ILAS 2019 abstracts

Toughening Advanced Ceramics with Laser Shock Peening

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This work presents a comprehensive, pioneering study of strengthening Si_3N_4 advanced ceramics with laser shock peening. A 10J DiPOLE, diode-pumped solid-state laser (DPSSL) system was employed to undertake experiment on laser shock peening of Si_3N_4 with single, double and multiple-passes at 1J laser energy, 4.5mm spot size, 1Hz pulse repetition rate, 10ns pulse duration with an operating wavelength of 1030nm. Fracture toughness (K_{Ic}), hardness and residual stresses were measured along with fracture morphology and microstructural observations. This was also confirmed by phase transformation and finite element modelling of LSP Si_3N_4 which verified the experimental residual stresses. The results showed a maximum increase in K_{Ic} of 24%, as the K_{Ic} was enhanced through increased impact resistance rendering low cracking profiles post Vickers diamond indentation test and yet improved the hardness by 22% compared to the as-received surface. The enhanced hardness would generally make the ceramic more brittle, but instead, the fracture toughness was improved which was attributed to induced compressive stress which came about with induction of both microplastic deformation that enhanced the dislocation activity and with phase transformation from alpha-phase to beta-phase. The rod-like grains of the beta-phase in this case enhanced the materials property and aided in resisting indentation loading, leading to the increased K_{Ic}. The work in this study showed that it is possible to laser shock peen brittle and difficult to peen ceramics which could now be used to build a mechanistic understanding of the strengthening mechanism(s) for further advancement of the process and improving material properties.

Keywords: Laser Shock Peening; Silicon Nitride; Residual Stress; Fracture Toughness; Microstructure