Research on Vibration Assisted Machining Equip ment and Mechanism

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Hard and brittle materials are widely used in aerospace, semiconductor, biomedical and nuclear energy applicatio ns due to their excellent physical and chemical properties such as high temperature stability, wear resistance, corr osion resistance, light weight and high strength. Prior to practical application, these hard and brittle materials mu st be precision machined to achieve satisfactory surface integrity. However, their relatively high hardness combine d with low fracture toughness makes them susceptible to subsurface damage and cracking during machining. Vibra tion-assisted machining technology is an advanced energy field-assisted manufacturing technology for hard and brit tle materials, which has the advantages of high efficiency and high precision manufacturing. However, its machinin g mechanism is still not clear. For example, the crack propagation and expansion mechanism under vibration con ditions, the chip formation mechanism during the ductile brittle transformation process, and the stress-strain transit ion behavior within the material under impact loading are not well understood. In addition, the critical ductile-br ittle transition depth of hard and brittle materials is always at the level of tens of nanometers to submicrometers, which is difficult to achieve with the precision of conventional high-speed scratching equipment. Therefore, we ha ve conducted research on vibratory scribing equipment and theory.

For the vibratory scribing machine, the machine tool error identification model shows that the spindle perpendicul arity error and the workpiece-guideway parallelism error are the most important factors affecting the scribing acc uracy. Therefore, spindle modulation and workpiece positioning methods were proposed, and physical prototypes w ere analyzed, optimized, and fabricated. Experiments show that these methods can well improve the machining acc uracy to realize the ductile removal of quartz glass. In addition, a 2-degree-of-freedom vibration device was devel oped to investigate vibration-assisted machining mechanisms.

For machining mechanisms, axial and radial vibration crack initiation and propagation mechanisms were investigat ed. First, indentation, scratch, and axial vibration scratch experiments were conducted on quartz glass, and the re sults showed that vibration scratch cracks are a combination of indentation cracks and scratch cracks. Vibration s cratch cracks change from indentation cracks to scratch cracks when the indenter moves from the entrance to the exit of the workpiece or when the vibration frequency changes from high to low. Second, radial vibration scratch tests were conducted on the self-developed scratch test platform. The results showed that surface cracks appeared outside the scratch grooves at the maximum curvature. Scratches with higher curvature peaks showed less crack i nitiation depth, and deeper cracks were induced inside the scratch. A novel finite-length curved stress field model is proposed to evaluate the damage evolution from the inside and outside of the scratch. Based on the theory of maximum principal stress and tensile stress, the mechanism of crack propagation under the curvature effect is reve aled. This research aims to provide new insights into the efficient non-destructive processing of hard and brittle materials.
