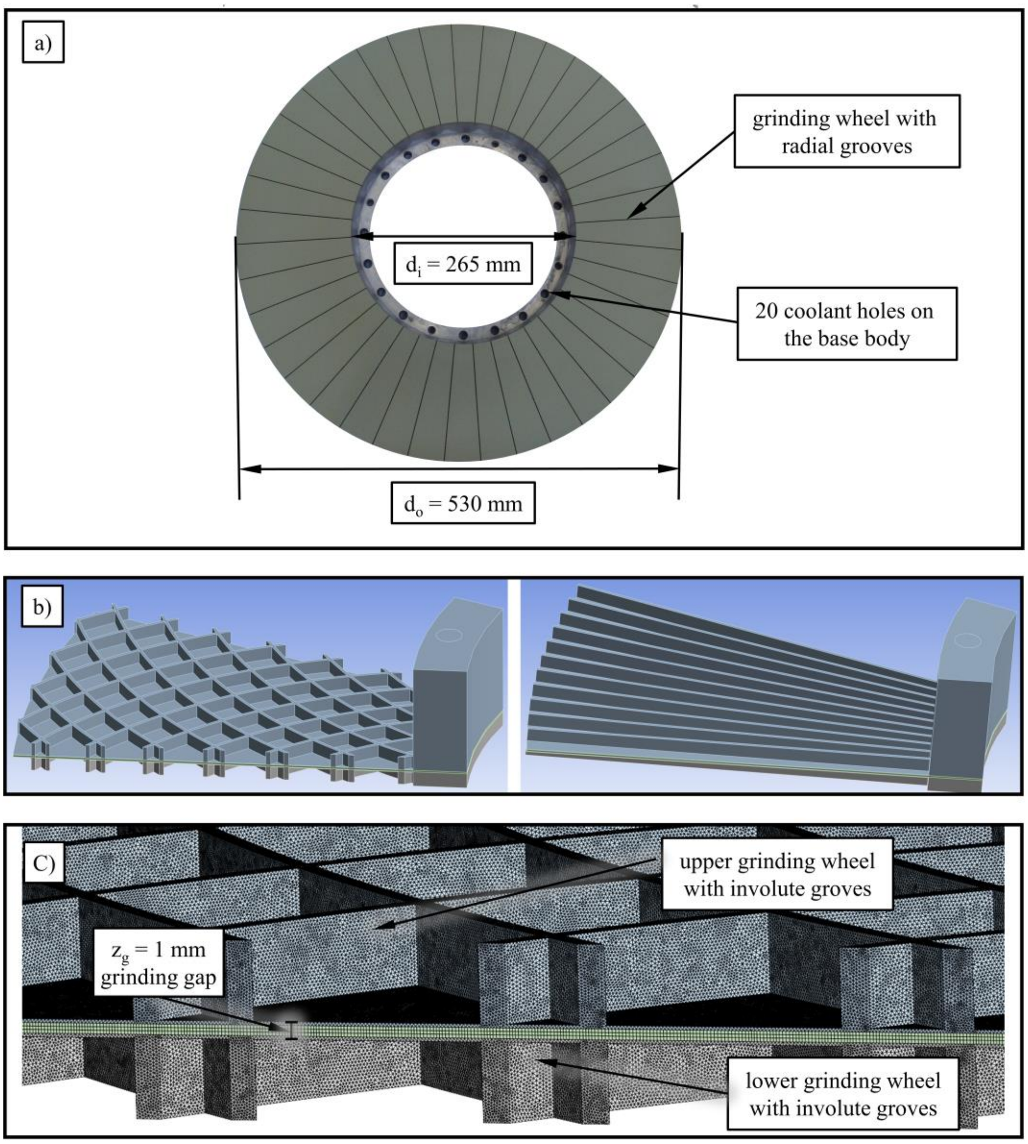

Fig. 2. Model creation in ANSYS FLUENT, a) grinding wheel dimension, b) simulation model with varying groove geometries, c) meshing of the geometry with involute grooves

In order to reduce the simulation effort, it was also assumed that the grinding gap was completely filled with the coolant at the beginning of the process. The grinding machine uses the grinding oil Rhenus GP5 from Rhenus Lub GmbH & CO KG, Mönchengladbach, Germany, as the cooling lubricant with a density of ρ = 830 kg/m^3 and a viscosity of η = 3.569 · 10^{-3} kg/(m·s). These parameters were transferred as characteristic data of the fluid. In double face grinding, the processes are usually designed so that the grinding wheels move in opposite directions. For this reason, a speed of n_u = -250 rpm was selected for the upper grinding wheel and a speed of n_l = 210 rpm for the lower grinding wheel. This corresponds to an average grinding wheel speed of $\overline{v}_c$ = 5 m/s. During the grinding process, a pump feeds a cooling lubricant volume flow of $\dot{V}_{cl}$ = 50 l/min into the grinding gap which is distributed to the 20 coolant holes. This corresponds to a coolant volume flow of $\dot{V}_{cl}$ = 2.5 l/min through one coolant hole which was selected as the input variable. At the outlet the pressure was set to ambient pressure. Figure 3 illustrates the selected boundary conditions.

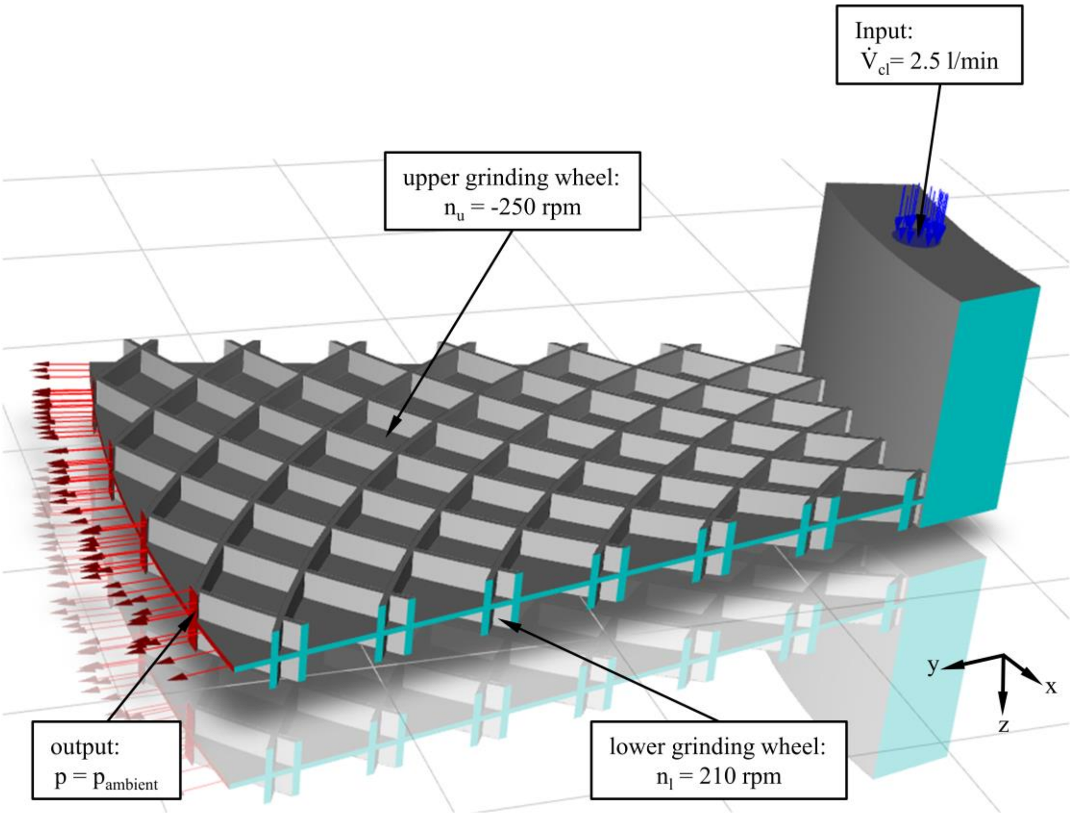

Fig. 3. Boundary conditions of the simulation model

3. INFLUENCE OF DIFFERENT ABRASIVE COATINGS ON THE COOLING LUBRICANT FLOW

Once the boundary conditions have been defined, the flow behaviour of the cooling lubricant in the grinding gap is then evaluated using the simulation. Therefore, the velocity field is used to identify the influence of the coating structure on the flow behaviour. Figure 4a shows the velocity filed on the grinding wheels. As expected, the velocity of the cooling lubricant increases over the grinding wheel diameter due to the impact of the grinding wheel surface and the increasing peripheral speed. The cooling lubricant in the grinding gab is entrained by the rotational movement of the grinding wheels and due to the wall adhesion condition, the velocity of the coolant corresponds to that of the grinding wheel speed. The observation of the velocity in the *y*-*z*-plane also shows that a boundary-layer flow forms in the grinding gap, Fig. 4b. In the area near the grinding wheel, the flow velocity of the cooling lubricant corresponds to the peripheral speed of the grinding wheel. Due to the higher peripheral speed of the upper grinding wheel, the flow velocity of the cooling lubricant is higher in the area near to the upper grinding wheel. The flow velocity decreases as the distance from the grinding wheel increases in the *z*-direction. In the middle of the grinding gap the flow velocity of the cooling lubricant is almost zero. From this it can be assumed that chips that accumulate in the middle of the grinding gap are not transported to the outside by the coolant flow. These observations apply to both grinding wheel structures.

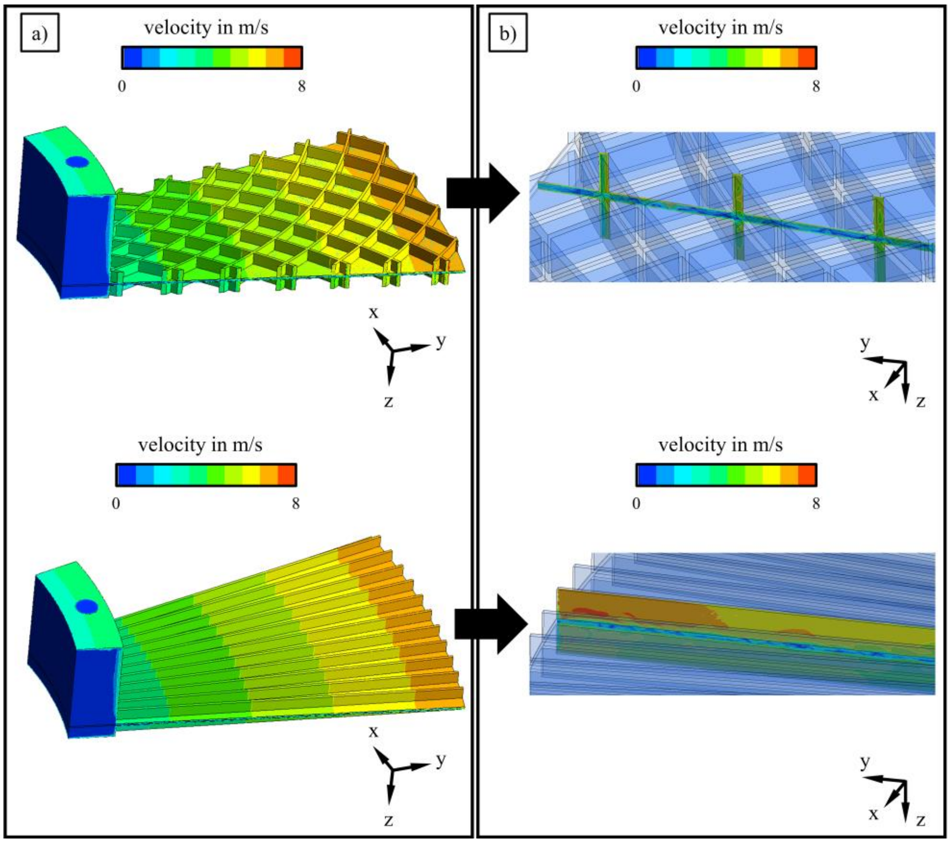

Fig. 4. Velocity field, a) cooling lubricant flow on the grinding wheel, b) cooling lubricant flow in the grinding gap regarding *y*-*z*-plane

In addition, the velocity distribution in the x-y plane at different z-heights was subsequently observed, Fig. 5. Here, the velocity increase of the cooling lubricant over the grinding wheel diameter can also be seen at $z = 100$ µm. This behavior is induced by the grinding wheel surface. The influence of the different structures on the flow behavior can be seen with increasing distance from the grinding wheels in z-direction. Therefore, the velocity is analyzed at $z = 500$ µm which corresponds to the center of the grinding gap. Here, the cooling lubricant is distributed mainly through the displacement effect of the coating structure. The use of intersecting curved grooves creates nodal points that promote the distribution of the cooling lubricant flow over the entire grinding wheel diameter, Fig. 5a. At the nodal points in the inner area of the grinding wheel the velocity of the cooling lubricant is in the range of $v_{cl} = 2$ - 3 m/s and in the outer area of the grinding wheel in the range of

v_{cl} = 3–6 m/s. From this it can be concluded that the involute structure can achieve a uniform distribution of the cooling lubricant in the grinding gap, which ensures the sufficient chip removal during the grinding process. When using radial grooves, the cooling lubricant is not evenly distributed over the grinding wheel diameter, Fig. 5b. This results from the low displacement effect of the radial grooves. In the inner area of the grinding wheel the velocity of the cooling lubricant is in the range of $\overline{v}_c$ = 0.5–2 m/s. Due to the inadequate distribution of the cooling lubricant, there is a high risk of chips accumulating in the grinding gap, which impairs the grinding process. Based on the analysis carried out, it can be concluded that the use of involute grooves leads to better coolant supply and chip removal in double face grinding.

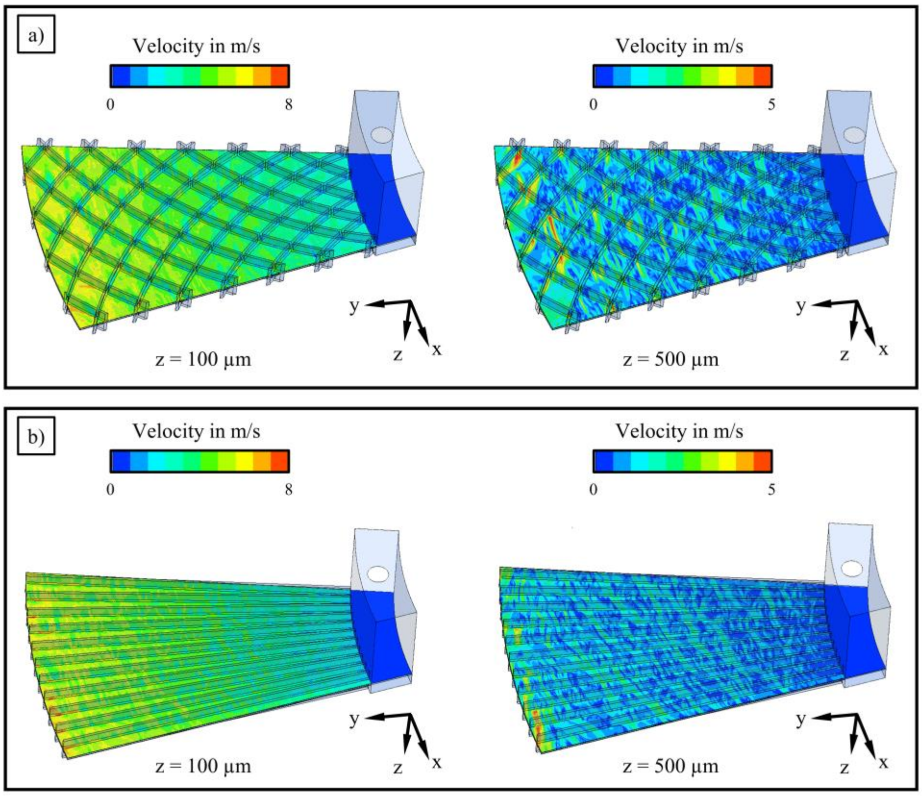

Fig. 5. Velocity distribution in the grinding gap regarding x-y plane, a) grinding wheel with involute grooves, b) grinding wheel with radial grooves

4. CONCLUSION

By means of the simulation model developed, the influence of different abrasive coating structures on the coolant distribution in the grinding gap was examined. It was shown that the use of involute grooves leads to a uniform distribution of the cooling lubricant over the entire grinding wheel coating which results from the displacement effect of the structure. By using involute grooves, the existing problems in double face grinding can be addressed and extremely hard and large components can be machined without clogging of the grinding wheel. In further investigations, the influence of structured grinding wheels is to be analysed by means of experimental tests. For this purpose, grinding tests will be carried out on the double face grinding machine STÄHLI AG, Pieterlen, Switzerland. Large ceramic components are used as workpieces which are currently processed using the lapping method. By identifying a suitable grinding wheel structuring, the scope of application of double face grinding shows potential to be extended.

ACKNOWLEDGEMENTS

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