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CLASSIFICATION AND DATABASE OF THERMOPHYSICAL CHARACTERISTICS OF HEAT PROTECTIVE MATERIALS

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Classification and identification marking of heat protective materials and a database of their thermophysical characteristics are developed.

Of all the existing methods of heat protection of objects of different technology, the use of various materials, which scatter, absorb, reflect, and remove energy from the object protected, is the most widespread for this purpose. In particular, over several decades the method of heat removal owing to physicochemical transformations has already been used for the products of space-rocket technology under the conditions of attack of moderate and high specific heat fluxes (0.5–30 MW/m^2). For this, ablation polymers and composition based on them are employed. They protect the forebodies and side parts of spacecraft and long-range ballistic missiles, serve for heat insulation of the casings and nozzles of solid-fuel rocket engines, combustion chambers of liquid-propellant rocket engines, and so on. Such a wide use of these materials is due to their ability to absorb, scatter, and entrap thermal energy at the expense of removal of some part of material as a result of the whole complex of physicochemical transformations occurring in it in heating, and this is named ablation [1-3].

To arrange in an orderly fashion the available information on different characteristics of heat protective materials (HPMs) (in particular, thermophysical characteristics (TPCs)), we worked out their classification (Fig. 1). All materials in it are subdivided into two classes: materials based on polymer binders and those without use of the latter. The emphasis in this work is on the first class of HPMs. These materials contain various polymer binders (epoxy, phenolformaldehyde, etc.) and their modifications, as well as fillers of various nature and structure (asbestos, glass, carbon fabric or fiber, etc.) [1-3].

Originally, the materials were classified according to the nature of the filler since this constituent of the material has, as a rule, a higher thermal conductivity than that of the polymer constituent, and at the same time the thermal conductivity of fillers can differ significantlt in value [1, 3]. Next follows a filler structure that also exerts a crucial influence on the thermal conductivity of HPM. These can be monolayer or multilayer fabric, fibers of different length, etc. Their effective thermal conductivity is also significantly different. Then the materials are classified according to the binder type, i.e., a polymer of different nature and chemical structure that performs several functions in HPM. These are the mechanical strength of a heat protective coating, formation of a carbonized layer that prevents heat penetration into the object protected, various physical and chemical processes in the heating of HPM which proceed mainly with heat absorption, and so on.

In a number of cases, the material has two binders. For this type of HPM, the second binder is commonly used for extra impregnation of material to decrease its porosity, and its content is considerably lower than that of the first binder [1, 3].

The class of HPMs based on organic binders (Fig. 1) also includes materials that have no binder in their composition. These are organites which are recently widely used in space-rocket technology owing to their low specific weight. Among them are rubbers which undergo various physical and chemical transformations in heating.

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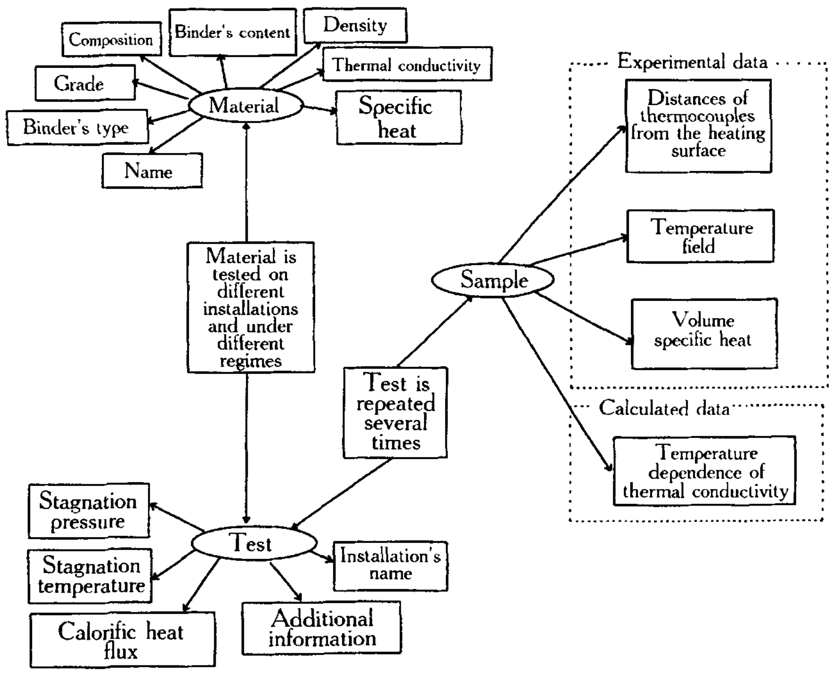

Fig. 1. Classification of the heat protective materials

This classification does not include materials sublimating at relatively low temperatures (e.g., naphthalene) and thermoplastics (polyethylene, polytetrafluoroethylene, etc.) since in interaction with high-temperature media the process of destruction of these materials proceeds in a very thin surface layer, determination of the thermal conductivity of which under the conditions of unilateral (especially intense) heating having no meaning.

As for the second class of HPMs, i.e., materials having no organic binders in their composition, the use of different ceramics for this purpose have not found wide application yet. In this class of materials the most active studies are concerned with carbon-carbon composite materials (CCCMs); to obtaining them, use is made of organic binders.

The classification above does not claim to cover all the heat protective materials existing currently. It allowed HPMs to be classified relative to their main characteristic, namely, thermal conductivity. This classification of materials served as a basis for the development of a database of TPCs of organic binder-based HPMs, for a complex determination of temperature fields in HPM samples, and for the systematization, analysis, and processing of results of determination of the thermophysical characteristics of materials of this class under different modes of unilateral heating.

In accordance with the HPM classification presented above, their identification marking is suggested. An example of this marking of materials based on phenolformaldehyde resin and glass filler is provided in Fig. 2. It is used for HPM identification in the database of thermophysical characteristics of materials and in an analysis of experimental and calculated information.

The database presents the results of determination of the temperature dependences of the thermal conductivities of HPM samples for different heat-transfer models and the results of determination of the specific heat of these materials using an IT-s-400 unit. Some results of investigating the specific heat of HPMs are reported in [4] where the authors also suggested identifying the temperature of the beginning of destruction of different HPM binders with the maximum of the temperature dependence of the specific heat of these materials, which takes place within 20–400°C at practically zero heating rate (0.14 K/sec).

To determine the temperature dependence of the thermal conductivity of the HPM under unilateral heating conditions, we used two procedures for solving the inverse (of a coefficient type) heat conduction problems (IcHCPs) [5, 6], the experimental basis for which was the temperature field in the samples of the mate-

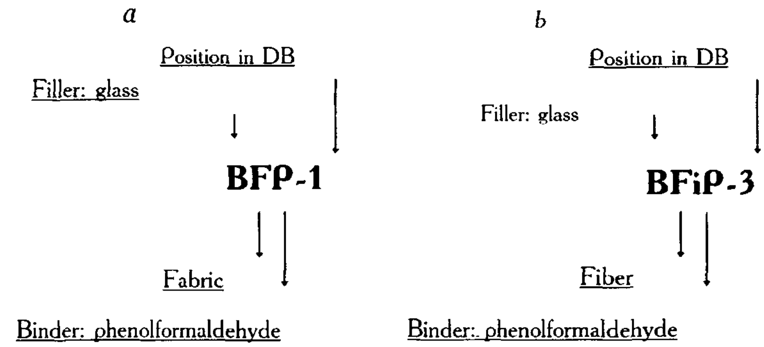

Fig. 2. Identification marking of heat protective materials: a) textolite; b) fibronite.

rials investigated. The procedures of solution of the IcHCP are implemented in the programs KV [5] and FRIEND [6].

KV is a program that uses a procedure based on the regularities of heat transfer under the quasistationary mode of heating (constancy of the temperature and the velocity of a heated surface (or an isotherm)) of the material, the sample of which models a semiinfinite body. To implement this procedure, it is necessary to record a temperature variation with time in one cross section of the tested material, provided that the linear velocity of material removal is simultaneously measured (for instance, by means of filming) or in two cross sections in the absence of independent measurement of the linear velocity of material removal. In the latter case, this parameter of the tested material is determined as the quotient of the distance between thermocouples and the constant time (the quasisteadiness condition) of passing this distance by any temperature. Next, the entire range of readings of the first thermocouple is subdivided into N intervals, in each of which the material thermal conductivity is assumed to be constant. A relation is obtained that makes it possible to calculate the temperature dependence of the thermal conductivity of the tested material with allowance for the temperature dependence of the specific volume heat and to allow for the heat absorption upon destruction of the binder and by gases produced by this process.

FRIEND uses the iteration technique of solving the inverse problems based on the theory of sensitivity functions. Use is made of the mathematical model of nonlinear unsteady heat transfer for an infinite plate with the first-kind boundary conditions. The sought temperature dependence of thermal conductivity is represented in the form of a functional series, the basic functions of which are cubic B-splines. To find the vector of the parameters sought, the iteration identification is employed. Here, an increment in the vector of the sought parameters is found by solving the system of linear algebraic equations by the least-squares method and using A. N. Tikhonov's regularization method. To implement this procedure, it is necessary to measure the temperature variation with time in 3–4 cross sections of the sample of the material investigated.

The procedures described above complement each other. At high heating rates and in the presence of material removal, when the temperature field is constricted and it is almost impossible to measure a temperature variation in several cross sections of the sample, the first procedure is used, while at low heating rates the second procedure is adopted.

Processing of files of experimental and calculated information and an analysis of the influence of a large amount of different factors on some characteristic or parameter calls for the use of up-to-date computing aids and software [7-10]. To arrange in an orderly fashion the information on the thermophysical characteristics of HPMs, we developed a database (DB). As the programming language, the object-oriented language Object Pascal (Delphi) is chosen [9, 10]. This is a full-scale means of development of databases for almost all known database management systems (DBMS) such as FoxPro, Dbase, Paradox, etc. The advantage of Delphi lies in the fact that in compilation an exe-file is created that can easily be transferred from one computer to another and that the Delphi programs are independent of the medium, in which they were developed. Delphi makes it also possible to develop rapidly and easily interfaces that are colorful and convenient for the user.

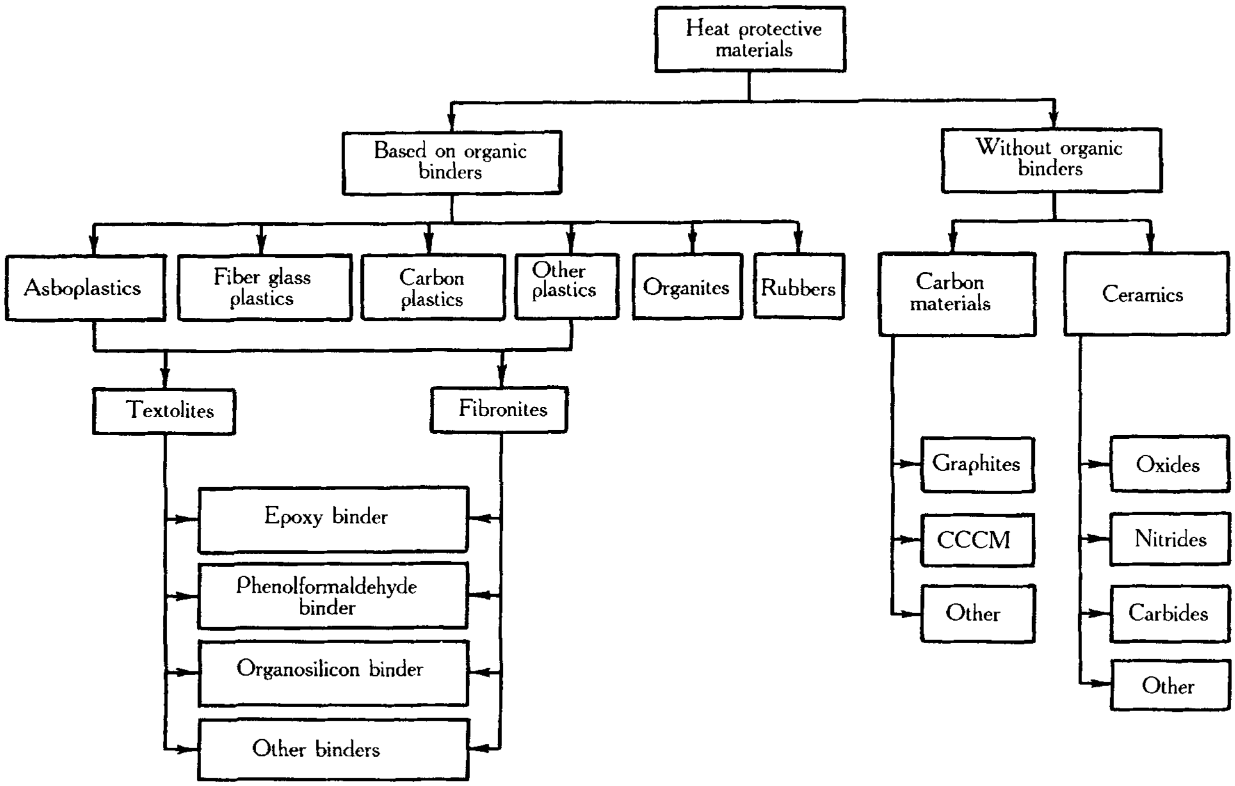

Fig. 3. Infological model of the database.

Figure 3 shows the structure of the database (an infological model) of the HPM TPCs that contains three types of information:

1) on material (name, grade, composition, density, type and content of a binder, etc.);

b) on test conditions (name of an installation, heat flux, pressure and stagnation temperature, and so on);

c) on the sample of the tested material (number, grade of material, distance between thermocouples, etc.).

In the database developed the information is classified according to both the name and the numbers of materials in the table with the initial information on their thermophysical characteristics at room temperature. The system provides the possibility of searching for both material and its samples and the tests. The search for the material is accomplished with respect to its name, binder's name, and the grade and number of the material. The search for the test is carried out with respect to the material name and test (an installation) and material numbers and tests.

The database is populated with information on results of the tests, i.e., temperature fields in HPM samples and determination of their thermophysical characteristics. A part of this information is given in [4, 5, 11]. Information in the DB is provided in tabular form. The database allows the available information to be presented in the form of a text file that, in its turn, can be used in any graphical editor for constructing a figure.

The present database can be used not only for heat protective but also for any other types of materials. It can be implemented both independently and as part of the systems of automated selection and handling of experimental information.

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