HEAT STORAGES BASED ON SHAPE-STABLE PHASE-TRANSITIONAL MATERIAL

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Abstract

In present paper there are presented the research results of new types of heat storage (HS) constructions with shape-stable phase-transitional material (PTM), called unpackaged. The researches were aimed at defining serviceability and operational efficiency of the new types of the HS. In the unpackaged HS, unlike the traditional ones, a working medium doesn’t demand hermetic encapsulation during phase transfers from solid state into liquid state and backwards.

The description of the physical and chemical properties of the heat-accumulating composite materials based on the paraffin and the production technology of a such kind of shape-stable PTM is presented.

As the working medium the heat-accumulating composite material based on the paraffin B-TAM-50 (V-TAM-50) with melting temperature of 53 °C was applied. Four specimens of the HS were used during experimental investigations. Analysis of thermal tests of the specimens was performed ; it verified the effectiveness of the new types of the HS in state-of-the-art technology.

KEYWORDS

Heat storage (HS), phase-transitional material (PTM), melting filler, heat storing material (HSM), unpackaged HS, shape-stable PTM.

INTRODUCTION

Lately more and more attention is being devoted to creation of the new types of heat storages (HS), including the ones in which thermal effects are used during transfer of the working medium from solid state into liquid state and backwards. Usually the HS of this type, especially, the ones sited on mobile and flying vehicles, demand hermetic encapsulation of volume, where the phase-transitional working medium is placed. This constrains their wide introduction in energy-saving technologies and other fields of man’s activity.

That is why undiverted attention is being given to making such constructions of the HS, that don’t demand hermetic encapsulation of volume of the phase-transitional material (PTM).

In the given paper research results are presented; their aim was definition of serviceability and operational efficiency of the new types of the HS, called unpackaged. In the unpackaged HS, the working medium doesn’t demand hermetic encapsulation during phase transfers, since it maintains its shape practically unchanged when a melting filler passes from the solid state into liquid and backwards in comparison with the conventional HS, which have the phase-transitional material (the melting working medium) placed in encapsulated volume. The melting filler is maintained in volume by means of special polymeric binders, allowing to make spatial linking of long-chain molecules. It enables to form an elastic spatial grid in whose meshes the melting filler is placed. The ability to maintain the PTM’s shape allows to considerably simplify HS structure, because there is no more the need to encapsulate the volume with the PTM. The volume encapsulation leads to unjustified increase of the construction mass; reduction of reliability and restriction of the application area of the effective PTM in energy absorption processes.

That is why the works intended to creating and finalizing the unpackaged HS with the shape-stable PTM are very important.

HEAT-ACCUMULATING MATERIAL

Development of the heat accumulating material begins with selection of the melting filler, providing specified stabilization temperature during high thermal effect (thermal absorption). When the heat-accumulating PTM operating, two main mechanisms of heat absorption are realized: heat consumption for phase transfer "melting – solidification" and for the process "heating – cooling of the material".

The most promising shape-stable heat-accumulating working medium turned out the substance, consisting of phase-transitional filler and polymeric binder, that provides maintaining of composite material shape.

Paraffin and polyethylene were selected as the melting fillers; elastomers were selected as the polymeric binder; they serve as a thickener of the melting filler [2 - 4]. Elastomers have long in helical manner twisted molecular chains. Presence of active groups along the chain length makes it possible to carry out the spatial linking of molecules and thus create the elastic spatial grid in whose meshes the melting filler is placed.

Thermal capacity component of the composition can be theoretically calculated upon the thermal capacity of each component taking account of its content in composition. Expenditures for phase transfer are determined by the melting heat of the filler with allowance for the thermal effect value (heat absorption) and the melting filler content of the composition, according to its percentage in the composition.

In view of the above-mentioned, one could draw a conclusion that the heat absorption of the composition can't reach the heat absorption value of the melting filler. It can be clearly illustrated by the below given Table 1, characterizing the relation: thermal effect of melting – melting filler content of the material.

Table 1. Thermal effect of melting – melting filler content of the material

Item	Melting filler content per 100 mass parts of the rubber, mass parts								
	20	50	100	150	200	250	300	350	400
Thermal effect, %	16	33	50	61	66,6	71,5	75,0	77,8	80

As may be seen from Table 1, the heat absorption of the material sharply increases at bringing the melting filler up to 150-200 mass parts per 100 mass parts of the rubber.

The stabilization temperature is determined by the melting temperature of the crystal phase of the melting filler. For the melting temperature of 50-55 °C, necessary for the equipment, the paraffin grade of П-2 (P-2) was chosen as the melting filler; its melting temperature is 53 °C; the melting heat is 110-120 kJ/kg [3]. For the material with the stabilization temperature of 130 °C it's expediently to use as the melting filler the crystal polyethylene, whose melting temperature is 125-130 °C, the melting heat is approximately 200 kJ/kg [6].

Upon the set of technological and physico-mechanical properties, the ethylene-propylene rubber СКЭПТ (SKAPT) was chosen as the polymer basis for the paraffin, and for the polyethylene – chlorosulfonated polyethylene.

Manufacturing PTM

The technology of the PTM manufacturing corresponds to the standard technology of rubber article manufacturing; it can be executed at the enterprises for rubber processing and consists of the following procedures:

– preparation of the components;
– mixing of the components on mixing mills;
– compression moulding and vulcanization.

When producing articles of complicated forms, processes of moulding and vulcanization are carried out separately. In the first stage blanks are moulded; they are held up to the jellification stage. The second stage provides moulding from the PTM articles and vulcanization of the rubber base.

On the basis of the developed technology specimens of the materials were made and the estimation of the heat absorption and thermal-physic properties of the shape-stable heat-accumulating materials was performed. The results of the estimation are presented in Table 2.

Table 2. Heat absorption and thermal-physic properties of the shape-stable heat-accumulating material

Material filler	Melting heat, kJ/kg	Density, kg/m^3	Heat conductivity, W/(m·K)	Heat capacity, kJ/(kg·K)	Melting temperature, °C
Paraffin	120	890	0,27-0,34	0,5-3,1	50-53
Polyethylene	200	1010	0,43-0,5	1,4-6,0	125-135

Presented materials withstand heating up to 150 °C without changing the shape. Long-term heating up to 100 °C is also allowed. The materials withstand long-term thermocycling without changing thermal properties and the shape.

To provide thermal conditions for radio equipments, the composite heat-accumulating material based on the paraffin of the brand П-2 – В-ТАМ-50 (P-2 – V-TAM-50), developed by Federal State Enterprise All-Russian Aviation Material Institute, was tested as the working medium.

The shape-stable heat-accumulating material В-ТАМ-50 (V-TAM-50) represents a composition, consisting of the polymer basis and the melting filler. The ethylene-propylene rubber with the vulcanizing group was used as a polymer basis. The paraffin serves as the melting filler.

The thermal-physic properties of В-ТАМ-50 (V-TAM-50):

– latent heat of phase transfer, r = 117 kJ/kg;
– temperature of phase transfer, T_{cr} =53 °C;
– density, ρ =900 kg/m^3;
– specific heat and heat conductivity depending on the temperature (Table 3)

Table 3. Specific heat and heat conductivity depending on the temperature

T, °C	-60	0	25	50	100
λ, W/(m·K)	0,26	0,27	0,28	0,29	0,3
C_p, kJ/(kg·K)	0,5	1,4	1,7	2,1	3,6

Heat storage (HS) with phase-transitional material (PTM)

Two methods were chosen for applying the shape-stable PTM on radiators and on surfaces of construction as applied to space hardware:

– preliminary moulding of partly vulcanized blanks with subsequent moulding and attachment of PTM on the hardware;
– moulding and attachment of the PTM on the items, made of raw materials.

With the view of experimental check of serviceability of the new heat-accumulating devices with shape-stable PTM, the specimens of the HS were produced on the basis of the В-ТАМ-50 (V-TAM-50). Two of them represented standard radiators with plate ribbing (Fig. 1), the space between the ribs was filled with the В-ТАМ-50 (V-TAM-50).

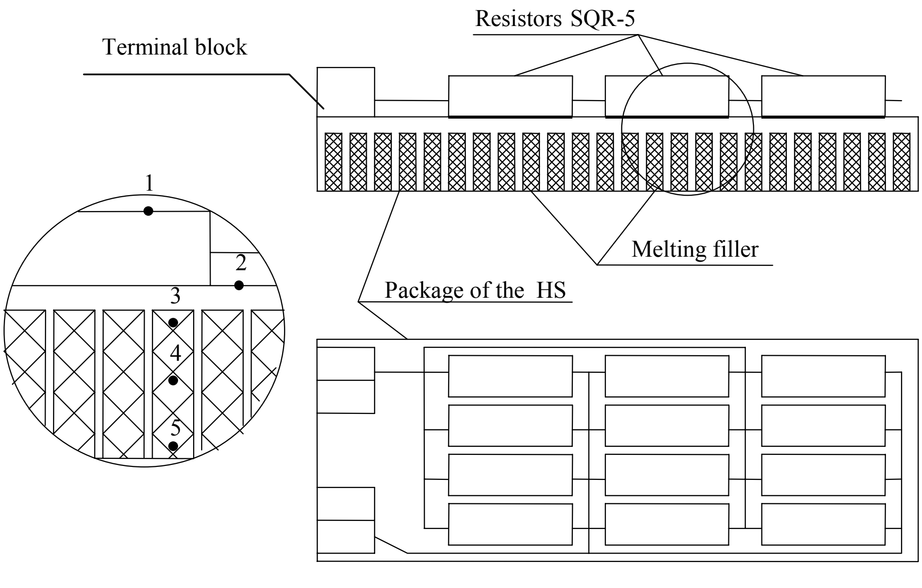

Fig. 1. Schematic diagram of the HS with the PTM, 1-5 – mounting points of thermocouples

For the third HS meshes of hexagonal section from aluminum, filled with the PTM, were used for the ribbing (Fig. 2).

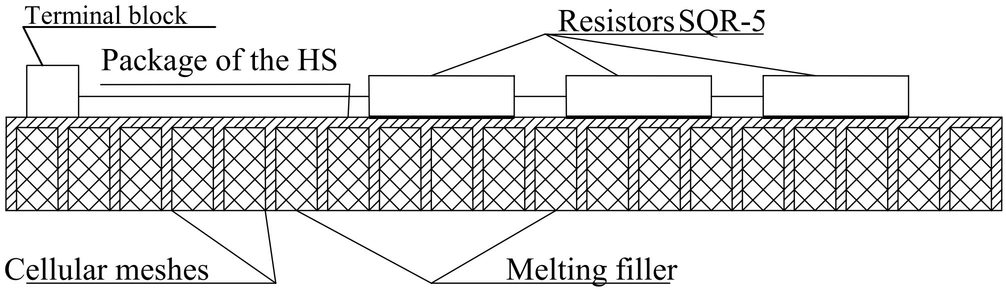

Fig. 2. Scheme of the HS with cellular ribbing, filled by the PTM

The fourth HS represented the construction of aluminum U-section; the inner volume of U-section was filled with the same PTM (Fig. 3).

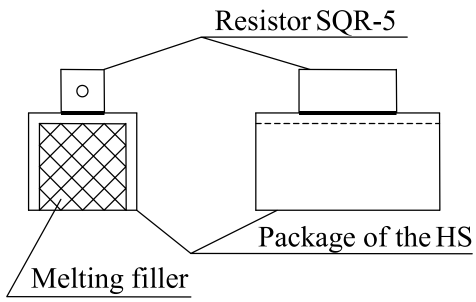

Fig. 3. Scheme of the HS, with U-form package, filled by the PTM

Attachment

Attachment of the shape-stable PTM B-TAM-50 (V-TAM-50) to the walls was made by means of a polysulfide jointing material. As the energy sources (ES), resistors SQR-5 were used; they were made of ceramics and had flat installing surface.

During the tests the following values were measured: electrical power of the ES; temperature in the characteristic points of the HS including the temperature across the PTM volume. The primary processing of the test results for defining values of HS energy capacity and thermal effect of phase transfer was conducted based upon the following equation of the heat balance:

$$Q = P\cdot\tau = C_{sol}\cdot(T)\cdot m\cdot(T_{cr} - T_{in\ sol}) + r\cdot m + C_{liq}\cdot(T)\cdot m\cdot(T_{f\ liq} - T_{cr}) + C_{es}\cdot m_{es}\cdot(T_{fin} - T_{in})_{es} + Q_{env.} \qquad (1)$$

Q, P and τ – respectively energy capacity of the HS; power, put into the HS; and the operational time of the ES;
C_{sol} (T), C_{liq} (T), m, $T_{cr,}$ r – respectively specific heat capacity of solid and liquid phases depending on the temperature; the PTM mass; melting (solidification) temperature; latent heat of the phase transfer;
$T_{in\ sol,}$ $T_{f\ liq}$, C_{es} , m_{es} , $T_{fin\ es}$, $T_{in\ es,}$ Q_{env} – respectively initial and final temperature of solid and liquid phases of the PTM; specific heat capacity; mass, initial and final temperature of the construction and the ES; losses to the environment.

In Fig. 4 there is one of the typical graphs, characterizing the temperature change of the HS (here with cellular structure): when initial heating prior to the beginning of the PTM melting; when the PTM melting; and after complete meltdown of the PTM; and besides the location of the solid and liquid phase boundary against the operational time of the ES. Here, one should mention that prior to the beginning of the phase transfer, the pre-melting phase takes place, which results in some decrease of heating rate of the HS. And besides, here , for comparison, relations of temperature changes of ES and radiators made of aluminum alloy, the same mass, but without the PTM are presented.

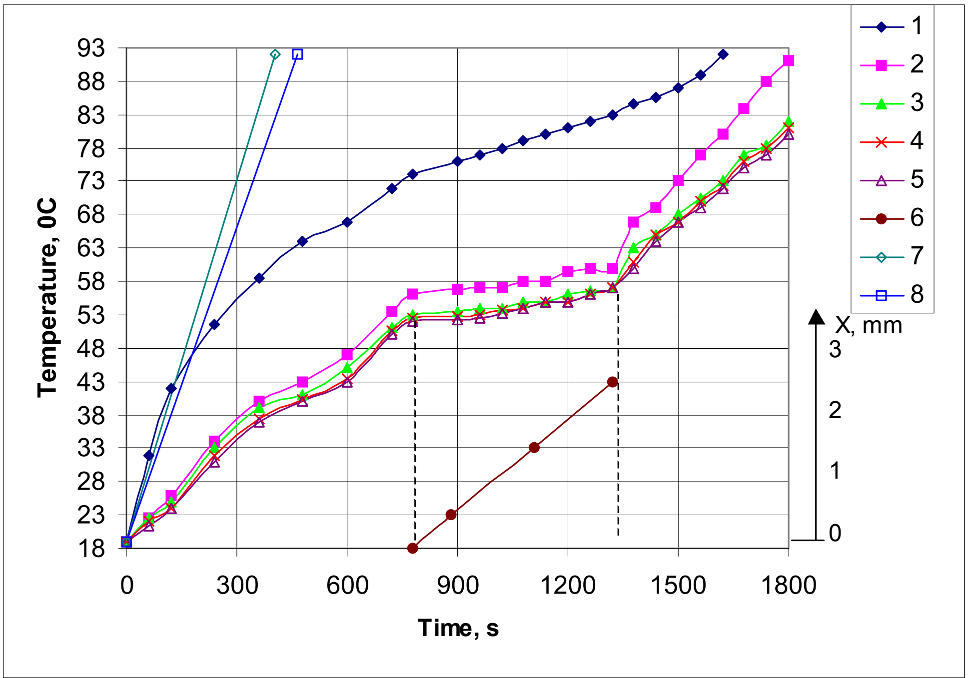

Fig. 4. The temperatures across the HS volume and location of the solid and liquid phase boundary of the PTM against the time at the power of the ES – 24 W, of : 1 – surface of the ES; 2 – package of the HS, where the ES is placed; 3, 4, 5 – across the PTM thickness inside the cellular mesh at a distance of $0{,}5x10^{-3}$, $1{,}5x10^{-3}$, $2{,}5x10^{-3}$; 6 – location of phase boundary; 7, 8 – surface of the ES and radiator frame made of aluminum alloy (without PTM)

It's seen that the operational time of the ES prior to reaching the temperature, specified for resistors (90 °), is three times longer for the HS with the PTM. Multiple repeated switching-on of the ES on each of the four specimens (about 20 times per each) verify invariability of the measured parameters of the HS, i.e. stable operation of the HS with the B-TAM-50 (V-TAM-50). It evidently demonstrates expediency of the HS application with the shape-stable PTM for state-of-the-art technology.

Results

The results of specimen test also showed that thermo-physical processes, taking place in the new types of the HS with the shapes-table PTM, that are called unpackaged HS , as there is no need to encapsulate the PTM volume during its melting, are similar to the ones that take place in traditional HS.

That is why, when selecting the parameters of the new types of the HS, probably, one can use calculation methods, developed for constructions with the PTM, placed in encapsulated packages and presented in [4, 5, 6].

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