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Abstract

The primary research goal was to investigate localized fracture damage due to single point cutting of ceramic materials and then to compare this to multipoint cutting during precision grinding of the same materials. Two test systems were designed and constructed for the single-point cutting tests. The first system used a PZT actuator for closed-loop load control. An acoustic emission data acquisition system was used for crack initiation detection. The second test system employed a high-precision diamond-turning machine for closed-loop position (cutting depth) control. A high stiffness load cell and data acquisition system were used for crack initiation detection. Microcutting tests were carried out on silicon, borosilicate glass and CVD silicon carbide. The crack initiation thresholds and the fracture damage distribution were determined as a function of the loading conditions using a Vickers diamond as the cutting tool. The grinding tests were done use a plunge-grinding technique with metal-bonded diamond wheels. Optical microscopy, surface roughness and specific cutting energy were measured in order to characterize the fracture damage as a function of the grinding infeed rate. Simulation models were developed in order to estimate the average grain-depth of cut in grinding so that the response could be compared to the single-point microcutting tests.

Major Research Results

The critical depths-of-cut, d_c, for a ductile-to-brittle transition during single point cutting ranged between about 50 nm to 1 μm for glass, silicon and CVD silicon carbide. The values depend on the cutting-point geometry (orientation of the Vickers diamond). cutting speed, loading rate, crystal orientation (silicon) and grain size (CVD silicon carbide). Significant features included the presence of large residual stresses in glass, extensive amorphization of silicon due to the high pressure β-tin transformation and grain-boundary fracture/grain ejection processes in CVD silicon carbide. Measurements of the normal and cutting forces during single-point cutting tests showed that the specific cutting energy was very high for ductile cutting (5 – 10 times the hardness), and that it dropped to a very low value (less than the hardness) when fracture processes were operative. The very high values of the specific cutting energy were attributed to a frictional component of the cutting force that becomes dominant at low cutting depths.

Because there is no cross feed in plunge grinding, examination of the ground surfaces gives a direct indication of the onset of fracture damage as the infeed rate increases (average grain depth-of-cut increases). Surface roughness was measured along the plunge-grinding grooves in

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order to eliminate the "geometric" roughness replicated in the workpiece by the wheel profile. The specific grinding energy was measured as a function of the volume of material removed and then the values were extrapolated to zero volume removed. This was necessary in order to eliminate the effects of wear on the grinding forces. Using these measurements, in conjunction with optical (Nomarski) microscopy observations, it was possible to determine the average grain depth-of-cut, d_g, at which fracture was initiated during the grinding tests. Comparison of the grinding results with the single-point cutting tests revealed behavior that was not anticipated. The average d_g value for fracture initiation in grinding were less than the single-point cutting d_c values for all materials tested and all of the grinding conditions used. Furthermore, the differences were substantial, being the order of 5 – 10 in many cases. The specific grinding energy was very large and showed a rapid drop during ductile grinding, analogous to the single point cutting tests, but the values for grinding remained high (relative to the hardness) when fracture processes were operative and there was only a small decrease in the values as the infeed rate increased.

Significance of the Results

Although single-point cutting tests give very useful information and insight into fracture initiation processes and the subsequent development of subsurface damage, the research work showed that the single-point critical depth-of-cut, d_c, is not a reliable measure of the onset of fracture damage during grinding at a critical value of the grain depth-of-cut, d_g. Significant differences exists both in the nature of the damage produced and the critical depth parameters d_c and d_g. The differences between the test results can be attributed to interaction between cutting grains for multipoint cutting processes such as grinding. From the results obtained in this research work, it appears that fracture initiation in plunge grinding can be associated with a fracture mode that involves very small scale damage initiation which is produced along the edges of adjacent grinding grooves. This effect would not be captured in single-point cutting tests made on flat surfaces. In effect, the grinding damage is akin to "edge" fracture processes as opposed to localized contact fracture on extended monothlic surfaces. Estimates of the edge fracture effect suggest differences the same order as those observed in the research studies.

Degrees Granted

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