FINISHING OF CAF$_2$-GLASS WITH A NOVEL FINE GRINDING CONCEPT

Hans-Werner Hoffmeister, Wiebke-Cathérine Hahmann
Institute of Machine Tools and Production Technology
Technische Universität Braunschweig
Braunschweig, Germany

INTRODUCTION
The finishing of glass and ceramics is still comparatively time-consuming and expensive, which is a significant reason why a broader application of this material group has so far been restricted despite its high technological potential. Surface machining with lapping kinematics, e.g. lapping, polishing and fine grinding, shows the best performances regarding surface shape and roughness. Nevertheless, these processes show several disadvantages. The conventional lapping process using loose grains takes a relatively long machining time and the subsequent disposal of lapping-suspension is difficult and expensive. A higher chipping rate can be reached by using a fine grinding process with bounded grains, but as the grinding wheels show wear, trueing and sharpening of the tool becomes necessary. This is complicated because of the required shape accuracy of the tool and hardness of the abrasive grains [1-4].

A novel machine concept combining the advantages of lapping and fine grinding with lapping kinematics by using foil tools instead of grinding wheels was used to analyze the cutting behaviour of CaF$_2$-glass. The first part shows the design of the novel machine concept. The second part deals with the fine grinding process results of CaF$_2$-glass.

MACHINE CONCEPT
The design of the novel machine system is based on the machine concept shown in figure 1, which clarifies the constructive requirements. The drafted test rig consists of a plane machined carrier disc combined with a tool drive and output, which provides unused abrasive foil. Those are rotating together with the carrier disc. The workpieces are rotating as well. That way the typical lapping kinematics are accomplished. The grinding force is transmitted by a pressure disc and controlled pneumatically.

FIGURE 1. Machine concept of the “Fine Grinder”.

Fine grinding with feed-controlled abrasive foils eliminates the disadvantages of conventional fine grinding with massive grinding wheels or pellets. These processes require sharpening and trueing of the tool and show a non-constant material removal rate. Furthermore, the tool change is complex and time-consuming. The “Fine Grinder” does not have these
disadvantages. The foil drive provides fresh foil and therefore new grains at every times. So, sharpening and trueing are not necessary anymore. Moreover, the process has a constant material removal rate and process behaviour. When the tool-life end is reached, the complete foil-roll is replaced.

TECHNOLOGICAL COHERENCES BETWEEN SETTING PARAMETERS AND MACHINING RESULTS
The influence of foil specification, foil feed rate and cutting speed on the flatness and roughness of the workpiece were investigated.

Due to the brittle material behaviour of CaF$_2$-glass a further increase of the grinding pressure over the tested pressure of 0.05 N/mm$^2$ was not possible. Although the grinding behaviour was more ductile, working with a grinding pressure of 0.1 N/mm$^2$ already caused a breaking of the workpiece.

Influence of Foil Specification on Machining Results
In order to find ideal foil specifications for the fine grinding process of CaF$_2$-glass, four different foil specifications (15 µm, 6 µm and 0.5 µm diamond grain in resin bond, 20 µm diamond grain electro-plated) were examined. The aim was to find a foil specification that provides a good surface quality and a sufficient removal rate. During these experiments the machining parameters were kept constant. Thus, the different foil specifications could be compared.

FIGURE 2. Surface of machined CaF$_2$-workpiece.

Figure 2 shows the surface of a CaF$_2$-workpiece, ground with the abrasive foil D6 and D20. The grooves caused by grinding with the D6 foil are typical for a ductile grinding behaviour. The surface roughness is determined by the crossing of several grooves. The groove depth and in conclusion the roughness depend on the protrusion of the grains. Compared to resin-bonded grains, electro-plated grains show a higher grain protrusion of the grains and therefore a more aggressive grinding behaviour. In fact, the material removal rate with the electro-plated D20 foil was 50 times higher than that of the resin-bonded D15 foil. Moreover, the flatness and surface roughness were not sufficient. It can be seen that the leading cutting mechanism is chipping. This lead to higher strains in the workpiece. Thus, the workpiece broke during machining. In conclusion, the examined electro-plated foil is not suitable for finishing CaF$_2$-glass.

Much better surface qualities could be reached by using the resin-bonded foils. The best average surface finish was reached with the D6 foil (R$_a$ = 0.03 µm). Using the D0.5 foil, the average surface finish improved marginal. The cause for this behaviour is that the material removal rate was extremely low compared to the other foils. In that way, the abrasive foil could not remove enough material to smooth the surface. In addition to that, the fundamental roughness was twice as high as it was for the experiments using D6 and D15. Thus, the foil had to remove more material in order to reach an equal roughness.

The choice of foil depends on the requested surface quality. To get the best results several foils could be combined. First, the flatness of the workpiece could be improved within a short period of time by using a D15 foil. Afterwards, the surface roughness could be improved with the D6 foil. The finishing process could be done with the D0.5 foil.

Influence of Cutting Speed on Machining Results
The surface quality does not only depend on the foil specification but also on process parameters. The influence of the cutting speed on the machining results was investigated using the D15 resin-bonded foil.

As expected, the cutting speed does not have any influence on the flatness of the surface, whereas the roughness decreases with higher cutting speeds. With a higher cutting speed, the grains enter the grinding zone more often, therefore, more but smaller grooves occur and the roughness decreases. This leads to the assumption that the material removal rate also increases with the cutting speed. However, the experiments showed that the cutting speed has
a contrary effect. The highest material removal rate was achieved with a cutting speed of 0.26 m/s. The material removal rate decreased until a cutting speed of 0.79 m/s was reached and remained static with rising cutting speed (figure 3).

The reason for this behaviour lies in the cutting mechanisms of CaF$_2$-glass. At a low cutting speed of 0.26 m/s the main cutting mechanism is brittle. The grinding behaviour is determined by chipping. In that way the material removal rate is comparatively high as well as the surface roughness. With rising cutting speed, the grinding mechanism becomes more ductile. Thus, the material removal rate declines. Furthermore, the surface roughness is better, since it is determined by the grooves.

Figure 4 shows a macroscopic picture of used D 15 foils at different cutting speeds. At a cutting speed of 0.26 m/s the foil is covered with sediments of CaF$_2$. This is caused by the high removal rate in addition to the chipping behaviour. Furthermore, the tool wear increases. As can be seen in figure 4, at a cutting speed of 0.26 m/s and 0.52 m/s several diamonds are already pulled out of the resin bond.

**FIGURE 3.** Influence of cutting speed on roughness and material removal rate.

**FIGURE 4.** Used foils at different cutting speeds.

**Influence of Foil Feed Rate on Machining Results**

As expected, the foil feed rate does not have any influence on surface roughness and flatness, as can be seen in figure 5. The material removal rate increases with the foil feed rate, since there is a continuous flow of fresh grains into the grinding zone. However, the increasing effect becomes less at higher foil feed rates. At one point the adding of fresh, unused grain is faster than the wear of the abrasive grain. Thus, a further increasing of foil feed rate does not have an effect on the material removal rate.
CONCLUSION

CaF$_2$-glass is a very brittle material and therefore hard to machine. Small cracks can already lead to a failure of the whole workpiece. A new machine concept using abrasive foils combined with lapping kinematics was used to finish CaF$_2$-workpieces and the influence of the machining parameters on the finishing results were examined. The highest material removal rate was reached with a D 20 electro-plated foil, but the cutting behaviour was brittle and the workpiece could not resist the aggressive grinding process. The best average surface finish ($R_a=0.03 \, \mu m$) could be reached by using a foil with a grain size of 6 $\mu m$ in resin bond. Thus a ductile cutting behaviour could be reached. The best flatness of 2 $\mu m$ could be reached using a D 15 resin-bonded foil, which is almost equivalent to the results of a lapping process. The experiments pointed out that the pressure and the grain size are important for the finishing results, since they determine the cutting behaviour and the strain on the workpiece.

Summed up it can be stated that the new machine concept improves the finishing process of CaF$_2$-glass. Compared to a lapping or polishing process, the flatness could be improved, since the effect of rounding off the edges did not take place. Furthermore, the attainable roughness is comparable to that reached by a lapping and polishing process. Nevertheless, these good finishing results were reached within a short period of time.

REFERENCES


