1.10.27. DIAGNOSIS OF PHYSICAL AND MECHANICAL PROPERTIES OF CONSTRUCTIONAL CARBON FIBER REINFORCED PLASTICS (CFRP)

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The most pressing problem of improving the reliability of the air-ship equipment is the problem of improving its quality as the main indicator for assessing the reliability of high-duty assemblies. The control of the reliability of components and equipment assemblies has gained considerable importance these days. It depends not only on the material properties but also on its latent structural inhomogeneities that lead to variation of physical-mechanical characteristics of the material from the nominal values.

In VIAM there has been developed a new research field to diagnose physical and mechanical properties and composition of polymer composite materials to determine elastic and strength properties, porosity, density, content of matrix and filler, the degree of polymerization of CFRP matrix in the airframe and other high-duty products by the laser-acoustic method of ultrasonic control by using the correlation equations. Their parameters are amplitude, temporal and spectral characteristics of acoustic signals that are defined directly in the construction without destruction.

Research and development were held to find crucially new informative parameters of CFRP diagnostic properties that can be determined with high accuracy and reliability in the details or CFRP constructions without their destruction, as well as to solve the problem of diagnosis parameters complexation to determine stronger correlations of complex diagnostic parameters with the CFRP defined characteristics. The main criteria for selecting a single or complex parameter in the diagnostic evaluation of physical-mechanical characteristics and CFRP composition is the correlation coefficient (or correlation ratio), and the reliability criterion of this factor.

Use of laser excitation of elastic fluctuations impulses of no more than 0.05 ms allows for spectral analysis of sensed acoustic signals in a wide frequency band from 0.1 MHz to 10 MHz, which allows to increase accuracy and reliability of diagnostic properties of CFRP by non-destructive method.

VIAM has developed a technique for determining CFRP porosity by laser-acoustic method of ultrasonic monitoring. Structural noise energy W is used as a diagnostic parameter of material porosity, which is determined by the spectral characteristics of ultrasonic oscillations impulses: $W = \varphi[S(f), S_0(f)]$, where $S(f)$ – impulse spectrum, scattered in the opposite direction, $S_0(f)$ – impulse spectrum reflected from the upper surface of the object under control (OC), f – frequency.

The energy of the noise component of back-scattered acoustic signal is best correlated with the material porous and that is why this characteristic has been chosen as the diagnostic parameter. CFRP porosity is determined by the previously established correlation connection of volume pores content Vp with the energy value W of the structural noise $Vp = \varphi(W)$. The content of CFRP fiber in CFRP and CFRP density in accordance with the established correlation with the diagnostic parameters is determined only at low porosity (from 0% to 1%). When the material porosity is more than 1%, the error of determination of reinforced fiber volume the content in the CFRP and the CFRP density increases, because the increasing number of pores in the material affects more and more results of determining diagnostics parameter. When the material porosity is more than 2% the definition of the CFRP density by the proposed method requires adjustment.

The main diagnostic parameter, speed c of ultrasonic oscillations passing impulse in CFRP is defined programmatically by the time Δt of signal passing and thickness h of the OC wall $c = 2h/\Delta t$. In the zone of control thickness h of the CFRP construction wall is determined by a thickness measurement instruments, ultrasonic thickness gages or by the construction design. CFRP fiber content is determined by the determined correlation of mass fiber content with the core diagnostics parameter $M_B = \varphi_1(c)$, and the CFRP density ρ is determined when the CFRP porosity of is not more than 1% by determined correlation of the material density with the same diagnostic parameter $\rho = \varphi_2(c)$.

With the introduction of CFRP in large integrated constructions a need of prior details prepressing by the material heating emerged, and in this case the binding polymerizes a bit. The excess cure of the prepressed subproducts of the acceptable size leads to the integrated construction strength connections weakening. To measure the polymerization degree of the CFRP matrix the main diagnostics parameter is determined. It is the joint parameter b_1 equal to the signal weakening and the time of its passage through the controlled material in the direction of its thickness. The polymerization degree of the matrix β in the CFRP OC is determined by the schedule based on the established correlation of the main parameter b_1 with the matrix polymerization degree β with the material porosity $Vp \leq 1\%$ or by the equation this regard $\beta = \varphi(b_1)$.

Mechanical as well as physical CFRP characteristics are mainly determined by the main components mechanical and physical characteristics, their ratio and the material porosity. Basic acoustic material characteristics are also determined by these factors - speed and attenuation of ultrasonic oscillations, which can be determined during the non-destructive testing. CFRP strength properties in the construction are determined by the established correlation of the joint diagnostics parameter b_2 with the strength τ_{mov} of the material at the interlayer shift $\tau_{mov} = \varphi_1(b_2)$ and the material strength σ_{pres} at the compression $\sigma_{pres} = \varphi_2(b_2)$, where b_2 is the joint diagnostic parameter equal to the ratio of k coefficient to the time Δt of its passing in the direction of construction wall thickness. The coefficient k is determined by the program method using the signals amplitude characteristics and is the counter value of the signal attenuation in the material when it passes through OC thickness.

Relative error of determining the porosity of CFRP by non-destructive method for is no more than ±10%, fiber content in the CFRP by weight is no more than ± 4% and CFRP density is no more than ±1%. Relative error of the method of defining CFRP strength at the shift or compression does not exceed ±8%.

Thus in the diagnostics of polymer composite materials there will appear a new approach to problems solving based on ultrasound laser excitation in the OC and on the spectral analysis of ultrasonic oscillations impulses in the OC that bear information on the structure and physic and mechanical material properties. Using laser excitation of elastic oscillations gives the possibility to get very short impulses with a broad spectrum and hold the analysis of ultrasound attenuation in a sufficiently wide frequency range, enabling to raise accuracy and reliability of diagnostics of the CFRP structure and properties by the non-destructive method.

As a result VIAM has developed control technologies. Also industrial technical guidelines for determining porosity, density, content of fiber and matrix in CFRP strength at interlayer shift and compression of uniaxial CFRP, the degree of matrix polymerization of the at various stages of integral structures manufacturing have been launched.