Finite Element Analysis of Subsurface Damage of Optical Glass after Grinding

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Abstract. The interaction between abrasive particles and optical element surface can result in various forms of subsurface damage while removing the material. In order to obtain the stress distribution during optical glass grinding, the finite element analysis of optical glass grinding is carried out by using ANSYS software. The stress distribution of optical glass was obtained by establishing the grinding model of consolidated abrasive and free abrasive. The simulation results show that different abrasives have different damage degrees to the glass surface, which provides a useful reference for improving the quality of optical material processing technology.

Keywords: Finite Element, Optical Materials, Subsurface Damage, Grinding.

1. Introduction
The increasingly extensive application of optical materials requires higher surface quality of optical elements [1]. The processing of optical elements is divided into grinding and polishing stages. However, in these processes, metals, oxide particles and subsurface damage including cracks, scratches and residual stresses are inevitably introduced into the surface sediments [2]. These processes will ultimately affect the integrated performance of the optical system [3-4]. In this paper, the influence of two grinding methods on the damage degree of optical glass is discussed by taking the finite element models of two different grinding methods as examples.

2. The establishment of consolidated and free abrasive grinding models
Prior to the establishment of the consolidated abrasive and free abrasive grinding models, the following assumptions are made to simplify the calculation:

1) The contact form between the diamond abrasive particles and the specimen is point contact, and the diamond abrasive particles are assumed to be round;
2) Without considering the influence of uneven particle distribution and size on pressure distribution, it is assumed that the abrasive particles are uniformly distributed and of the same size;
3) The rotation speed of the specimen is equal to the spindle speed;
4) The hardness of diamond is very high. It is assumed that the diamond in the model is a rigid body and no deformation occurs in the analysis.

When the free abrasive is grinding, the material is mainly removed by means of three-body brittle fracture. When the specimen moves relative to the cast iron plate, the abrasive grains roll between the cast iron plate and the specimen. The purpose of material removal is achieved by the impact on the surface of the specimen during rolling. When the consolidated abrasive is grinding, the material is mainly removed by two-body fracture. When the specimen moves relative to the grinding pad, the abrasive particles are consolidated on the pad without rolling, and the material is mainly removed by cutting the specimen, so the surface of the material is mainly in the form of scratches.

2.1. Establishment of the model
The free abrasive and consolidated abrasive grinding models are shown in Figure 1 and 2. In the free abrasive grinding model, the impact of abrasive particles on the specimen surface is a transient dynamic analysis. In the consolidation abrasive grinding model, static response can be used to analyze the effect of abrasive particles on the specimen [5].

![Figure 1. Free abrasive grinding model.](image1)

![Figure 2. Consolidation abrasive grinding model.](image2)

2.2. Dividing the grid
APDL (ANSYS parameter design language) is used to establish the analysis and calculation model, and the grid is divided (to ensure high calculation accuracy and speed up the convergence time of calculation) [6]. Because the contact between abrasive and sample is a contact nonlinear analysis, PLANE182 is selected as a two-dimensional solid structure model. The unit behaviour is set as plane strain, and the unit has four nodes, which contain two degrees of freedom for each node, so that it has large deformation and large strain analysis ability. The contact class unit selects TARGE169 and CONTA175 to define contact pairs for simulation. The contact unit itself covers the entity unit surface.
TARGE169 represents the deformed entity boundary corresponding to the potential target surface. The grid division is shown in Figure 3 and Figure 4:

![Mesh division of consolidated abrasive grinding model.](image1)

**Figure 3.** Mesh division of free abrasive grinding model.

![Mesh division of consolidated abrasive grinding model.](image2)

**Figure 4.** Mesh division of consolidated abrasive grinding model.

### 2.3. Definition of contact

All the contact modes involved in the model adopt the face-surface contact mode, which requires one boundary as the main surface and another boundary as the slave surface. The abrasive particles in the free abrasive grinding model are taken as the main surface and the surface nodes of the specimen are taken as the slave surface. In the consolidated abrasive grinding model, the abrasive particle is the main surface and the sample surface is the slave surface. The model defined after contact is shown in Figure 5 and Figure 6.

![Free abrasive grinding model contact settings.](image3)

**Figure 5.** Free abrasive grinding model contact settings.
2.4. Define boundary conditions and loads
In the free abrasive grinding model, the bottom edge of the specimen is fixed. The position at which the velocity is applied is the reference point at the center of abrasive particle. In the consolidated abrasive grinding model, the left side is set to be fixed in the X direction and the bottom side to be fixed in the Y direction, and a speed load of 0.2m/s is applied to the free abrasive grinding model mill at the central reference point of the abrasive particles, and a pressure load of 7.5Pa is applied to the consolidated abrasive grinding model. The two models are shown in Figure 7 and Figure 8 after applying boundary conditions and loads.

3. Conclusion
The simulation results of the free abrasive and consolidated abrasive grinding model are shown in Figure 9 and Figure 10. It can be seen that the equivalent stress is distributed along the Y direction after the abrasive particle and the specimen contact, and the stress decreases successively from the surface of the specimen downward. When extending the same distance to the inside of the specimen,
the stress value of the specimen after the free abrasive grinding is much greater than the stress value after the consolidated abrasive grinding, that is to say, the stress depth when the material reaches the breaking strength limit during the free abrasive grinding is greater than that of the consolidated abrasive grinding. It can be concluded from the simulation results that different grinding methods will produce different stress distributions. Because of its special removal mode, the free abrasive will produce greater stress than the consolidated abrasive at the same depth. Therefore, the crack depth of the free abrasive is greater than that of the consolidated abrasive. When using consolidated abrasive, the crack damage depth is small, which can be used as a small damage, high quality optical material processing technology.

Figure 9. Calculation of grinding stress of free abrasive.

Figure 10. Calculation of grinding stress of consolidated abrasive.

Figure 11. Calculation of grinding strain of free abrasive.
Figure 12. Calculation of grinding strain of consolidated abrasive.

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