Study of the Destruction of Carbon Composite Panel using High-Speed Jet of Liquid

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Abstract. The article discusses the task of assessing the damage of carbon fibre plastics arising from the destructive effect of radiation using the diagnostic capabilities of ultra-jet technology. A technique is proposed for determining the thickness of a carbon fibre package that can protect an imaginary interior from the negative effects of radiation waves. As informative diagnostic parameters in the method, the geometrical dimensions of the cavern created on the surface of the sample following exposure to a high-speed jet of liquid (water) are used. Based on the results of the experiments, it was found that a decrease in the depth value indicates a decrease in the penetrating effect of radiation and the destruction of the binder in the structure of the composite material.

1. Introduction

In recent years, there has been a tendency to expand the use of Polymer Composite Materials (PCM) in the construction of spacecraft. Firstly, such interest in introducing composite materials in Russia and abroad is associated with their physical and mechanical properties, which can significantly (up to 40-50%) reduce the weight of the product [1-3]. It should be noted that some PCM have a lot of special properties. So, for instance, carbon plastics are characterized by such properties as: high strength and stiffness, wear resistance, resistance to the negative effects of aggressive environments, low thermal expansion coefficients, electrical conductivity, the ability to resist fatigue loads under static and dynamic loads, etc [2, 4-6].

Currently, carbon fibre reinforced plastics are widely used in the design of spacecraft and launch vehicles for the manufacture of fairings, antenna bodies, electrical wires and cables, etc. Nevertheless, the problems of the behaviour of carbon composite materials under the influence of adverse outer space conditions were not yet sufficiently studied [7]. The reasons for this are associated with the lack of well-developed methods for diagnosis and testing, and engineering methods for the existing control and diagnostic technologies [8-11]. Because of the need to ensure high levels of reliability of critical space products, extending capability for monitoring, diagnostics and testing is an urgent scientific and technical task. This prompts us to formulate the goal of the study, which in the present work is formulated as the development of an engineering technique for ultra-jet PCM diagnostics for assessing carbon fibre damage [12-15].

To assess the performance of a particular spacecraft design, it is necessary to evaluate and identify the totality of factors affecting the product life and its physical and mechanical properties and other
characteristics. Among these factors, the following can be singled out: cosmic radiation fluxes with high-energy electrons and ions, cold and hot cosmic plasma, electromagnetic solar radiation, probable meteoroid impact [13, 15]. Each of these can not only disable working equipment and devices, but also reduce the strength characteristics of PCM structures as a result of various physical and chemical processes, leading, for example, to embrittlement of the binder and deterioration of adhesion in the binder-fibre structure [10, 16-17]. Moreover, some types of exposure, such as cosmic plasma and ultraviolet solar radiation, as a rule, affect the surface and subsurface layers of the material. This is particularly the case for the above mentioned high-energy charged particles [20-23].

These circumstances indicate that the existing variety of unfavourable factors of outer space, the variability and cyclic variations of the space environment, as well as the complex processes accompanying their influence and course, for example, wide spectra of corpuscular and electromagnetic radiation of various periodicities, significantly complicate the development of effective methods for predicting the resource and assessment of controlled quality parameters of PCM [16, 17]. In this regard, taking into account the experience in the development of technologies for Ultra-Jet Diagnostics (UJD) of materials, an attempt was made to adapt existing methods for diagnosing metallic materials and alloys with a high-speed fluid flow to the test sample [23-25].

2. The hypothesis of the study
The hypothesis of the study was the phenomenological position on the change in the parameters of hydro-erosive destruction of the surface layer of the sample exposed to radiation. As a result of the very likely embrittlement of the binder material, the propagation of cracks in it, and the decrease in adhesion with carbon fibre, a high-speed fluid flow will wash it out of the material volume, providing a deepening of the jet into the material thickness under conditions of low resistance to its dynamic high-energy impact. In this case, the parameters of surface hydro-erosion are the main informative data of ultra-jet diagnostics by which it is possible to judge the current state of the material, its degree of damage, internal defects [20]. Moreover, the defectiveness of the material can be either: present initially, associated with the imperfection of the manufacturing process; or acquired as a result of the negative influence of radiation.

3. Experimental technique
Figure 1 shows a schematic diagram of the UJD process, the implementation of which in this work was carried out on a machine for waterjet cutting Flow Mach 3 3131b (USA) at the Centre for Hydro-physical Research at Lomonosov Moscow State University.

![Schematic diagram of ultra-jet diagnostics with the composition of the main elements of hydraulic equipment.](image)

An engineering technique was developed to implement the idea of PCM UJD for assessing the level of damage/defectiveness. The first stage of this was the production of a batch of carbon-plastic panel samples in accordance with the standard technological process specified by the LLC Special Development and Technology Bureau “Plastic”. The samples were manufactured using carbon tape LU-P/0.1, impregnated with a binder ENFB, and layup (0°/45°/135°/90°/90°/135°/45°/0°). The
The resulting panel had the following properties: modulus of elasticity 59.166 MPa; tensile strength 263 MPa; and thickness 3.6 mm.

At the second stage, samples of 150 x 20 mm in size cut from the panel were collected in a bag and placed in the chamber of the industrial XT H 450 fluoroscopy and computed tomography system, see figure 2(b), to exert an exposure to radiation in accordance with the parameters presented in table 1. Preliminarily, the samples were collected in a bag, as shown in figure 2(a).

![Image](image.png)

Figure 2. UJD implementation scheme:
(a) – 1st stage
(b) – 2nd stage

| №  | Voltage, kV | Current, μA | Experiment time (working time), min |
|----|-------------|-------------|-----------------------------------|
| 1  | 376         | 185         | 37                                |
| 2  | 360         | 185         | 37                                |
| 3  | 360         | 185         | 35                                |
| 4  | 300         | 100         | 5                                 |
| 5  | 310         | 105         | 37                                |
| 6  | 350         | 145         | 105                               |
| 7  | 375         | 185         | 74                                |
| 8  | 360         | 100         | 37                                |
| 9  | 360         | 100         | 37                                |
| 10 | 325         | 120         | 57                                |
| 11 | 300         | 105         | 14                                |
| 12 | 300         | 105         | 14                                |
| 13 | 300         | 105         | 14                                |
| 14 | 300         | 105         | 14                                |
| 15 | 300         | 105         | 14                                |
| 16 | 265         | 100         | 14                                |
| 17 | 380         | 200         | 26                                |

Following a series of test trials, the following diagnostic mode was selected by the experimental method: feed of the cutting head 7500 mm/min; water pressure 130 MPa; distance from the focusing tube cut to the sample surface 160 mm (figure 1). With the choice of these parameters, it was possible to ensure surface destruction of the binder without noticeable destruction of the fibre. An increase in pressure, a decrease in distance and a feed rate were observed penetrating destruction of the material with rupture and damage to the fibres (figure 3). When conducting experiments on the UJD, the authors assumed that, when moving away from the radiation source, the damage to the samples in the packet (see figure 2a), especially the binder, decreases.

The UJD parameters were selected as follows: 160 mm from the cut of the focusing tube to the surface of the sample (figure 1); the feed rate of the cutting head is 7500 mm/min; the working fluid
pressure in the hydraulic system is 130 MPa. The selection of these parameters was carried out empirically according to the criterion of not breaking through the sample and the formation of a local notch – a cavern.

Figure 3. (a) Carbon fibre samples on the substrate, and (b) areas for exposure to ultra-jet on the surface of the samples.

4. Experiment results

Figure 4 shows 3D images of hydro-caverns and their profilograms, measured after the experiment was carried out using a Keyence VHX-6000 digital microscope (Japan). Statistical processing of the results of measurements of depths of hydro-caverns made it possible to construct a dependence of their depth on the distance to the radiation source. Figure 5 shows this dependence. In the docking areas of the samples, the average values of the depth of the cavern were calculated.

5. Discussion

In total three samples of each type of material were examined. Table 1 shows the average values. The spread of values was less than 5%. The research demonstrates that the UJD method proposed has potential for implementation in production for the assessment of PCM damage in carbon plastics arising from the destructive effect of radiation using the diagnostic capabilities of ultra-jet technology. According to the results of simulation and accelerated tests, the control valve can be used to assess the influence of certain adverse environmental factors, such as climatic, various types of radiation, temperature, thermal cycling, alternating loads, and others, on material damage. Damage resulting from the action of a single or combination of factors can manifest itself in the appearance of various defects, such as delamination, pore formation or poor adhesion.

6. Conclusion

The UJD method has shown its versatility and flexibility in the example of solving various diagnostic problems of mechanical engineering, which made it possible to adapt the previously obtained results to assess the damage to carbon fibre panels and determine the depth of its penetration into the thickness of the package.

The proposed engineering method will allow to determine the rational thickness of the composite material, for example, according to the criterion of protecting the internal space from the negative effects of radiation, for example, protecting personnel working with radiation equipment, NPP rooms and other critical human life objects.

The method is distinguished by the breadth of possibilities for controlling the technological parameters of the UJD, which allows it to be used both for surface diagnostics and for studying subsurface layers of a composite material, the presence of defects, damage, and violation of adhesive bonds in them.

Because the method has a small but non-negligible effect on the surface layer of the material, this limits the site of application, which should therefore be focused on selective inspection of products, diagnostics of test specimens, and large structures for which this damage will not affect performance, reliability and resource.
1 – Profile of the cavern
2 – Section with tracing
3 – Profile.

**Figure 4.** Image of a cavern as a result of a study using a digital microscope.

**Figure 5.** Dependence of the depth of the cavern on the distance to the radiation source.

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