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Nondestructive Characterization of Heterogeneous Coatings Based on Ultrasonic Reflection and Scattering Mechanism

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The characterization of coatings features, such as thickness, elastic modulus, and interfacial morphology, especially in a nondestructive way, is significant to ensure manufacturing quality of coatings as well as the high performance of the components in service. However, it is still difficult to achieve an accurate nondestructive measurement of these coating features, especially for heterogeneous coatings, using conventional ultrasonic technique, due to the coupled material and geometry constrains including ultra-thin thickness, multiple interfaces, and coating material heterogeneity that cause recorded ultrasonic signals in complicated interfered, scattered, and distorted forms. In this work, a characteristic response is clarified to solve such a problem by exploring the ultrasonic reflection mechanism in coatings of four layers and three interfaces and the scattering mechanism on tiny scatterers from the heterogeneity. Using the wave-mode conversion analysis, phase-screen approximation theory, and acoustic scattering self-consistent theory, the ultrasonic reflection coefficient amplitude spectrum (URCAS) is identified as a characteristic response. Therefore, the quantitative relationships between the coating features and the URCAS can be established to derive the coating thickness, elastic modulus, interfacial roughness, and porosity from the resonant frequency, phase and amplitude of URCAS. It is demonstrated that, a novel ultrasonic small angle incidence scheme is developed by utilizing the identified characteristic response for characterizing of WC-Ni coatings thermally sprayed on steel components. The thickness measurement is less than 10% error for 300-400 μm thick coatings, in comparison with the destructive characterization on optical microscopy. The measured elastic moduli are in the range of 315-351 GPa, and the Poisson's ratios were during 0.221-0.245, in good agreement with published data. Moreover, the interfacial roughness of the coatings can be measured as decoupling the effect of the attenuation coefficient α(f) in the URCAS, with less than 1.4 μm absolute error and 11.0% relative error for an interface roughness of 13.1 μm.

Keywords
Heterogeneous coating; Reflection mechanism; Scattering mechanism; Ultrasonic reflection coefficient amplitude spectroscopy