CFRP STRENGTH MEASUREMENT BY ACOUSTO-ULTRASONIC TECHNIQUE

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ABSTRACT

SWF criterion values for CFRP specimens (10 mm thickness) with a variety of strength characteristics have been calculated. Strength values are determined by destructive flexural testing methods. Correlation-regression analysis of the data obtained is carried out. Correlations of SWF criterion and flexural strength are plotted. Fallibility of strength characteristics determination by acousto-ultrasonic technique and established correlations is estimated.

Key words: carbon fiber reinforced plastics (CFRP), acousto-ultrasonic technique, physicomechanical characteristics, flexural strength, stress wave factor (SWF).

1. Introduction

Acousto-ultrasonic technique (AU) has been widely applied since the 1970s. It is used for nondestructive evaluation (NDE) of flaws and physical characteristics that affect the mechanical properties and relative strength of composite structures (such as filament-wound pressure vessels), adhesive bonds (such as joints between metal plates), and interlaminar and fiber/matrix bonds in man-made composites and natural composites (such as wood products) [1].

The method is named due to strong resemblance of received AU signals to acoustic emission (AE) signals. Moreover AU method combines aspects of AE signal analysis with ultrasonic materials characterization methods [2].

AU differs from the usual ultrasonic methods primarily in the nature of the received signal. Instead of attempt to have well defined wave propagation paths, as in flow detection, AU requires that the received signal be the result of multiple interactions with the material microstructure. An objective is to produce stochastic wave propagation. In fiber reinforced plastics this means that multiple, reflected, scattered and mode-converted waves form the signal that arrives at the receiver [3]. The typical highly modulated complex output signal is illustrated in Fig.1. This AU signal is a rich source of information that carries the integrated imprint of material properties, microstructure and diffuse flaw population but its analysis is quite difficult. The major problem in AU signal analysis is to isolate and quantify the information contained in simulated stress-wave signals. This is achieved by calculating a quantity called the stress wave factor (SWF). There are many ways to define and calculate the SWF. Several of them are as
follows: peak voltage, ringdown count, weighted ringdown, voltage integral, power spectrum, spectral moments, ultrasonic spectroscopy methods etc.

![AU signal](image)

Fig. 1: Typical AU signal received in CFRP plate 10 mm thick

New SWF calculation method called “integral of optimal spectrum” (IOS) was suggested and proved to be efficient in FSUE “VIAM” [4]. Useful signal spectrum information is used more efficiently and minimized structural features influence by using this method. IOS includes the material damage acoustic characteristic calculation procedure. This characteristic was named “weighted spectrum function”. Signal spectrum changes information due to structure changes is stored in this function. And as the result weighted spectrum function stores physicomechanical material properties changes information.

FSUE “VIAM” is mainly carrying out fiber reinforced plastics (FRP) strength properties definition researches by using plotted correlations of SWF and strength characteristics [5].

2. Researches

The research into CFRP specimens with production and service defects is presented in the report. Specimens (plates) with dimensions of 220x220 mm and thickness of 10 mm were made by autoclave and hydraulic press technology. The plates have a 0°/90° lay-up scheme. As a result two specimen groups with different strength characteristics values were obtained. The specimens of the first group contain production defects only and the specimens of the second one contain both production and service defects. At first nondestructive testing by AU technique was carried out. About eleven AU signals were recorded for each plate. The distance between two 0.5 MHz ultrasonic transducers was 118 mm. Then SWF values were calculated by IOS method for each signal. After it all specimens were cut to 150x20x10 mm dimension specimens and destructed by flexural testing method to have flexural strength values.

Correlation-regression analysis of the data was carried out and two regression equations obtained [6]:

\[
\text{SWF}_1 = 3509 - 5.251\sigma; \\
\text{SWF}_2 = 10094 - 16.563\sigma;
\]

were:
\( \sigma = \text{flexural strength.} \)

Two correlations of SWF criterion and flexural strength in accordance with equation (1-2) are plotted in Fig.2-3.

![Correlation of SWF and flexural strength for specimens group containing production defects only](image1)

**Fig. 2**: Correlation of SWF and flexural strength for specimens group containing production defects only

![Correlation of SWF and flexural strength for specimens group containing both production and service defects](image2)

**Fig. 3**: Correlation of SWF and flexural strength for specimens group containing both production and service defects

In both cases we have inverse relations. The increase in the flexural strength values causes the decrease in SWF values. Correlation coefficients are -0.849 and -0.746. As it can be seen, correlations of SWF criterion and flexural strength are obvious enough.

95% confidence boundaries were plotted for each correlation (Fig.3-4). True correlation curve with the probability of 95% falls within the internal confidence boundaries. All possible individual SWF values for the examined strength range with the probability of 95% fall within the external confidence boundaries.
Fallibility of strength characteristics measurement by AU and established correlations was estimated. It is up to 15%. Thus, plotted correlations of SWF criterion and flexural strength can be applied to flexural strength estimation of flat CFRP aircraft structures 10 mm thick and with 0°/90° lay-up scheme. Like some other methods [7] this strength estimation technique can be widely adopted for different FRP types with different lay-up schemes.

3. Conclusions

CFRP specimens 10 mm thick and with 0°/90° lay-up scheme flexural strength measurements with the fallibility 15% were carried out at FSUE “VIAM” NDT laboratory by using plotted correlations. In spite of the fact that IOS method applied allows us to use signal spectrum information more efficiently and minimized structural features influence in
comparison with other SWF calculation methods, there are still some problems of the stable acoustic contact. It can directly influence testing results reproduction during the service. Our specialists are working on this problem now. It is noteworthy that in the case of changing the structure materials, thicknesses, lay-up scheme, geometry, production conditions new correlations plotting is necessary. Thus, the AU technique applied for CFRP strength measurement is an effective tool for parts and structures quality monitoring and is expected to be improved by VIAM.

4. References