The influence of crystal orientation on the surface finish in lapping of diamond

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Keywords: diamond; surface morphology; fracture; friction

Abstract

Diamond exhibits a highly anisotropic tribological behavior. The dependency of wear rate on crystal orientation of diamond has long been noticed. In this paper, the relation of surface morphology and crystal orientation under certain lapping condition is examined. Angle of lapping direction from [001] on a (110) surface changes in our experiments, while the lapping velocity and pressure are fixed. It is found that a fine surface finish can still be obtained at the 60° angle from [001] crystal direction. But, with respect to the near 90° a bad surface with nano-fracture appears. This result comes down to two aspects. The first is the anisotropic amorphization that is the depth variation of phase change of diamond to sp^2 and sp carbon atoms on a crystal surface. The second is that there is a potential maximum scratch depth when abrasive grains on the diamond wheel slide on the diamond sample surface. On (110) surface, as the lapping angle from the [001] approaches [110], the phase change of diamond gets more difficult, which causes the amorphization depth becomes thinner. For a smaller amorphization depth, the bulk bodies of the diamond sample and abrasive grains can impact each other with a high possibility. Under this condition the surface fracture is likely to happen. The explanation provided in this paper gives a further understanding on the relation of material removal mechanism of diamond and lapping direction.

1. Introduction

The diamond exhibits an interesting anisotropic tribological behavior. One of the aspects is the variation of material removal rate with lapping direction. Directions of lapping in which lapping processes easily with a relatively high material removal rate are termed as 'soft' directions, while 'hard' directions are those where little wear to the diamond can be achieved. So far the material removal mechanism of diamond surface in friction has been studied by some researchers [1-3]. Another fact is that the fracture is apt to arise in the 'hard' direction, which affects surface finish. This implies a relation between the emergence of fracture and the diamond lapping direction to which is not paid much attention. In this paper, we change the lapping direction on the diamond (110) crystal surface to investigate the orientation in which the fracture may occur under a certain lapping condition. A perspective is proposed to explain the high likelihood of fracture in the diamond 'hard' direction. The explanation helps to understand the relation of lapping direction and the material removal mechanism of the diamond surface.

2. Materials and methods

In preparation of the specimen, the MWL 110 system (Multiwire Laboratories Ltd.) was employed to test the crystal orientation of the diamond lattice plane, based on which an adjustment could be made to approach the perfect (110) and (001) lattice planes. A copper bond diamond grinding wheel was applied. The diamond specimen was fixed on the tool head of a natural diamond conical grinding machine (PG3B, Coborn Engineering Co. Ltd.), as show in Figure 1. In our experiments, angles of lapping direction from [001] on (110) surface were about 0°, 30°, 60° and 90° (the [110] direction). The diamond specimen lapped in every direction under a normal pressure of 15 N and velocity of 8 m/s. The contact surface area is 8 mm^2.

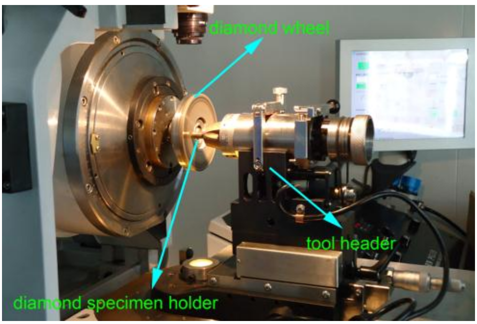

Figure 1. Experiment equipment.

3. Results and discussions

The confocal scanning laser microscope images of the diamond specimen surface are presented in Figure 2. It can be seen that, at the azimuthal angle of about 90°, fractures occur on the edge of the diamond sample surface as well as in the inner region. Under the same friction conditions, the surface topographies at 0°, 30° and 60° azimuthal angles are smooth along the lapping direction without fractures on the whole surface.

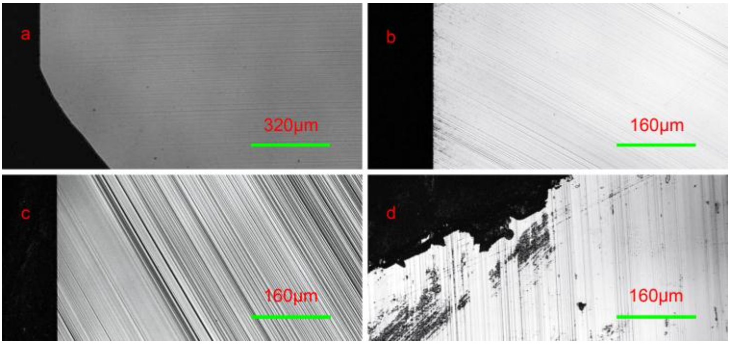

Figure 2. Confocal scanning laser microscope images of the diamond sample surface lapping at different angles from [001] crystal orientation: a) 0°, b) 30°, c) 60°, d) 90°.

The variation of surface topography on (110) plane (Figure 2) implies that there are two types of material removal mechanisms during diamond lapping on (110) lattice plane. The grooves are formed by cutting process when small diamond fragments (order-of-magnitude approximation minimum size is 30 nm) scratch the diamond surface [4]. Depth of these grooves mainly distribute in the range of 5 to 30 nm (Figure 3). These grooves give rise to surface roughness, and the values of *Ra* and *Rq* (Figure 3) characterize the mean depth of the grooves for the three surfaces. Bigger *Ra* and *Rq* imply bigger diamond fragments. There is a maximum scratch depth independent of lapping direction because of limit of diamond fragments size. On the other hand, the variation of amorphization rate results in thinner amorphous layer in 'hard' directions and thicker amorphous layer in 'soft' directions during diamond lapping. So there is a significant possibility of that the scratch depth of diamond fragments can exceeds the thickness of already formed amorphous layer in 'hard' directions. Under this condition the bulk bodies of the diamond sample and abrasive grain, all with a diamond atomic structure, can impact each other, so the surface fracture is likely to happen.

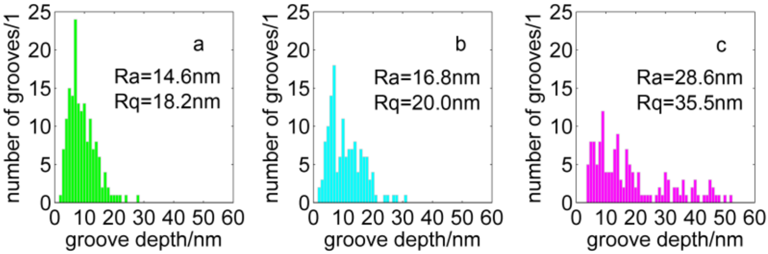

Figure 3. roughness values (Ra, Rq) and depth distribution of the grooves at different angles from [001] crystal direction on (110) surface: a) 0°, b) 30° and c) 60°.

4. Conclusions

With the increase of the angle of lapping direction from [001] on the (110) surface, the surface fracture will occur at a certain degree, near the [110] direction. We consider it from the perspective of diamond amorphization rate in lapping along different crystal orientations and the scratch depth of diamond fragments. The fracture can be avoided when the scratch depth is smaller than the thickness of already formed amorphous layer.

5. Acknowledgments

This work was supported by grants High-end CNC Machine Tools and Basic Manufacturing Equipment major national science and technology (No. 2011ZX04004-031), China.

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