Evaluation of Epoxy Composites using Fusion of Vibration and Ultrasound Sensors

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Abstract - *The increase of epoxy carbon fiber applications in our life is improving the performance of many machines and applications, like, Airplane composite structure, Automobile chassis, wind turbine blades and sports good. So, the need for monitoring these composite structures arises to determine the early damage in its structure. In the current investigation a novel technique is used for detecting and determines the internal and external damage of the carbon Fiber reinforced Epoxy (CFRE). The current method is based on the sensor measurements fusion of the ultrasonic wave and vibration acceleration to merge them together and correlate the fused data to the damage. The data are acquired using precise devices and pulse analyzer, in addition to; software specialized in data processing and analysis. The experiments were carried out for two dimensions of CFRE plates, to confirm the results. The result reveals that, effectiveness of the fusion measurement method to detect defects in CFRE structures.*

Key Words: Vibration, carbon, fiber, damage, fusion, CFRE

1. INTRODUCTION

Regarding the increasing of carbon fiber reinforced epoxy CFRE composite application and to prevent the failure of the composite structure, there are many researchers are looking forward to monitor the composite structure and estimate the damage regions even detect the location of the cracks. There are few methods are developed to monitor the damage characteristics. Vibration analysis one of the most common methods used for damage detection in the composite structures, as the mode shape and natural frequency [1-4]. Vibration analysis of cracked composite laminated plate and beam structure was developed by [5-7]. The authors concluded that, the damage influenced by the natural frequency as the presence of damage decrease the natural frequency. Furthermore, change the mode shape. Finite element analysis was used to deduce crack and damage detection through vibration and dynamic characterization [8-12]. Image processing technique was developed to use wavelet transformation to detect damage in different structures [13-17].

Ultrasonic spectroscopic analysis was conducted to carbon hybrid flax plates in order to detect the damage via the different resonance frequencies applied to the plates, the study was verified using simulation model [18]. The previous technique depends on one source to receive the impact signal from excitation source. In addition, this technique not valid for large structure. Acoustic emission AE such as ultrasonic testing used to detect vibration signals traveling in a structure, however sometimes it may work and detect the damage and cracks as well eddy current methods, but both methods are not suitable for non-metal structure[7, 19].on the other hand, there is another acoustic signals depends on microphone, hence sound signals are recorded via set of microphones to detect damaged occurred in composite structures [20]. The experimental results are promising and constitute the first step towards the development of a complete solution for damage detection in composite structures. Then, a pattern recognition system for global damage detection composite materials is presented.

Acoustics method is used to determine damages includes fatigue cracks, fiber separation and delamination [21, 22]. It has been presented that the nonlinear ultrasonic measurements can use to detect the early damage stage better than the lean ultrasonic measurements [23]. AE that collected form buckling tests developed to detect the type of damage that occurring in CFRE composite structures [24].

Regarding the previous works, it can be noticed that the damage monitoring of the CFRE is a problem that is needed for accurate solution to localize the internal and external cracks or damage. Therefore, in the current study the new technique is based on the sensor fusion between the ultrasonic with vibration measurements at the same time. The results of fusion data depend on the natural frequency, damping capacity and mode shapes that analyzed from the dynamic characteristics of the CFRE composite structure.

2. EXPERIMENTAL WORK

2.1 Material

CFRE composite laminates plates with 3 mm thickness CFRE plates were supported by special fixture to hold the plate as cantilever sheet, Figure 3 shows the test rig. Vibration signals were picked up by two CCLD accelerometers. Hence, the accelerometers were supported on the CFRE plate by mounting clips. While the acoustic signal picked up by one microphone. The microphone was separated by 5 mm from the CFRE plate. Excitation was performed using impact hammer with a force transducer. Acoustic and Vibration signals were acquired and processed using pulse analyzer LAN-XI and pulse lab shop software. The fusion process was carried out, using post-processing software

3. Results and Discussions

The free vibration technique used to identify the natural frequency of structures, furthermore determination their mode shapes. In the current investigation, damping capacity is another dynamic property used to identify the damage or crack at CFRE. The CFRE plates were exited using impact hammer. Consequently, the vibration waves transmitted through the plate to accelerometers, at the same time the microphone detects the sound wave resulted from the impact action. The raw data is acquired in time domain for the three sensors at the same time as shown in Figure 1.

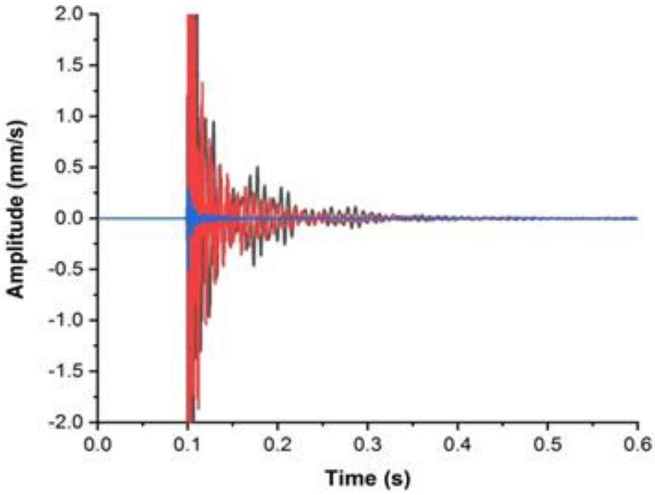

Fig. 1 Free decay in time domain for three sensors

3.1 Signal Process

The dynamic properties of the composite structure can be characterized by single sensor or multi sensors , depend on the volume and the area of the investigated structure .Hence , the large structures are need to use multi sensors in order to evaluate the dynamic response in accurate manner. Single sensor it may expose the measurements to some errors, principally if the structures have damage.

The multi sensor system used in the current work reveals that, at higher frequency ranges the frequency response function FRF of each sensor were changed as shown in Figure 2 and Figure 3. In contrast at low frequency range, the vibration signals were consistent. The output signal in time domain can be process by smoothing function; It smooth's the Trace data by replacing each Trace sample with the average value of specific number of data surrounding each sample. In addition, Divides the sum of the Trace values at each sample by the number of Traces, and stores the result in a single Trace. Fast Fourier Transform (FFT) to simultaneously transform all Traces in a time domain of the input data into their equivalent frequency domain (frequency spectrum) or frequency response function FRF representations. The data collected form the three sensors were fused in one clear spectrum to represent the accurate response during measurement as shown in Figure 4.

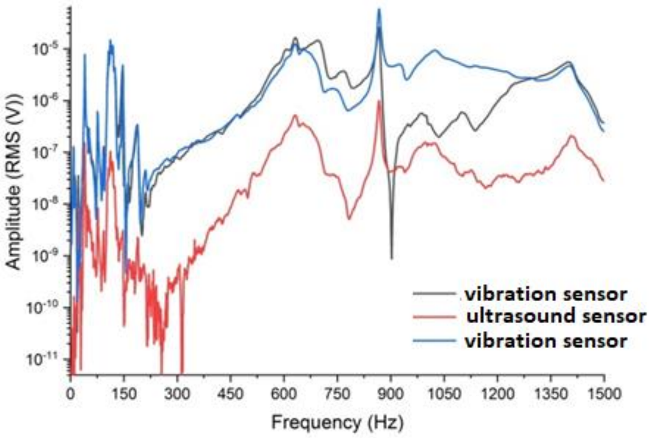

Fig. 2 FRF of the three signals for undamaged CFRE plate.

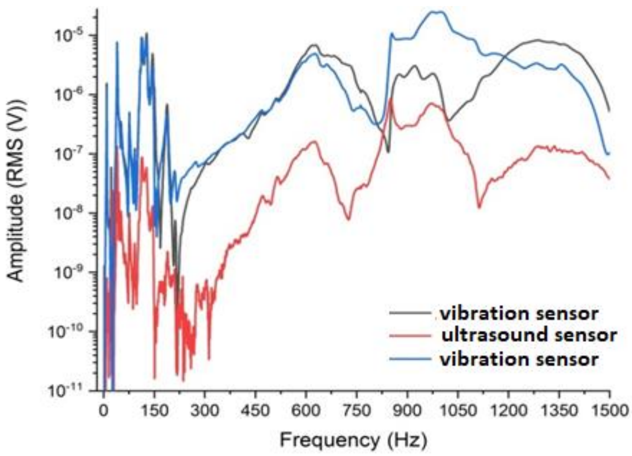

Fig. 3 FRF of the three signals for damaged CFRE plate

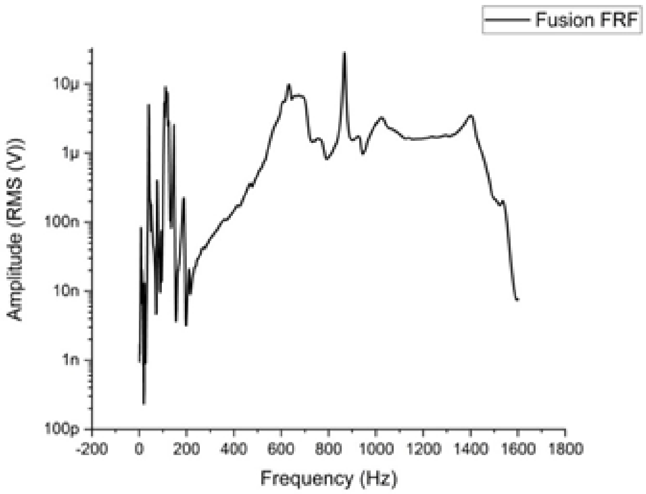

Fig. 4 FRF of fusion data for three sensors

3.2 Dynamic Properties of CFRE plate

In the current investigation, there are two main parameters were identified; Eigen frequencies and damping ratio. The natural frequency and damping ratio were precisely measured and calculated using free vibration (impact hammer test) and verified by ME 'Scope software (Vibrant Technology, Centennial, USA). Half power band width method was chosen because of the frequency spectrum have many modes, while logarithmic decrement method results only one mode. Equation 1, represent the classical form of damping ratio[25], the approach applied with assuming that the damped frequency is approximates equal to undamped frequency. Figure 5 show calculation method.

$2\zeta=(f_b-f_a)/f_n$ (1)

Where; ζ damping ratio, fn natural frequency, fb-fa bandwidth frequency

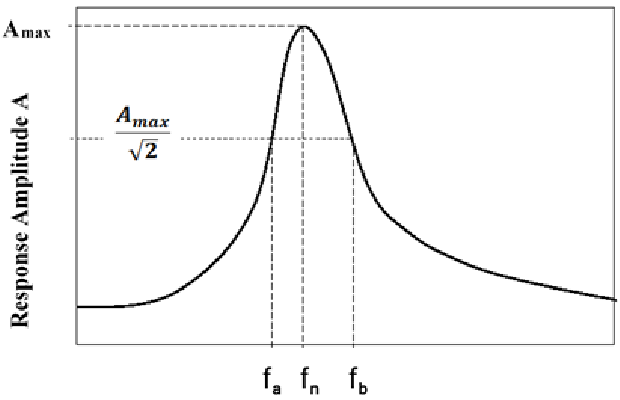

Fig. 5 Half-power bandwidth methods

CFRE Undamaged plate was characterized by a low damping ratio at the first mode, as remarked in the previous table. Furthermore, most of the resonance modes were lower than the damaged plates. The natural frequencies at the first mode were not having a significant change. Damaged CFRE was characterized by the high damping ratio compared with undamaged plate. The damage orientation in 0o and 90o have different signatures due to the position of the impact force exited the CFRE plate. In contrast, 45o damage orientation is not influenced by the direction of the impact force during free vibration test , the orientation were demonstrated as the following sequence 1, 2,3 and 4 for the undamaged , 0, 45 and 90 respectively . The Natural frequency at low frequency range or at the first mode in all the experimental models has the same value, but in higher modes the damage can be revealed, as shown in Figure 6.

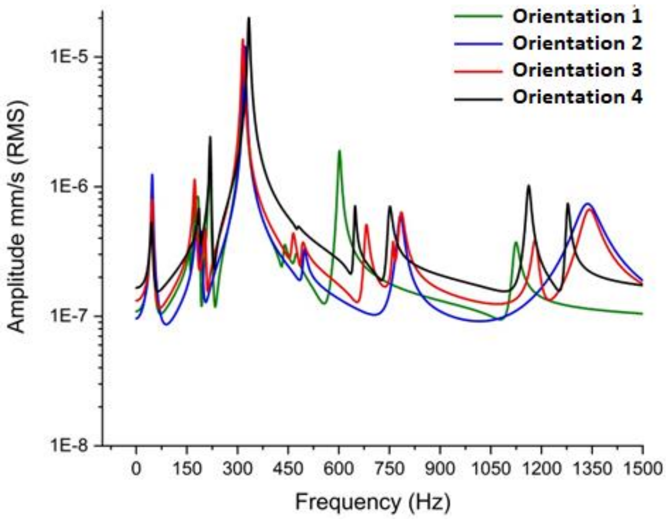

Fig. 6 Fused FRF for different CFRE damage orientation with respect to the undamaged CFRE plate

4. CONCLUSION

The fused analysis showed precise results in both time and frequency domain. Multi accelerometers sensors in addition to using one or more microphones for measuring damage occur in CFRE were efficient to detect the structural damage. The first mode natural frequency change is not reliable to detect the damage in CFRE structure, in contrary higher modes can detect the damage or cracks. Damping ratio effectively helped to detect defects and damage even in the first mode natural frequency. Fused FRF gave more clarity to the results. Hence, it turned out undamaged CFRE has fewer fundamental frequency modes compared to damaged plate.

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