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Design of the corrugated-core sandwich panel for the arctic rescue vehicle

S.A. Lurie [a,b,*], Yu.O. Solyaev [a,c], D.B. Volkov-Bogorodskiy [a], V.M. Bouznik [d], A.A. Koshurina [e]

[a] Institute of Applied Mechanics of Russian Academy of Science, Leningradsky prt 7, Moscow 125040, Russia
[b] Dorodnicyn Computing Center of Russian Academy of Science, Russia
[c] Moscow Aviational Institute, Russia
[d] All-Russian Research Institute of Aviation Materials, Russia
[e] Novgorod State Technical Univercity Named After R. E. Alekseev, Russia

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ABSTRACT

This paper represents the methodology of analytical design and the selection of the optimal geometry of sandwich panels made of glass fiber reinforced plastic (GFRP) with a thermal insulating core and external heat shielding coating for the rescue vehicles operating in Arctic. The proposed methodology is based on the use of analytical solutions for the problems of thermal physics and structural mechanics for a preliminary assessment of the heat shield and strength characteristics of the panel. In the design process, we solve the optimization problem with objective function of the mass per unit area. Optimization constraints are formulated based on the conditions of thermal protection in a steady-state and transient cooling and heating conditions, strength and local and global buckling under shear, compression and bending of the panel. It is shown that the optimization could be limited by the strongest conditions, which are thermal protection at low temperatures and the condition for the web plate local instability under impact loading. It is shown that the use of a thermal barrier coating inevitably entails significant and not always allowable increase in structural mass, the panel thickness and strength safety factors.

1. Introduction

At present, owing to the expansion of research and development in the Arctic areas, connected inter alia with the objectives of the oil industry, there is an acute need to develop rescue vehicles that are capable of operating under extreme Arctic conditions [1–3]. The used materials and the structural schemes of rescue systems (boats, rafts etc.) must ensure their reliable operation under conditions of prolonged exposure to extremely low temperatures, high humidity, seawater, intensive mechanical stress associated with high-launching or blows on the ice, etc. Additional design requirements are imposed by the specifics of rescue operations conducted in emergencies on oilrigs: the used rescue equipment must ensure the survival of the crew in movement at the scene where oil is burning. It is desirable to ensure maintainability of the rescue vehicle, as the cost of purchasing a new piece of equipment is relatively high. In addition, there is a limit on the mass of the structure associated with the limited possibility of placing the rescue boats on the transporting ships and drilling platforms.

The purpose of this work is to develop and to test a design technique of the rescue vehicle cladding panels intended for use in arctic conditions. An example of the developed vehicle is shown in Fig. 1. We consider a flat panel with corrugated core, with the thermal insulation fiber material located inside and protected by a thermal coating on the outside of the panel. This panel design allows us to provide thermal protection of the inner space of the construction and to use the panel as a construction load bearing element under conditions of intense heating. The presence of an external thermal protective layer allows us to use the GFRP with relatively low operating temperature as a structural material. This ensures the gain in weight in comparison with similar metal structures [4], which can be alternative solutions for creation of the types of vehicles under study. Another alternative is to use the seawater irrigation system instead of the thermal barrier coating. In this case, the surface of the polymer composite plating of the vehicle must be continuously washed by water to avoid overheating. The disadvantage here is the requirement of high reliability and complexity of such an irrigation system, including traffic conditions on ice.

* Corresponding author at: Institute of Applied Mechanics of Russian Academy of Science, Leningradsky prt 7, Moscow 125040, Russia.
E-mail address: salurie@mail.ru (S.A. Lurie).

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Fig. 1. General view of the rescue vehicle.

The methods of analytical and numerical modeling of sandwich panels with a corrugated core are widely represented in the literature devoted to the analysis of structures made of composite materials. One of the first studies in this field was the work [5] where the analytical method for calculating the effective stiffness characteristics of the panels with corrugated core was presented. Comparisons of the results of analytical predictions [5] with experimental data and numerical simulation results were presented in a number of works [6–9]. It was shown that analytical techniques can accurately predict the bending and in-plane stiffness of corrugated core panels [6–9]. It was shown that corrugated cores of a triangular shape have the highest shear rigidity [6] and the influence of shear can be neglected in such sandwich panels [8]. Determination of the effective thermoelastic characteristics of sandwich panels based on analytical asymptotic homogenization method was presented in [10–12].

To simulate the stress state and stability of the sandwich structures, the models of rods, plates and shells of varying complexity can be involved. In such calculations, the equivalent stiffness characteristics of panels are used, which are determined on the basis of the above-mentioned analytical or numerical methods, or experimentally. One of the most comprehensive reviews of existing methods of calculation and optimal design of sandwich panels is contained in the work [13]. A recent monograph [14] presents various classical models and high order theories of sandwich plates and shells, and provides a detailed overview of the problems of sandwich structures fracture mechanics. Optimization of sandwich panels with various types of cores under static and impact loading and heating was provide in number of work (see [15–19] and references therein). It was found among other things that the triangular shape of corrugation is optimum for the panels under low low-velocity impact [19].

Analytical and numerical methods for the optimal design of sandwich panels are widely used in the development of different vehicles, operating under conditions of mechanical and thermal influences [20–33]. The work [20] one of the first proposed a numerical method to optimize the geometry of the panel with corrugated core for integrated thermal protection system (ITPS) of reentry space vehicles with the requirements of minimum weight, thermal protection and durability. Analysis of the results showed that maximum temperature of the inner surface of the panel and the restrictions on the local stability margin under the action of thermal stresses should be used as the main optimization criteria for the ITPS panels. Approach for the ITPS stress-strain state modeling based on the first-order shear deformation theory has been presented in [22–24]. Optimization of different modified and lightweight types of ITPS were provide in [26–32].

The distinctive feature of the design methodology proposed in this paper consists of the extensive use of analytical modeling for pre-selection of sandwich panel geometry during mechanical and thermal calculations. For the development of design technique, we pre-formulated a list of requirements for life-saving appliances under consideration (Fig. 1), operating on oil drilling platforms. We defined a set of estimated cases, characterized by the level and type of the external mechanical and thermal influences. On the basis of analytical models of structural mechanics, thermal physics and mechanics of composite materials, the optimization technique for the panel geometry was developed. The objective function in the optimization process is the mass per unit area of the panel, which must be minimized. As constraints, we used conditions for thermal protection, thermal stability and strength of the panel. All the conditions are formulated in a closed analytic form that allows us to carry out the optimization procedure in the shortest time.

A peculiarity of the realized calculations is the presence in the structure of the panel of low-strength thermal-protective coating layer. Therefore, in the preliminary design, it is necessary to not only take into account the conditions of local buckling, but also the strength conditions that are usually not considered during design of similar panels with corrugated core. Finite element simulation in the Ansys is used to verify the optimization results, as well as to estimate the strength and stability of the panel elements under unsteady heating and under dynamic loading. In estimation of the strength and stability of the panel in bending, we use the Kirchhoff-Love plate theory. Typically, modeling of sandwich panels should involve higher-order theories [13,14,34], but in the preliminary design-to accelerate the optimization process-the classical theory can be used as the first approximation [13]. We also noted that the geometry of the panel found as the result of optimization contains a triangular core, for which the using of the classical theory of plates gives the smallest errors [22].

2. The initial data

2.1. The structure and properties of the materials of the panel layers

We consider a sandwich panel consisting of two faces separated by a corrugated core (Fig. 2). The thickness of the faces (load