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Method of verification of performance of composite package for protection of thin-walled constructions against non-stationary one-sided loadings

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Method of verification of performance of composite package for protection of thin-walled constructions against non-stationary one-sided loadings

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Abstract. Computing-experimental method of verification of operability of composite porous package for protection of thin-walled constructions from non-stationary one-sided loadings is proposed. A set of explosive devices for generate loads of the required space-time distributions is described. Two new explosive devices for generation of low-pulse loads of microsecond duration with low difference in loading time at the surface of the tested composite constructions are considered. Time deformation profiles of glass-plastic cylindrical shell under low-impulse load of microsecond duration are given. It is received that use of wire or foil sensors for measurement of deformations give close results when the shell stage of deformation of glass-plastic thin-walled constructions is investigated.

1. Introduction

Present-day rocket and space equipment (RSE) operates under conditions of possible mechanical effects of radiation [1–3] and impact action of compact solids (bullets, fragments, soil particles, birds, etc) [4,5]. Both types of action cause transient deformations of RSE constructions and in some cases their subsequent destruction. When the construction is protected by a multi-layer porous package, the wave stage of deformation is generally not dangerous and destruction occurs at the shell stage. The presence of a protective package levels the peculiarities of mechanical action of radiation and impact action of bodies. As a result, it is reduced to the action of non-stationary one-sided pressure on the surface of the protected construction. It is very difficult to provide the protection of thin-walled constructions against this type of load and at least the justification of strength of the RSE is required in this case. Therefore, the development and verification of the method of confirming the performance of the multilayer package which provides protection of the RSE against non-stationary one-sided loading are relevant and of great practical importance.

There is no such method right now. This is due to the fact that the main attention of the RSE developers is aimed at the confirming of strength and performance of the construction under the action of operational loads. Therefore, the providing of protection against external effects is made at the final stage of construction development by introducing the protective packages into already designed product. This approach leads to the inefficiency of the RSE as a whole. Inefficiency is due to the obvious fact that non-stationary mechanical action is formed as a result of interaction of stress waves in both the construction and the protective package as well as at their boundaries. Therefore, only the joint consideration of the operation of both construction and protection package ensures the correctness of the results.

However, carrying out the experimental investigations on full-scale constructions with protective packages in the process of creating a new RSE is unacceptable in terms of financial costs. Multiple tests aimed at creating of effective protective package cause damage to the expensive constructions. Therefore, the accepted option is the use of crusher-panels or cylindrical model shells for experimental studies of the performance of protective packages. In this case, the question comes about how to transfer the results to full scale structures. For the shell stage of deformation such transfer is possible only with the help of numerical modeling methods and calculated data on deformation of the whole full scale construction. Then the development of a computing-experimental method is necessary. One variant of such a method is discussed in this article.

2. Logics of protection package verification method

As mentioned above, for a number of reasons we do not have the possibility to test the protective package located on the full-scale constructions of the RSE. However, the processes of deformation and destruction at the shell stage for the whole construction and its part may differ not only in quantity, but also in quality. In particular, the deformation and destruction of fragments of the cylindrical housing in the form of a jammed or a simply supported panel differ significantly from these processes for the housing as a whole at times comparable to the period of its oscillations. Therefore, it is proposed to determine the parameters of the load generated after the protective package at the wave stage with the help of crusher-panels protected by the examined package (at the wave stage the operation of the package is less dependent on which fragment is protected).

Specially designed aluminum crusher-panels together with fragments of protective packages are tested. Load parameters are the numerical solution of the reverse problem for the crusher-panel. Experimentally determined characteristics of the response of the protected panel-crusher serve as the initial data for this problem. The results of solving of the reverse problem are also tested experimentally on the panels without protection.

At the final stage of the investigation, the load parameters found from the solution of the reverse problem are used in numerical studies of deformation of the RSE construction. The role of the protective package at this stage is considered only as an attached mass and additional rigidity of the structure. Additional rigidity occurs if the package is undamaged earlier in wave processes. Note that the rigidity of the protective package can be neglected in many cases.

The main advantage of the described approach is the ability to carry out calculations of the full-scale construction without detailing of the processes in a protective package consisting of new composite materials. The deformation and strength characteristics of composites for wave stage deformation rates are generally unknown. In addition, the calculation of wave processes in multilayer protective packages containing porous layers is difficult and unreliable. But particularly these processes determine the parameters of the non-stationary load acting on the protected construction.

The proposed approach is applicable both in the case of mechanical action of radiation and in the case of impact action, if the impact cavity does not reach the protected structure. Small depth of the cavern takes place at small angles of the striker meeting with the outer surface of the protective package and ricocheting.

3. Method implementation

The numerical codes are required for modeling of the deformation under the effect of non-stationary loads generated by mechanical action of radiation and impact due to wave processes in the protective package, of the following thin-walled structural elements:

- composite orthotropic shells which are protected by a porous multilayer package;

Table 1. Explosive devices for reproduction of mechanical action of radiation.

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Type of explosive device	τ_p, μs	I_p, kPa s	Purposes (modeled actions)
Contact sector charge	1–10	0.8–5	uv or x-ray radiation
Contact light detonating charge	0.2–1	0.05–0.5	x-ray radiation
Equidistant surface charge	30–200	0.3–3	vl or uv radiation in air
Volume distributed charge	100–500	1–2	ir or vl radiation in air
Cumulative volume distributed charge	100–500	1–2	purpose 5
Multi-channel blast tube	50–200	0.5–2	purpose 6
Multi-channel blast tube with nozzles	50–200	0.5–2	purpose 7
System of the rotating charges	100–200	0.5–2	purpose 8

- elastoplastic crusher-panels;
- elastic cylindrical shell-models.

Corresponding mechanical-mathematical models and numerical codes were developed earlier [3, 6] and are used in the proposed method.

Methods of calculating of wave processes are also necessary to justify the adequacy of the proposed computing-experimental method when numerical modeling of wave processes is possible (data on mechanical characteristics of layers and numerical methods of modeling their behavior at high strain rates are available).

The presence of a set of explosive devices generating one-sided non-stationary loads together with a stand for tests of elastic-plastic crusher-panels and shell-models with or without protective packages is a necessary condition for experiments. The test stand shall be equipped with a measuring system allowing determining the parameters of the construction response to non-stationary loading. These construction response parameters are used to determine the characteristic of loads (pressure pulse duration and momentum) transmitted through the protective package. The capabilities [2] of explosive devices are shown in table 1 (τ_p is pressure impulse duration and I_p is pressure impulse; vl is visible light; purpose 5—distributed ir or uv radiation in air; purpose 6—pulse-frequency resonant action of ir or vl radiation in air; purpose 7—pulse-frequency resonant action of distributed ir or vl radiation in air; purpose 8—multiple action of radiation on high-temperature flows for initiation of engine surge). As can be seen from table 1, the presented set of modeling devices do not provide generation of low-impulse loads of microsecond duration with high simultaneous action on the RSE surface.

4. New explosive devices

The tape charge [7] and the controlled initiation charge [8] are the most promising of the explosive devices for generating of low-momentum pulse loads of microsecond duration.

The tape charge is made of explosive tapes which are placed on circular tubes, figure 1(a). Tubes are equidistant from surface of loaded object. This device generates loads with τ_p = 5–10 μs, I_p = 0.1–1 kPa s. Multipoint initiation system of explosive tape ends is used to ensure simultaneous loading of surface.

The charge with the controlled initiation is produced in the form of thin ($\leqslant$ 3 mm) shell from fibrous material. The shell has milled channels filled with plastic-bonded explosive, figure 1(b). Placement in channels offers a number of advantages over other methods of localization of explosive (for example, by solid layer or sectors on a porous substrate). Controlled initiation

(a) (b)

Figure 1. Gasdynamic devices for generation of low-impulsive loads: (a) tape explosive charge; (b) controlled initiation explosive charge.

is implemented by the method taken from the technology of generation of pressure of megabar level [9, 10]. This device generates loads with $\tau_p = 3$–$5\ \mu$s, $I_p = 0.05$–1 kPa s.

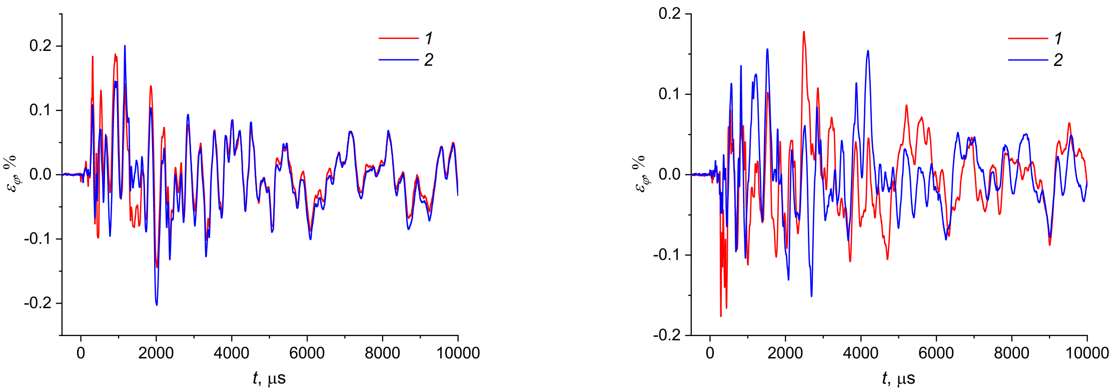
Note that the set of devices [1,2], supplemented by new developments, offers more capabilities. The use of this set is planned for testing of thin-walled RSE constructions for strength to thermal and mechanical actions of radiation and particles fluxes of different physical nature and impact of compact solids.

5. Fiberglass construction test results for shell stage

Strength tests of the fiberglass cylindrical shell ($h/R = 0.06$, $L/R = 3$) were done to compare the performance of various [produced by Central Research Institute for Machine Building (CRIMB), Russia, and produced by Zhonghang Electronic Measuring Instruments Co Ltd (ZEMIC), China] resistive strain sensors. The choice of fiberglass as a composite shell material is due to the fact that strain measurements on fiberglass give more reliable results than for many other composites. For example, organoplastic produced by means of filament winding [11] are characterized by substantial non-uniformity of structure. In this case, the correct measurement of deformations becomes very problematic. One-sided and non-stationary load was generated by a controlled initiation explosive device. Angular dimension of the loaded cylindrical surface was 115° and pressure impulse was $I_p = 0.4$ kPa s.

Shell was firmly connected with two steel bottoms by means of bolts and steel straps. All construction was installed in a ballistic pendulum to measure the pressure impulse. The shell at the ballistic pendulum with the explosive device is shown in figure 2. Strain sensors were glued at an inner surface at points (φ is a circular coordinate from the center of a loaded surface): $\varphi = 0°$, 90° and 180°. In a point $\varphi = 0°$ the wire sensor KB-10-200 (produced by CRIMB) was paired with the foil sensor BF350-3AA (produced by ZEMIC). The results of comparisons of circular deformations measured by different sensors are shown in figure 3(a). It can be seen that

Figure 2. Fiberglass construction test: the shell with explosive device in ballistic pendulum.



(*a*) (*b*)

Figure 3. Fiberglass construction test: (*a*) comparison of circular deformations at $\varphi = 0°$ measured by the KB-10-200 (*1*) and BF350-3AA (*2*) strain sensors; (*b*) circular deformations vs time t, $\varphi = 90°$ (*1*) and 180° (*2*).

wire and foil sensors in one experiment register deformations that differ by 5–15% relative to each other. Time dependences are also consistent with good accuracy, but the signal of sensor KB-10-200 is noisier. Data of strain sensors in points $\varphi = 90^\circ$ and 180° (wire sensors KB-10-200 were used at these points) are provided in figure 3(b).

Note that the load parameters were insufficient to significant destruction of the test shell (cracks, delaminations and spalls were not observed). Also, the relatively small (up to 0.2%) deformations did not result in delamination and separation of strain sensors.

6. Conclusions

A computing-experimental method of confirming the performance of a multilayer porous package for protection of the thin-walled composite RSE constructions is proposed.

Original explosive devices for generation of low-momentum pulse loads of microsecond duration with small time diversity for the loading of composite constructions are designed and tested.

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