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Surface oxidation of porous ZrB_2-SiC ceramic composites by continuous-wave ytterbium fibre laser

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ABSTRACT

Surface treatment of ceramic substrates by a laser beam can allow to incorporate interesting properties to these ceramics. In the present work, surface oxidation of ca. 30% porous ZrB_2-SiC ceramic composites by using an ytterbium fibre laser was conducted. Oxidation of ceramic substrates through this process under ambient conditions has certain advantages compared to the classical oxidation method. A particular spiral laser pattern was created in order to produce an oxidized structure on ZrB_2-SiC porous substrates. The laser parameters were as follows i.e., laser power of 50, 60 and 70 W, a beam diameter of 1.25 mm, velocity of 2 mm/s, acceleration and deceleration of 1 mm/s^2. The microstructural and morphological changes in the laser-treated region was examined using scanning electron microscopy, energy dispersive X-ray spectroscopy, and X-ray diffraction. At laser power of 70 W, the sample exhibits uniform oxidation. It revealed that the very porous bulk beneath remained unaffected and unoxidized because this laser-formed oxide scale protects the substrate from oxidation. The presence of oxidized and unaffected regions indicated a high degree of heat localization. The dense glassy SiO_2-rich layer prevents the inward oxygen diffusion into the inner bulk hence enhances the oxidation resistance.

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1. Introduction

Laser treatments have found a great interest in ceramic applications due to their attractive benefits which offer rapid process [1,2], precision of operation [1,3], high energy efficiency during laser irradiation [2,4], high degree of treatment localization [1–8] and cost effective operation [2,3]. It can also be employed onto the metal-matrix composite surface materials. D'Amato et al. [6] and Avril et al. [7] have performed laser surface alloying of an A356 aluminium alloy and X30Cr13 stainless steel, respectively, in order to improve the tribological behaviour of its surface. It has been shown that the corrosion resistance can be improved by laser surface treatment as studied by Hu et al. [9]. These experiments have demonstrated the emergence and feasibility of laser to be employed as major tool for surface treatment as demonstrated by several articles reported elsewhere [9–14]. Ytterbium fibre laser is one of the laser types which has been developed into industrial level usage [15] and it has been successfully employed in the multiple experiments [2,4,8,15–20].

Ultra-high temperature ceramics (UHTCs) are widely studied materials, particularly the ZrB_2-based ones, because of their well-known high melting point. They are widely chosen mostly due to the high interest in the technology of hypersonic flight, atmospheric re-entry and solid oxide fuel cells [17,21,22]. ZrB_2 is a transition metal diboride. It has a high melting point of >3000 °C that enables it to maintain strength at elevated temperature [22–27] and generally used for extreme environment applications. Moreover, it has a theoretical density of 6.09 g/cm^3 [23,24] that is among the lowest densities of the UHTCs and desirable for aerospace applications [27]. Other interesting properties of ZrB_2 are high thermal conductivity (58.2 $W m^{-1} K^{-1}$), excellent thermal shock resistance, low electrical resistivity (~10 μΩ cm) [14] which could be useful for electrical applications such as furnace heating elements, high temperature electrodes and metal evaporator boats [25]. In addition to that it has high hardness (23 GPa), high Young's modulus and good electronic conductivity ($\rho = 10^{-7}$ Ω m) [14,27–29]. Despite the fact that ZrB_2 has numerous attractive properties, it also has a major drawback. It oxidizes at temperatures around 700 °C [24,27]. To overcome this drawback, the

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