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# INVESTIGATION OF THE SERVICEABILITY OF THE HEAT SHIELD OF THE ORBITAL AIRCRAFT "BURAN" UNDER THE CONDITIONS OF RADIANT HEATING ON SOLAR PLANTS

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*We have investigated the serviceability of the heat-insulating tiles of the orbital aircraft "Buran" under radiant heating on an SGU-7 solar plant with a mirror concentrator 5 m in diameter. Cycles of aerodynamic heating with a duration of 20 min were simulated. For the total number of cycles for different materials from 20 to 85, the efficiency and serviceability of TZMK-type materials with different coats have been corroborated. The results obtained agree with the test data obtained on gas-dynamic (power consumption 1 MW) and radiation (250 kW) test beds, which enables such tests to be recommended for use at preliminary stages in power-saving and ecologically harmless solar furnaces.*

In recent years, due to space research and the exploration of space the role of thermal radiation as the basic factor of heat removal, which received the name radiative cooling, has greatly increased. Its role is particularly important in operating recovery cosmic systems. Normal temperature conditions for many heat-releasing elements of these systems exposed to the high temperatures of fuel combustion products of liquid-fuel rocket engines (LR) and aerodynamic heat were provided only due to the effective use of radiative cooling. Besides the surface temperature, the radiative cooling intensity is also determined by the integral emissivity factor. The latter depends, in turn, on many parameters, such as the properties of the material, the structure and temperature of the surface, the direction of propagation of radiation, etc. [1, 2]. Unlike the integral one, the spectral emissivity factor $\varepsilon(\lambda)$ depends relatively weakly on the radiating surface temperature but sharply changes with the wavelength $\lambda$.

This principle forms the basis for protection against radiation thermal flows. Thus, to protect the recovery spaceship "Buran" against solar radiation and aerodynamic heating, mainly two types of coats applied to a high-porosity fibrous material are used. The white coat of the upper part of the vehicle, having a low emissivity factor in the visible region of the spectrum and a large $\varepsilon(\lambda)$ in the infrared region, is used to protect against solar radiation flows, and the black coat with a high emissivity of ~0.8 effectively radiates heat obtained due to the aerodynamic heating of the lower part of the space vehicle [3].

The heat shield of the recovery orbital aircraft (OA) "Buran" should sustain multiple, relatively long heating cycles (up to 20 min). If we take into account that the size of one heat-insulating tile of the OA is $150 \times 150$ mm, as a rule, modeling of such conditions on gas-dynamic beds with electric arc gas heaters requires considerable expenditures of energy. At the same time, the glassy coat of the heat-insulating tile is practically not destroyed due to the erosion-mechanical action of the gas-dynamic flow, and in many cases it

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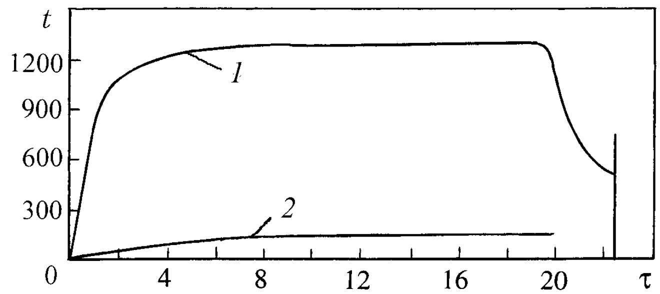


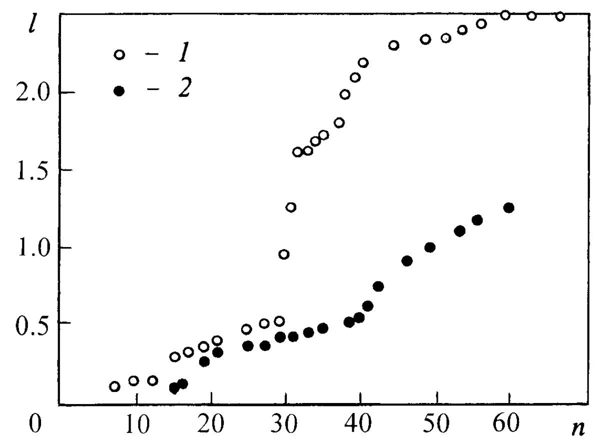


Fig. 1. The HIE surface (1) and substrate (2) temperature as a function of the heating time. $t$, $^oC$; $\tau$, min.

Fig. 2. The dependence of the material shrinkage ($l$) on the number of heating cycles ($n$): 1) panel 25005032044; 2) 25005042044. $l$, mm; $n$, cycles.

is enough to reproduce the required temperature of the surface and the cycle duration by using radiant heating. Of particular interest is the use of solar concentrators (solar furnaces), since they practically do not consume electric energy, are ecologically harmless in operation, and provide a chemically pure heat in the air atmosphere. Their high potentialities for studying the physicochemical properties and operating and technical characteristics of materials and coats at high temperatures have been confirmed by a large number of investigations [4, 5].

The serviceability of the heat-insulating tiles of the OA "Buran" was investigated on the SGU-7 solar plant of the Institute of Problems of Material Science of the NAS of Ukraine with a solar energy concentrator 5.0 m in diameter. The concentrator is the main part of the SGU-7 plant, which is also equipped with a sun-tracking system that ensures the continued presence of the model being heated in the focal region of the plant. To observe the behavior of the model surface being heated, a commercial telescope is used.

Tests were carried out for four varieties of a TZMK high-porosity heat-insulating material representing compositions of various densities from a hyperfine quartz fiber. The outer and side surfaces of the heat-insulating element (HIE) have erosionally moisture-proof coats. The basic components of the black coat are quartz glass and silicon tetraboride providing a high emissivity factor. The HIE specimen for testing under the conditions of one-sided radiation heating was a 150 × 150 mm tile pasted through a damping substrate on a metal panel measuring in plan 250 × 250 mm and imitating in its thermophysical properties a fragment of the OA shell. To reduce the heat loss by the lateral surfaces, "masks" from a material analogous to the material of the specimen were placed on the side of the lateral faces.

The surface temperature of the model was controlled by the readings of control thermocouples with remote displacement of the model in the focal region of the plant. The value of the thermal flow in the focal region of the concentrator reached 500 $kW/m^2$, which permitted obtaining the required temperature on the tile surface. For the white coat, this temperature was $800^oC$ and for the black one — $1250^oC$. The change in the surface temperature of the model as a function of time is shown in Fig. 1, curve 1.

Since the location of the thermocouple immediately under the glassy coat leads to a distortion in the temperature field due to the disturbance of the specimen's integrity, the surface temperature on the test models was controlled with the aid of Chromel–Alumel thermocouples set in the "masks" at a distance of 85 mm from the center of the model. Because the nonuniformity of the heat flux distribution in the focal region of the SGU-7 plant does not exceed 10% only in an area 200 mm in diameter, these thermocouples were pre-

TABLE 1. The Test Data for Some Heat-Insulating Elements Obtained on the SGU-7 Plant

| Brand of material | Coat | Number of cycles | Appearance |
|---|---|---|---|
| TZMK-10 | EVS-4 | 19 | The surface appearance remained unchanged, no shrinkage was revealed. |
| TZMK-12 | EVCh-4 MIV-3 | 50 | During the first 15 cycles, beginning with cycle 8, cracks appear on the coat surface. During the following 15 cycles the coat remained unchanged. |
| TZMK-20 | EVCh-4 MIV-3 | 50 | After cycle 10, in the central part of the specimen lustre appeared. No further noticeable changes in the surface were observed. |
| TZMK-25 | EVCh -6 | 85 | After 85 heating cycles, the coat was somewhat fused and in the central part of the surface slight ripples appeared. |

liminarily calibrated against the readings of the central thermocouple set in a special model. The temperature of the metal substrate was controlled by the Chromel–Alumel thermocouples and reached 80–100$^o$C at the end of the heating cycle (Fig. 1, curve 2).

In the process of the HIE life tests, after every 2–3 cycles the material shrinkage was measured by a clock-type indicator. Figure 2 shows the change in the shrinkage value at the central point of the HIE depending on the number of cycles. From this figure it is seen that during the first 30 cycles of heating the shrinkage increases directly with the number of cycles, whereupon the shrinkage curve sharply increases and takes on the initial character again. During the last 25 cycles, no shrinkage of the tile material occurs.

Thus, the investigations made have corroborated the efficiency and serviceability of TZMK with different coats under long-duration cyclic heating by concentrated solar light to a temperature of 1250–1350$^o$C.

The test data obtained on the SGU-7 solar plant with a concentrator 5 m in diameter are in good agreement with the test data obtained on the gas-dynamic (1 MW) and radiation (250 kW) test beds, which supports the expediency of replacing, at preliminary stages of testing, the power-intensive beds and plants by power-saving ecologically harmless solar furnaces.

## REFERENCES


1. L. I. Latyshev, V. A. Petrov, V. Ya. Chekhovskii, and E. N. Shestkov, *Radiative Properties of Solids* [in Russian], Moscow (1974).
2. R. Siegel and J. R. Howell, *Thermal Radiation Heat Transfer* [Russian translation], Moscow (1975).
3. V. G. Andrianova, Yu. G. Goryachkovskii, V. A. Petrov, and V. N. Reznik, *Teplofiz. Vys. Temp.* No. 5, 992–995 (1982).
4. V. V. Pasichnyi, *Poroshk. Metallurg.*, No. 7/8, 160–172 (1995).
5. V. V. Pasichnyi, in: *Proc. Int. Symp. "Advanced Thermal Technologies and Materials"* [in Russian], Pt. 2, September 22–26, 1997, Katsiveli, Crimea, Ukraine, Moscow (1999), pp. 147–152.