Vibration-Based Non-Destructive Evaluation of Internal Damage in Foam Cored Sandwich Structures Using Wavelet Analysis

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Modern mechanical and civil structures are increasingly designed using polymeric composites that ensure great strength-to-mass ratio and are resistant to various environmental interactions, like corrosion. The application of sandwich structures in the design of mechanical and civil constructions is determined by their good stiffness properties and very low mass, which is a very attractive combination. Due to their wide applicability, these structures should be properly maintained and diagnosed, and thus, appropriate non-destructive testing (NDT) methods should be developed in order to detect and identify various types of damage. Special attention should be paid to internal damage (damage to the core of a sandwich structure), which cannot be detected during a visual inspection. In the paper, an NDT method based on modal analysis and further processing of modal shapes using a wavelet transform is proposed. Three sandwich structures with damage to the core of various types were experimentally tested using modal analysis, the damage positions were detected and identified using wavelet analysis, and verified by comparing the results of previously performed thermographic tests. The obtained results show a high effectiveness of the proposed approach, which could find an application in the industrial inspection of sandwich structures in a non-destructive and non-contact manner.

1. INTRODUCTION

Sandwich composite structures are manufactured from various materials and in different configurations depending on the area of their application. One of the types of such sandwich composites which has found wide application both in mechanical and civil constructions is a foam cored sandwich that consists of a thick core and thin face sheets usually made of an aluminium or glass fibre-reinforced polymeric (GFRP) composite. Considering the wide applicability of these structures’ appropriate inspection procedures, they are necessary both at the stage of quality control (manufacturing-damage assessment) and at the stage of maintenance (damage caused by fatigue, overloading, sudden accidents, etc.). The inspection and diagnosis of sandwich structures, due to the modern demands of industry, should be non-destructive and sensitive enough to detect and localize damage positions at possibly an early stage of their development.

Numerous NDT methods dedicated to the inspection of thick polymeric sandwich structures have been developed or adapted to date. The most often applied methods for such structures include acoustic emission (AE) testing, ultrasonic testing (UT), infrared thermography (IRT) and X-ray computed tomography (CT). A comprehensive overview on these methods applied for thick composite structures was presented by Ibrahim. Several recent studies describe AE-based methods of damage evaluation; however, they are based mostly on comparison with reference measurements, e.g. Burlayenko and Sadowski who have analysed a delamination in foam and honeycomb cored sandwich plates using a numerical model based on shifts of natural frequencies. Arora et al. compared the frequency response functions (FRFs) and modal shapes of healthy and damaged structures in order to detect damage. An original approach was presented by Dickinson and Fletcher, where they tested aircraft composite panels with impact damage in honeycomb cored sandwich structures by using a reference-free AE-based method, and they detected and localized the damage with high confidence. Several other approaches of damage detection are described in Ben et al. and Masmoudi et al. However, the tests were based on fatigue tests, counting the number of hints, and the observation of evolution of mechanical properties of tested structures until the failure.

Various UT-based techniques have been applied for damage identification in sandwich structures. The results presented by Holmes et al. and Smith et al. confirm the effectiveness of these techniques in damage detection and identification. In the experimental study presented by Chakraborty et al., the authors used Lamb waves for damage detection in honeycomb cored sandwiches with wavelet-based post-processing, and based on the obtained results, they could detect and distinguish the damage. This group of methods is efficient in damage evaluation in sandwich structures. However, such methods are often limited to the laboratory conditions. Successful damage identification is also possible using transient IRT and vibrothermography, the method which uses ultrasonic-vibration excitation of a tested structure with a simultaneous measurement of thermal response using IRT. Both external and internal damage in sandwich structures can be effectively detected and identified using this method. Finally, X-ray CT methods provide a possibility of obtaining a 3D scan with the best resolution as compared to other NDT methods. The application of this technique to damage detection and identification of thick sandwich structures gives very precise results.