

Laser Shock Processing of Ceramic Materials

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Laser Shock Processing of Ceramic Materials

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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 μm 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°C 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.

PREVIEW

Table of Contents

List of Figures	xi
List of Tables	xix
Chapter 1 Introduction	1
1.1 Motivation	1
1.2 Research Objectives and Methodology	4
1.3 Dissertation Structure	6
1.4 References	7
Chapter 2 Literature Review	14
2.1 Laser Shock Processing	14
2.1.1 Development of Laser Shock Processing	15
2.1.2 Generation of Shock Waves by Laser Shock Processing	18
2.1.3 Introduction of Residual Stress by Laser Shock Processing	19
2.1.4 Advantages of Laser Shock Processing	20
2.1.5 Influencing Factors	22

2.2 Effect of Laser Shock Processing on Materials	38
2.2.1 Surface Morphology.....	39
2.2.2 Surface Hardness.....	41
2.2.3 Microstructure	42
2.3 Applications of LSP	44
2.3.1 LSP Enhancing the Fatigue Life of Metallic Materials.....	45
2.3.2 LSP Improving the SCC Resistance of Metallic Materials.....	46
2.3.3 LSP Ceramics	47
2.4 Literature Review on Alumina	49
2.5 Literature Review on Silicon Carbide.....	53
2.6 References	56
Chapter 3 Experimental Materials and Methods	77
3.1 Materials.....	77
3.2 Laser Shock Processing Experiments	80
3.3 Microstructure Characterization.....	84
3.3.1 Surface Morphology Characterization	84

3.3.2 TEM Sample Preparation and Observation.....	85
3.4 Residual Stress Measurement	86
3.4.1 Residual Stress Measurement by X-ray Diffraction.....	86
3.4.2 Residual Stress Measurement by Raman Spectra	87
3.5 Mechanical Property Measurement.....	89
3.5.1 Hardness Test	89
3.5.2 Bending Strength Test	89
3.6 References	90
Chapter 4 Room Temperature Laser Shock Processing of Polycrystalline Alumina	95
4.1 Background	95
4.2 Experiment	98
4.3 Results	101
4.3.1 Residual Surface Stresses Induced by Laser Shock Processing.....	101
4.3.2 Microstructural Changes by Laser Shock Processing	104
4.3.3 Mechanical Response to Laser-Driven Shock Waves	107

4.3.4 Improved Resistance to Indentation Cracking	109
4.4 Conclusions	111
4.5 References	112
Chapter 5 Room Temperature Laser Shock Processing Polycrystalline Silicon Carbide.....	121
5.1 Introduction	121
5.2 Experimental procedures.....	124
5.3 Results	127
5.3.1 Surface Morphology Changes by LSP	127
5.3.2 Subsurface Microstructural Changes by LSP.....	131
5.3.3 Compressive Residual Stress Distribution After LSP	132
5.3.4 Mechanical Properties of LSP-treated SiC Ceramics	133
5.4 Discussions.....	135
5.5 Conclusions	140
5.6 References	142

Chapter 6 Microstructure-Property Relation in Alumina Ceramics during Post-Annealing Process after Laser Shock Processing	152
6.1 Introduction	152
6.2 Experimental Procedure	154
6.3 Results and Discussion.....	156
6.3.1 Compressive Residual Stresses after LSP and Thermal Annealing	156
6.3.2 Microstructural Changes after LSP and Annealing	159
6.3.3 Mechanical Properties after LSP and Post-annealing	164
6.4 Conclusions	166
6.5 Reference.....	167
Chapter 7 High-temperature Laser Shock Processing of Alumina	174
7.1 Introduction	174
7.2 Experimental procedure	178
7.3 Experimental Results.....	181
7.3.1 Laser Induced Shock Wave Pressure.....	181
7.3.2 Surface Morphology of Alumina after LSP	182

7.3.3 Microstructural changes by LSP	184
7.3.4 Compressive Residual Stress Distribution after LSP	189
7.3.5 Improved Mechanical Properties by LSP	190
7.4 Conclusions	194
7.5 References	195
Chapter 8 Conclusions and Future Work	205
8.1 Conclusions	205
8.2 Future Work	207

List of Figures

Figure 2.1(a) Schematic diagram of laser shock processing (LSP). (b) Scanning pattern of laser beam with 50% overlap ratio on the material surface.....	15
Figure 2.2 Schematic of the shockwave generation process. (a) a beam of high energy laser was irradiated to sample surface; (b) sacrificial layer evaporated by the laser beam and generated plasma; (c) the explosive expansion of the plasma was confined by the confining layer; (d) shockwaves generated by the plasma expansion penetrated into sample.	19
Figure 2.3 Schematic of how plastic deformation and compressive residual stress is introduced in LSP process.....	20
Figure 2.4 Schematic of (a) LSP, (b) shot peening, and (c) ultrasonic impact peening.	21
Figure 2.5 Influencing factors of LSP.	22
Figure 2.6 Peak pressure as a function of laser power intensity in the water-confined regime [49].....	26
Figure 2.7 Schematic of the three stages of peak shockwave pressure as a function of laser power intensity.	27

Figure 2.8 Residual Stress profiles in depth in Ti-6Al-4V at three different laser shock peening intensity levels [52].	28
Figure 2.9 The influence of pulse duration on the relationship between shockwave pressure and laser power intensity [58].	29
Figure 2.10 Peak pressure as a function of laser power density for different wavelengths [60].	31
Figure 2.11 The depth profile of residual stress generated by lasers with different spot sizes [68].	33
Figure 2.12 Average residual stress at the surface of 55CI steel after different LSP conditions with laser power density of 5 GW/cm ² and water as plasma confining media [74].	36
Figure 2.13 Influence of laser pulse numbers on the depth profile of the residual stress in 35CD4 steel induced by LSP [70].	38
Figure 2.14 Typical surface topography of sample after (a) shot peening and (b) LSP [78].	40
Figure 2.15 SEM images of surfaces (a) unpeened (b) LSP 22 pulses and (c) LSP 32 pulses [80].	40
Figure 2.16 SS304 plate after laser peening without protective coating [82].	41

Figure 2.17 Work-hardening of 316 steel induced by shot peening and LSP [53].	42
Figure 2.18 Typical TEM images of the near-surface microstructures of 304 austenitic stainless steel treated by LSP: (a, b) deformation twins (arrowed); (c, d) stacking faults (SF); and (e, f) dislocation network. [87]	43
Figure 2.19 Micrographs on the surface of the AZ31B Mg alloy (a) before LSP; (b) with one impact; (c) with two impacts; and (d) with four impacts [86].	44
Figure 2.20 Schematic of how LSP-induced compressive residual stress could provide a buffer against tensile load and inhibit crack propagation.	45
Figure 2.21 Compressive strength of alumina and SiC vs strain rate at room temperature [122].	51
Figure 2.22 TEM micrograph of dynamically ruptured SiC fragments: (a) SiC grain with stacking faults emanating from grain boundaries; (b) SiC grain with stacking faults and dislocations [142].	55
Figure 3.1 (a) Image of the polycrystalline alumina sample used in this research. (b) SEM image of the grains in the alumina sample.	78
Figure 3.2 (a) Image of the single crystal alumina used in this research. (b) SEM image of the single crystal alumina surface.	79

Figure 3.3 (a) Image of the polycrystalline SiC used in this research. (b) Optical image of the SiC sample showing the Si impurity at grain boundaries. (c) X-ray diffraction of SiC.....	79
Figure 3.4 (a) Schematic diagram of the laser shock processing (LSP) system. (b) Scanning pattern of laser beam on the ceramic sample surface.....	80
Figure 3.5 The temporal profile of shockwave pressure estimated based on the Fabbro's model.....	83
Figure 3.6 FIB lift-out process.....	85
Figure 3.7 (a) ceramics samples for 3-point bending test. (b) 3-point bending test fixture on the MTS testing system.....	90
Figure 4.1 Schematic of the LSP process of ceramics: (a) the ceramic sample is covered by a sacrificial layer and a plasma-confining media; (b) a plasma is formed by laser irradiation and the explosive expansion of the plasma generates shock waves which penetrate into the bulk material.....	99
Figure 4.2 Compressive residual stress in LSP-treated α -Al ₂ O ₃ ceramics: (a) residual stress on the surface vs. laser pulse energy at 4 laser pulses; (b) residual stress on the surface vs. laser pulses at a laser energy of 850 mJ; (c) stress distribution along the depth vs. laser pulses at a laser energy of 850 mJ.....	103

Figure 4.3 Microstructures of α -Al₂O₃ ceramics treated by LSP. (a, b) SEM image of the surface morphology of LSP-treated α -Al₂O₃ ceramics by: a) a laser pulse energy of 400 mJ and 4 laser pulses; b) a laser pulse energy of 850 mJ and 16 laser pulses. Black arrows indicate the damage region where grains were pulled-out. (c) Bright-field TEM micrograph of the microstructure underneath the intact region. No crystal defects such as dislocations are present in the microstructure. (d) Weak-beam dark-field TEM micrograph of the microstructure underneath the damage region. Dislocations arrays on the prism-plane slip system $[1\ -1\ 0\ 0]$ ($1\ 1\ -2\ 0$) are revealed. 104

Figure 4.4 Comparison of the Vickers indentation in (a) untreated α -Al₂O₃ ceramics; and (b) LSP-treated α -Al₂O₃ ceramics by a laser pulse energy of 850 mJ and 13 laser pulses..... 110

Figure 4.5 The values of $P/c^{3/2}$ vs. the number of laser pulse in LSP-treated α -Al₂O₃ ceramics by a laser pulse energy of 850 mJ..... 110

Figure 5.1 (a) Schematic diagram of the laser shock processing (LSP) system. (b) Scanning pattern of laser beam on the SiC surface..... 124

Figure 5.2 (a) SEM image of the surface of α -SiC sample before LSP. (b) Bright-field TEM image of the cross-sectional image for the microstructure of the SiC sample before LSP. (c) SEM image of the surface of the SiC sample after LSP. Microcracks are marked by white arrows..... 128

Figure 5.3 (a, b) 3-D topography of the SiC surface a) before, and b) after LSP. (c) Line scan of the surface roughness before and after LSP.....	129
Figure 5.4 XRD patterns of SiC sample before and after LSP.....	131
Figure 5.5 TEM images of dislocations in α -SiC ceramics generated by LSP: (a) weak-beam dark-field and (b) bright-field images of dislocations underneath the surface; bright-field images of (c) perfect dislocations as well as (d) partial dislocations that are bounded by stacking faults (SF) near the grain boundaries at a depth of about 6 μm from the surface. Dislocations are marked by white arrows.	132
Figure 5.6 Residual stress distribution along the depth of LSP-treated SiC ceramics.	133
Figure 5.7 Comparison of the radial cracks on the edge of Vickers indentation in (a) untreated and (b) LSP-treated SiC ceramics.....	134
Figure 5.8 Comparison of the apparent fracture toughness and bending strength of the untreated and treated SiC ceramics.....	135
Figure 5.9 Schematic diagram of the mechanisms of LSP-induced localized plastic deformation in (a) coating/ceramic interface and (b) grain boundary in α -SiC ceramics.	138

Figure 6.1 Schematic diagram of the laser shock processing of ceramics: (a) the experimental system; (b) scanning of laser beams on the sample surface.....	155
Figure 6.2 Compressive residual stress on the surface of LSP-treated α -Al ₂ O ₃ samples as a function of annealing time at 1100, 1300 and 1500 °C.	159
Figure 6.3 Scanning electron microscopy image of the surface of LSP-treated α -Al ₂ O ₃ ceramics.	159
Figure 6.4 Bright-field TEM images of Dislocations in α -Al ₂ O ₃ ceramics after: (a) laser shock processing; and (b) LSP and post-annealing at 1500°C for 1 hour.....	160
Figure 6.5 Bright-field TEM images of the cross-section view of microcrack healing in α -Al ₂ O ₃ ceramics after LSP and annealing at (a) 1100°C for 20 hours, (b) 1300°C for 20 hours and (c) 1500°C for 1 hour. Dislocations and voids are marked by red and white arrows, respectively.....	161
Figure 6.6 Schematic view of the possible microcrack healing process in α -Al ₂ O ₃ ceramics after the LSP and annealing process. (a) The original microcrack generated by LSP. (b) The original microcrack healing process started with the blunting of the sharp crack tip, followed by the bridging of two opposite edges of microcracks by atomic diffusion. (c) Dislocations and voids formed in the transitional stages of the microcrack healing process.....	163

Figure 6.7 SEM images of the indentation cracks on (a) α -Al ₂ O ₃ ceramic sample before LSP; (b) after LSP (850 mJ, 4 LSP scans); and (c) after LSP and post-annealing at 1100 °C for 30 hours.....	165
Figure 6.8 $P/c^{3/2}$ of the untreated, LSP-treated, and post-annealed α -Al ₂ O ₃ ceramics. The two LSP conditions are shown.....	165
Figure 7.1 Schematic of the high temperature LSP system.	179
Figure 7.2 SEM images of the surfaces of the alumina samples (a) before LSP, (b) severely damaged after LSP at room temperature, (c) mainly intact with few microcracks after LSP at 1200°C.....	183
Figure 7.3 TEM images of dislocations in α -Al ₂ O ₃ ceramics generated by LSP: (a) bright-field images of sample without LSP showing no dislocation in the original sample; (b) and (c) dislocations underneath the sample surface after LSP. Dislocations are marked by white arrows.....	186
Figure 7.4 Surface residual stress distribution of the alumina sample after high temperature LSP.....	190
Figure 7.5 Comparison of the radial cracks on the edge of Vickers indentation in (a) untreated and (b) LSP-treated alumina ceramics.	192

List of Tables

Table 3-1 Typical experimental parameters for laser shock processing of ceramics ...	81
Table 7-1 Mechanical properties of alumina before and after LSP.....	193

PREVIEW

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