Shooting at Ceramics

IN CORROSIVE, high-temperature environments, metals quickly lose their elasticity. Beyond certain temperatures the material fails and its properties are compromised; metallic springs stop working if heated above 500 degrees Celsius, for example. But what to do if these are exactly the conditions a production process requires? One way of avoiding the problem has been to make components out of ceramic, a material that is lightweight, rigid, corrosion-resistant and able to withstand high temperatures. Yet this only offers a partial solution, as producing thin ceramics for parts such as leaf springs, lightweight mirrors for optical and extraterrestrial use, or membranes for sensors and fuel cells, is both time-consuming and expensive. This is because ceramics can only be machined using costly diamond tools, and the process itself creates tensions within the surface of the material which cause the finished part to distort as soon as it is removed from the machine. Reshaping the components after manufacture has never been a viable option before as the material is too brittle, and so the large amounts of waste that are generated push the costs up.

Precisely Calculated Paths Guide the Way

Researchers at the Fraunhofer Institutes for Mechanics of Materials IWM in Freiburg and for Production Systems and Design Technology IPK in Berlin have now found a way to straighten out distorted ceramics using shot peening, a process by which small pellets, known as shot, are fired at the surface of a component with a blasting gun. The shot strikes the surface and alters the shape of the thin, outermost layer of material. By moving the gun over the ceramic part along a precisely calculated path, scientists are able to counteract any undesired warping or create lightly curved mirrors out of thin, even ceramic plates. "Shot peening is common practice for working metals," says Dr. Wulf Pfeiffer, who manages this business unit at the IWM, "but the technique has never been used on ceramics because they are so brittle – they could shatter, like a china plate being hit with a hammer. This meant that we had to adapt the method to the material with great precision." The researchers began by analyzing which size of shot would be suitable for use on ceramics, as the surface could be destroyed by pellets that were too big. Cemented carbide balls in the range of 90 µm up to 700 µm were chosen. Pellet speed is another critical factor: hitting the material too fast causes damage; too slow and the shape of the surface is not altered enough. They also discovered that it is important not to bombard the same spot too often with too much shot. Before producing a new component, the scientists first conduct experimental analysis to determine what can be expected of the particular ceramic involved. They fire a beam of shot at it and then measure the resultant stresses to see what sort of deformation is possible and how the beam should be directed.

The experts have already produced various prototypes, including a ceramic leaf spring and a concave mirror. For manufacturing simple components, the technique is now advanced enough to be used in series production. The IWM scientists have recently gone one step further and are developing a computer simulation that will allow components to be worked in multiple axes. Meanwhile their colleagues at the IPK are working on automating the process using a robot.

Shot is fired from a blasting gun at a ceramic leaf spring to correct its shape or cause specific warping as desired. (© Fraunhofer IWM, Felicitas Gemetz)

Editor's Note:

Dr. Wulf Pfeiffer will present his paper, "Shaping of Ceramics Using Residual Stresses," at the 9th International Conference on Residual Stresses (ICRS9) in October 2012. He wrote the paper in conjunction with Heiko Höpfel, a fellow researcher at Fraunhofer Institute for Mechanics of Materials IWM. Here is an excerpt from the paper's abstract:

> This paper describes the first successful experiments aimed at shaping ceramic specimens using shot peening. Strips of different thicknesses, made of silicon nitride ceramic, were shot-peened using different shot sizes, peening pressures and coverage. The residual stress-depth distributions were determined using X-ray diffraction. Based on the experimentally-determined stress states, the curvatures of the strips were determined analytically and using Finite Element calculations (FEM).

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