Experimental study of thermal degradation in ferritic Cr–Ni alloy steel plates using nonlinear Lamb waves

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1. Introduction

Heat-resistant steels have been widely applied in high temperature components of petrochemical industry and power plants due to their excellent high-temperature strength and creep resistance. However, when the heat-resistant steels are used for long periods at elevated temperature in practice, they generally experience degradation of thermal damage or creep damage, which would shorten the lifespan of components and would bring about serious disaster due to the unforeseen fracture. Therefore, it is of increasing importance to evaluate such degradation of strength of materials at early stage for structural health monitoring (SHM). In order to conduct a nondestructive evaluation (NDE) on the state of structural material damages, ultrasonic monitoring (SHM). In order to conduct a nondestructive evaluation (NDE) on the state of structural material damages, ultrasonic methods are often used for its capability of evaluating both the surface and internal damage state of in-service components with the comparatively simple and easy instrumentation.

During thermal damage, the formation of various precipitates in heat-resistant steel would cause local strain concentrations and therefore would produce different dislocations concentrated near the precipitates. The volume fraction of the precipitates has a direct influence on the changes of dislocation density and average length. Moreover, the dislocation pileups caused by strain concentration or residual stress would make the precipitates break off from the matrix and then leads to formation of micro voids. All these microstructure changes during thermal degradation would produce a very clear nonlinear response in material. The classical theory of nonlinear wave propagation in elastic solids has been discussed and presented for nearly half a century [12]. Most previous researches have measured the acoustic nonlinearity parameter $\beta$ using longitudinal waves, which is a function of the second- and third-order elastic constants, and have indicated that $\beta$ is sensitive to subtle damage in materials and can be correlated with certain microstructural changes during fatigue damage [8,13], thermal damage [3,7], or creep damage [10,11]. Compared with the nonlinear ultrasonic techniques that use bulk acoustic waves, ultrasonic guided waves such as Lamb waves have obvious advantages, such as one-side access of pitch-catch configuration and high efficiency in a long distance propagation, for using as a more suitable candidate to interrogate large plate- and shell-like structures in the field applications.

**ARTICLE INFO**

**ABSTRACT**

The thermal degradation in ferritic Cr–Ni alloy steel plates is measured using the nonlinear effect of Lamb wave propagation. Experiments were carried out to introduce controlled levels of thermal damage to determine the nonlinear response of Lamb waves. A “mountain-shape” change in the normalized acoustic nonlinearity of Lamb wave versus the level of thermal degradation in the specimens has been observed. The variation in the measured acoustic nonlinearity reveals, based on metallographic studies, that the normalized acoustic nonlinearity increases due to the second phase precipitates in the early stage and it decreases as a combined result of dislocation change and micro void initiation in the material. The results show a potential application of the nonlinear Lamb waves for the quantitative assessment of thermal damage in metallic plates or pipes.

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