Prospects for the use of computed tomography for the control of integrated composite structures

Khaliulin V.I.¹,a, Batrakov V.V.¹,b, Iuferev R.B.²,c,*, Bezzametnov O.N.¹,d
¹Kazan National Research Technical University named after A.N.Tupolev - KAI, 10, K.Marx St., Kazan, Tatarstan, Russia, 420111
²Melytec LLC, Babushkina st. 3A, St.Petersburg, Russia, 192029
E-mail:* pla.kai@mail.ru,      b wwa@list.ru,      c roman.iuferev@melytec.ru,      d bezzametnovoleg@mail.ru

Abstract: Various designs of composite materials with a and the description of methods for their manufacture and control are given. The possibilities of computed tomography for the analysis of the internal structure of composite products are shown. A technique has been developed for determining defects and porosity in areas of complex geometry, volume filling ratio, evaluation of the quality of the surface of walls in closed cavities, as well as the quality of the metal-composite compound.

Keywords: Composite materials, transfer molding methods, preforms, integral structures, non-destructive testing, computed tomography, defect.

Introduction

One of the most important problems in modern aircraft industry is to ensure a high level of operational characteristics. The solution to this problem is impossible without the use of the latest composite materials and advanced manufacturing techniques. [1], [2], [3], [4]. A wide range of reinforcing materials and binders allows to obtain structures with desired properties and high weight efficiency [5], [6]. However, ensuring the stability of the unique characteristics of such structures is impossible without reliable control of the internal material structure. The most common method of non-destructive testing for aeronautical engineering is ultrasonic pulse echo monitoring [7], [8]. This method has a number of limitations associated with the need to locate the receiver and emitter directly in the vicinity of the studied structure. The most informative method of control is computed tomography (CT) [9] identifying the macro - and microdefects of the composite structure. CT enables full volumetric scanning of the object and reconstructing the crosssections at any plane of structure, opening up new possibilities for analyzing and saving time during industrial quality control.

Perspective composite structures

In order to increase the efficiency of composite structures a transition to complex integral parts takes place. Figure 1 shows the spoilers of an Airbus A-350 aircraft. The advantages of such structures include: weight reduction due to the reduction in the number of mechanical connections; cost reduction due to the exclusion of operations of fitting, drilling and assembling reducing the whole technological cycle. The development of technological methods for the manufacture of integrated structures is based on the principle of time-combined molding of all structural elements.
According to the complexity of manufacturing technology, all versions of integrated designs can be attributed to several groups. The first group includes open structures with access to any surface, their structural elements do not intersect. The most common types of structures are panels supported by longitudinal ribs - stringers, spars, walls (Fig. 2, a). The designs of the second group characterized by the presence of reinforcement elements in the form of spars, forming T-shaped zones.

A characteristic feature of the third group structures is the presence of nodal zones where three or more curvilinear planes or surfaces intersect. As an example, Figure 3 shows a wafer-type panel and a spar with an integrated bracket.
The next group of difficulty can be attributed to the structures containing closed cavities (Figure 4). Cavities are formed by intersecting skins, walls and ribs. The most important in the non-destructive testing of such structures is the analysis of the geometry of the internal walls of the closed space.

The fifth group includes frames and trusses made of tubular elements (Fig. 5). Ultrasonic non-destructive testing of those structures is complicated by the approach of the emitter and receiver in the zone of materials intersection.
The study of integrated composite structures by computed tomography

X-ray computed tomography (CT) has successfully entered the field of airspace composite materials. The output of a CT scan is the 3D model of the part. This model is used to perform accurate measurements of the entire workpiece without any form of contact or need to cut or destroy the part. CT also enables material inspection and identification of internal defects such as voids and cracks and can be used to identify delaminations when inspecting composite materials. Samples were scanned using a micro-computed tomograph X5000 (Fig. 6) manufactured and developed by North Star Imaging (NSI) (Rogers, USA). The X5000 is the most versatile system offered by North Star Imaging. The system boasts a large scanning envelope and excellent ergonomics for loading sizable objects while still maintaining the sensitivity to inspect even the smallest of items.

The microfocus X-ray source is a pumped type source (open type x-ray source) with spot size up to 500nm. The X-ray source voltage and current were set at 190kV and 30μA. The exposure time was 375ms per radiograph. efX-ct software was used for tomographic reconstruction and Volume Graphics software was used for 3D visualization and analysis.

The study of the internal structure was carried out on various types of integrated composite structures. In each case, a specific task was solved. The analysis of the T-shaped zone of the transition between the spar and plating of the aircraft wing mechanization (Fig. 7). The highest concentration of
defects in such structures is observed at the place of filling the cavities with carbon between the inner and outer layers of the T-zone.

Along with an increase in the composite structures degree of integrity, nondestructive control of the possible defect concentration locations is complicated. Those places include T-zones in different planes, the intersection of layers of carbon cloth. (Fig. 8, a). Figure 8b shows an element of wing mechanization - an interceptor with integrated hinge fittings.
To determine defects in the metal-composite connection zone, the hinge assembly with an integrated sleeve is of the greatest interest (Fig. 9).
The study of the wall geometry in closed cavities of integral structures is an important task. This is due to the inability to visually monitor the final wall surface, and as a result, the calculation of the final bearing capacity and fiber filling ratio. To demonstrate this kind of problem, an enhanced element of wing mechanization with an integrated hitch assembly was selected (Fig. 10). The manufacture of this design includes the use of non-removable embedded elements in the form of foam Rohacell.
Reinforced interceptor with an integrated hitch assembly.

On the example of X-shaped bar of the spacecraft power structure (Fig. 11), the analysis of porosity in the intersection zones and the actual orientation of the fibers was carried out.

Summary

Feasibility of computed tomography (CT) for accurate nondestructive measurement of the manufacturing defects including wrinkles and porosity is illustrated. CT can become a powerful diagnostic tool and enable the subsequent ability to predict part capability and remaining useful life. Such abilities are required to enable the condition-based composite part utilization.
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