Detection of Ceramic Cracks Using a Distributed High-Resolution Brillouin Fiber Optic Sensor

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Abstract: A distributed sensor system is highly desirable for detecting, locating, and monitoring fine cracks at unknown locations in advanced ceramics. This paper presents a distributed high-resolution fiber optic sensor based on the Brillouin scattering principle, and its application in ceramic crack detection for the first time. The existence of cracks, together with their locations, is identified by measuring the strain distribution on a sensing fiber bonded to the ceramic surface. By employing the innovative coherent probe-pump interaction technique, the Brillouin sensor developed in this study achieves a high spatial resolution (100 mm) and measurement accuracy. Capable of detecting and locating fine cracks less than 40 μm, the efficacy of the distributed Brillouin fiber optic sensor is demonstrated through experiments.

Key Words: Brillouin scattering, crack detection, strain measurement, fiber optic sensor, advanced ceramics.

1. Introduction

Advanced ceramics are valued for their hardness, high-temperature strength, light weight and abrasion resistance, and hence find wide use in such applications as ballistic protective armor components, wear components of equipment in oil, gas, and mining operations, and high-performance engines. However, due to the brittle nature, advanced ceramics are subjected to cracking upon impact during operation. Cracks, including invisible micro cracks, significantly degrade the strength of a ceramic component.

The traditional inspection of cracks in ceramics relies on visual inspection including the dye and the fluorescent penetrant methods. Recently nondestructive evaluation (NDE) methods such as X-ray and ultrasonic imaging have been applied to detect cracks in ceramics, but have limited sensitivities to micro cracks. Both the visual and NDE inspection methods are laborious, time consuming, and more importantly, difficult to perform continuously during operation.

Optical fiber based sensing has received increasing attention over the last two decades for the purposes of structural health monitoring. Different sensing techniques have been developed to monitor specific parameters. Recently it has been reported that fiber Bragg grating (FBG) sensors were applied to detect cracks in ceramics, but have limited sensitivities to micro cracks. Both the visual and NDE inspection methods are laborious, time consuming, and more importantly, difficult to perform continuously during operation.

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The Brillouin Fiber Optic Sensor

The Brillouin fiber optic sensor is based on the Brillouin loss technique [4], whereby two counter-propagating laser beams, a pulsed Stokes beam and a continuous wave (cw) pump beam, exchange energy through an induced acoustic field. The interaction magnifies the pulsed Stokes beam at the expense of depleting the pump beam, which is then detected as a loss signal. The maximum depletion of the pump beam at a point along the fiber occurs when the frequency of the acoustic wave \( v_B \) at that point matches the beat frequency of two laser beams, i.e., \( \nu_B = \nu_p - \nu_s \), where \( \nu_p \) and \( \nu_s \) are the frequencies of the pump and Stokes beams, respectively. The frequency of the acoustic wave, hereafter referred to as the Brillouin frequency shift, is related to the fiber properties and the laser wavelength. The sensing capability of Brillouin scattering arises from the dependence of the Brillouin frequency shift, \( v_B \), on the local acoustic velocity and refractive index in the fiber core glass, which has a linear temperature and strain dependence through...