Laser Shock Processing of Ceramic Materials

by

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Laser shock processing (LSP) has been successfully used to introduce beneficial compressive residual stress by plastic deformation to metallic materials to improve their performance since the 1990s. LSP has just recently been applied ceramic materials to improve their mechanical properties. However, technique challenges exist due to the intrinsic brittleness of ceramics at room temperature. In addition, the fundamental mechanism related to the interaction of laser-driven shock waves with ceramic microstructure was poorly understood.

In this study, LSP is proposed as a potential approach to improve the crack resistance of ceramics by introducing of compressive residual stress. Room temperature LSP has been applied to polycrystalline alumina and silicon carbide ceramics to investigate the influence of LSP on residual stress distribution, cracking resistance, and microstructure change of the ceramics. Post-annealing has been conducted on the polycrystalline alumina after LSP to heal the microcracks generated during the LSP process. In addition, LSP, at elevated temperatures, of single crystals alumina has been done to study the influence of temperature on the LSP process.

Throughout these studies, it has been found that: (1) room temperature LSP can generate compressive residual stress of several hundred mega Pascals on the surface and extend to a depth of 700~1200 um of polycrystalline alumina and silicon; (2) the compressive residual stresses on the surface can improve the resistance of ceramics to indentation cracking; (3) the majority of the surface remains intact after LSP. Localized plastic deformation occurs near the surface and grain boundaries at room temperature; (4) during the post-LSP annealing process, the microcracks could be healed and the surface compressive residual stress was stabilized to ~300 MPa after annealing at 1100 ℃ for 10 hours; (5) a high temperature LSP process could be applied in alumina crystals to generate large compressive surface residual stress, which is beneficial to cracking resistance of the alumina and possibly other ceramics. This research proved that LSP could be a promising toughening method used for different ceramics.

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Chapter 7 is being prepared for publication of the materials. Wang, F., Zhang, C., Yan, X., Deng, L., Lu, Y., Nastasi, M., & Cui, B. are the coauthors. The dissertation author is the first author of this work.

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Chapter 1 Introduction

1.1 Motivation

Ceramics are important materials with a combination of excellent properties, such as high compressive strength [1-3], good heat resistance [4], good wear resistance [5, 6], corrosion resistance properties [7, 8], and low thermal expansion coefficient. Ceramics are of growing interest and have been widely used in medical, aerospace, automobile, nuclear power plant and other modern industry fields as cutting tools [9], artificial bone[10, 11], dental products [12, 13], space shuttle tiles [14, 15], thermal barrier coatings [8], rocket nozzles [16, 17], bulletproof vests [18, 19]and even turbine blades [20]. The benefits of using ceramics instead of metals include lower weight, higher working temperature, and better environmental corrosion resistance. However, their mechanical reliability is limited by the low toughness and crack sensitivity. Therefore, improving the toughness and crack resistance of ceramics are always desirable and can improve the performance of ceramic products.

The strength and toughness of ceramics highly depend on the type and magnitude of residual stresses [21]. Introducing compressive residual stress into ceramics can improve their flexure strength, Weibull modulus, thermal shock resistance, and contact damage resistance [22, 23]. Various toughening methods have been developed to improve the toughness and mechanical reliability of ceramics by introducing