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How to Shot Peen Ceramics

The work of Dr. Wulf Pfeiffer

Dr. Wulf Pfeiffer, with the Fraunhofer Institute for Mechanics of Materials in Freiburg, Germany, has conducted extensive research on how to strengthen ceramics through shot peening—a process that was believed to be impossible due to the brittle nature of the material.

The results of Dr. Pfeiffer's work, in conjunction with Tobias Frey, also with the Fraunhofer Institute, made the extended service life of the space shuttle's pump bearings possible. Pfeiffer and Frey will be presenting their findings at ICSP9 this September in Paris in a paper titled "Advances in Shot Peening of Silicon Nitride Ceramics."

Advances in Shot Peening of Silicon Nitride Ceramics, by Wulf Pfeiffer and Tobias Frey, will be presented at the Ninth International Conference on Shot Peening.

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For a closer look now into the science behind the shot peening of ceramics, read Pfeiffer and Frey's paper, "Shot Peening of Ceramics: Damage or Benefit." The Abstract and Introduction follows. (You may download the complete paper from the online library at www.shotpeener.com, document #2002026)

Shot Peening Of Ceramics: Damage Or Benefit?

Abstract

Non-transformation toughened ceramics show the typical brittle material behavior of failure before deformation at room temperature. Thus, strengthening of ceramics due to deformation induced compressive residual stresses has been thought to be not possible. Nevertheless, preliminary investigations had shown that, using ceramic-specific parameters, shot peening can introduce high compressive residual stresses into the near-surface of silicon nitride and improve the load capacity.

The aim of the presented investigation was to improve the shot peening conditions in order to extend the increase of load capacity while maintaining the surface integrity. The materials investigated where alumina and silicon nitride, the properties determined were residual stresses, load capacity and topography.

The results show that high compressive residual stresses in the GPa-range can be introduced in silicon nitride and alumina which may boost the load capacity of the near surface layers by a factor of up to 9. Only little effect on the surface integrity could be obtained.

Introduction

Residual stresses due to mechanically induced plastic deformation has been thought to have significant effect in brittle materials like ceramics. Thus, also mechanical strengthening methods like shot peening, which are based on a partially plastic deformation of near-surface regions and which are widely used for metals, have not been applied to ceramics.

Contrary to the typical macroscopic behavior of ceramics – failure before plastic deformation – high microplastic deformation and residual stresses have been determined by X-ray diffraction methods for ceramics due to hard machining procedures like lapping and grinding [1], [2]. Fracture mechanically based calculations could prove that both machining induced residual stresses and damage effect the strength. Fig. 1 shows that, due to high compressive residual stresses, conventionally ground silicon nitride reveals a slightly higher transverse bending strength than creep feed ground silicon nitride although a higher amount of damage is introduced.

Recent rolling wear tests of silicon nitride have shown [3] that also under rolling wear conditions high compressive residual stresses up to 1 GPa may develop. Since also severe cracks were visible after only a few hundred cycles, the residual stresses may be proposed to have a significant contribution to the surprisingly high overall lifetime of more than 10^5 cycles (see Fig. 2).

The possibility of a controlled development of plastic deformation and compressive residual stresses without additional significant damage can be concluded from the result of contact loading tests (ball-on plate tests) performed on silicon nitride using silicon nitride balls (Fig. 3), In this experiment the load F was increased until plastic deformation or fracture, respectively, was observed. If the diameter of the indenter sphere is below a certain critical value, plastic deformation is obtained before fracture occurs.

Thus, first shot peening experiments on silicon nitride where carried out using small zirconia beads in the range of 75 μm up to 425 μm. The results showed that under specific shot peening conditions, high compressive stresses could be introduced near the surface which increased the fracture load of the material up to 50% [5].

Nevertheless, from the comparison of the total (= load + residual) stress fields at fracture load of polished and shot peened samples it could be concluded that these shot peening conditions still introduced some damage. Additionally, some amount of the shot peening materials was deposited on the silicon nitride due to debris and fractured zirconia beads.

Thus, the aim of the recent investigations was to evaluate shot peening conditions which result in minimized damaged and high surface quality and maximum surface strengthening effects. (Download the complete paper from the online library at www.shotpeener.com, document #2002026)

We thank Dr. Wulf Pfeiffer for his permission to share this information with our readers. Dr. Pfeiffer has worked with Fraunhofer since 1980. He leads the research field of "surface engineering" which is the characterization and assessment of near-surfaces of materials, the deposition of diamond-like coatings and the surface strengthening of ceramics by a novel shot peening process. He earned his PhD with "Characterization and assessment of hard machined ceramics using X-ray diffraction and fracture mechanical methods." He has published over 50 papers related to residual stresses and ceramic materials and holds international patents on the surface strengthening of ceramics using mechanical methods. He is member of the European commission which prepares a standard for X-ray stress analysis.

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