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THE USE OF ACTIVE THERMOGRAPHY TO DETECT MATERIAL INCLUSIONS IN THE WALLS

ZASTOSOWANIE TERMOGRAFII AKTYWNEJ DO DETEKCJI WTRĄCEŃ MATERIAŁOWYCH W ŚCIANACH

Abstract

One of the non-destructive testing methods of building envelope of unknown structure is active thermography in reflective mode. This method was used to test a model of the concrete wall with the material inclusions with significantly different thermal properties. The study performed in climatic chambers consisted of heating the model wall with a 7.2 kW heat pulse, and then recording the thermograms during wall cooling, at regular intervals, using a thermal imaging camera. Based on the recorded temperature distribution on the thermograms the thermal properties and location of subsurface defects were concluded.

Keywords: *external wall, material inclusions, thermography survey, active thermography in reflective mode*

Streszczenie

Jedną z nieniszczących metod badania przegród budowlanych o nieznanej strukturze jest termografia aktywna w trybie odbiciowym. Metodę tę zastosowano do badania modelu ściany betonowej z wtrąceniami materiałowymi o znacznie różniących się właściwościach cieplnych. Badanie w komorach klimatycznych polegało na nagrzewaniu modelu ściany impulsem ciepła o mocy 7,2 kW, a następnie rejestrowaniu termogramów podczas stygnięcia ściany w stałych odstępach czasu za pomocą kamery termowizyjnej. Na podstawie zarejestrowanego na termogramach rozkładu temperatury wnioskowano o właściwościach cieplnych i położeniu defektów podpowierzchniowych.

Słowa kluczowe: *ściana zewnętrzna, wtrącenia materiałowe, badania termowizyjne, termografia aktywna w trybie odbiciowym*

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1. Introduction

Traditional infrared surveys of buildings and other building structures consists of the identification of the temperature distribution on the boundary surfaces, i.e. on the exterior and interior surfaces, without the externally controlled interference and the thermal stimulation into their thermodynamic state [2]. There can be places with discontinuity or lack of thermal insulation in the building envelope, around the heated (or cooled) volume of the building. In these places, there are varied temperature fields on the boundary surfaces, which can be used for the identification of material inclusions. In addition, one thing should be noted, not every difference seen in the temperature field of the wall surfaces is because of its thermal insulation defects [6]. Based on the surface temperature distribution (thermograms) of an analyzed wall we can draw conclusions about its thermal insulation properties (as a qualitative assessment). In practice, this means that the building thermal envelope is tested "in a state as it is", without any controlled thermal force. Of course, research should be done in accordance with the IR camera measurement rules in the buildings. In this case, the detection of internal material inclusions in the building envelope with the thermographic method is based on the relationship between the external temperature field of the wall with its thermal conductivity and temperature difference on both sides of the wall. This type of the thermographic survey is typical and has been widely used from many years. In practice, it is rarely called "passive thermography" and is usually referred as "infrared thermography" or simply "thermovision survey" (or "thermographic investigation").

The active thermography is used to detect material defects or inclusions in the superficial layer of the tested material (building component) and for determining the unknown thermal characteristics of the tested element materials. The active method of infrared thermography is based on two things:

– controlled external thermal forcing of tested wall by a high-power (several kW) heat source to create thermal contrast between areas containing defects (inclusions) and the area of homogeneous material,
– periodically recorded thermal images of the element during its cooling, after turning off the heat stimulation sources [1, 3, 4].

The essence of active thermography is a time function analysis of the wall's (material's) thermal response to controlled heat pulse stimulation. Material inclusions in the construction are shown as different temperature areas, where the surface temperature differs from the temperature of the remaining part of the tested wall, due to their different properties of the heat conduction. The tested wall response, during its cooling, is periodically recorded using a thermal imaging camera. Thermograms of a cooling surface, in other words the time sequence of the temperature distribution on the test surface, contain information about the subsurface defect location and enable the depth and size identification of these defects (material inclusions) and material discontinuities. Temperature distribution measurements on the surfaces of the tested wall can be carried out on the heat pulse stimulated side (so-called reflective mode) as well as on the other side (so-called transmission mode) [5, 7].

The active thermography in transmission mode is applied for detecting material inclusions (defects) located deeper, i.e. located closer to the other "colder" side of the tested wall. In contrast, reflective mode is used to detect defects (material inclusions) located near the heated surface. Thermograms of wall surface cooling are carried out at regular intervals, which allows to for the observation of the dynamics of surface temperature changes in the homogeneous material and in the heterogeneous parts. With proper processing and interpretation of the wall surface cooling thermal images it is possible to obtain information about the areas where there is discontinuity of the material and to identify these places.

The article presents the exemplary results of the first stage of research for wall made of concrete blocks with the inclusion of different materials using the method of active thermography in reflective mode. The material inclusions had significantly different thermal conductivity coefficients and were placed at different depths in the wall. The aim of the study was to evaluate the effectiveness of this method for identifying the size and depth of the material defects in the wall. The next stage of research will be to solve the inverse heat conduction problems for the tested wall.

2. Description and test results

The study was performed in climatic chambers in the laboratory of the Institute of Civil Engineering at Wroclaw University of Technology. A wall made of concrete blocks (with dimensions of 120 × 250 × 380 mm) with material inclusions (100 × 200 × 20 mm) was placed in the connecting sleeve between the ‘warm’ and ‘cold’ chamber (air temperatures respectively +20°C and –10°C) (Fig. 1).

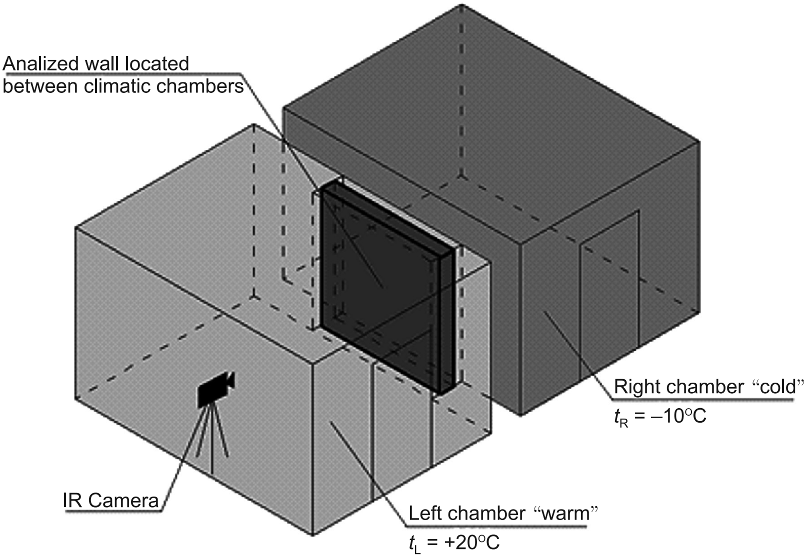

Fig. 1. Wall testing scheme in climatic chambers

Material inclusions in the wall were made by placing materials with significantly different thermal conductivity coefficient λ. Materials used:

- extruded polystyrene (XPS foam) , λ = 0.033 [W/(m K)],
- granite, λ = 3.500 [W/(m K)],
- steel, λ = 50.000 [W/(m K)].

These were placed at two different depths in the concrete block wall. Inclusions were located, at two depths, 6 cm – in the existing wall layer, 4 cm – in the glued after thinner plate layer of the same material. Schematic layouts of material inclusions are shown on Fig. 2 and 3. During the measurements, the following were recorded:

- air temperature, relative humidity and air velocity in the chambers by:
  - NiCrNi thermocouples,
  - FVA935 – TH4K2 and FVA605 – TA5O anemometers,
  - FHA646 – E1 and FHA646 – E1C temperature and humidity sensors connected to the Ahlborn ALMEMO datalogger types 2690-8, 2890-9 and 5690-2M09,
- wall surface temperature on the warm and cold sides by NiCrNi thermocouples,
- temperature inside the wall between the existing wall and concrete plates by means of NiCrNi thermocouple and RTD Pt100 sensor,
- thermograms using the thermal imaging camera FLIR P65 and FLIR B360.

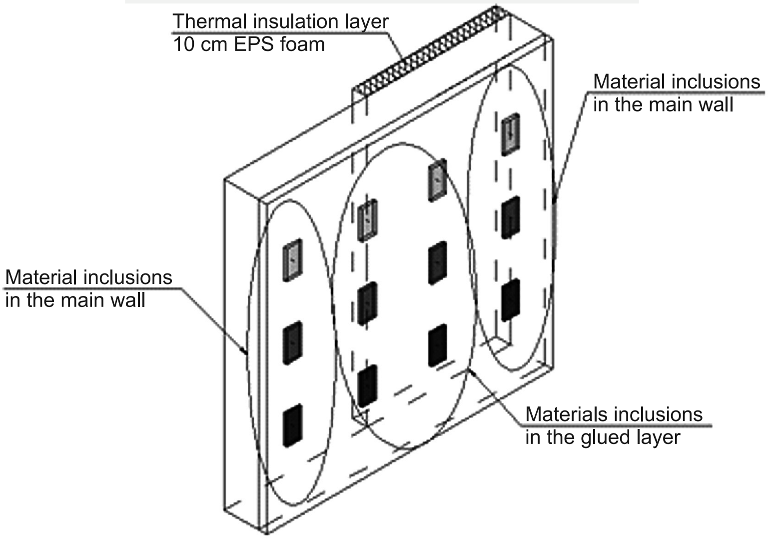

Fig. 2. Analyzed wall with material inclusions scheme

The research of the wall with inclusions started with heating their surface from the inclusions side (warm side) with infrared radiators with the summary power of 7.2 kW, shown on Fig. 4. The time of wall heating was 40 min and the uniformity of the heating surface of the wall of 2.0 × 2.0 m was carried out by placing an arm stand with infrared radiators in three positions in 5 min cycles.

After wall heating, the next step was to start the surface temperature recording with the thermal imaging camera while the wall started to cool down. In order to accelerate the process of wall cooling and to direct the heat flow the right (‘cold’) climate chamber was

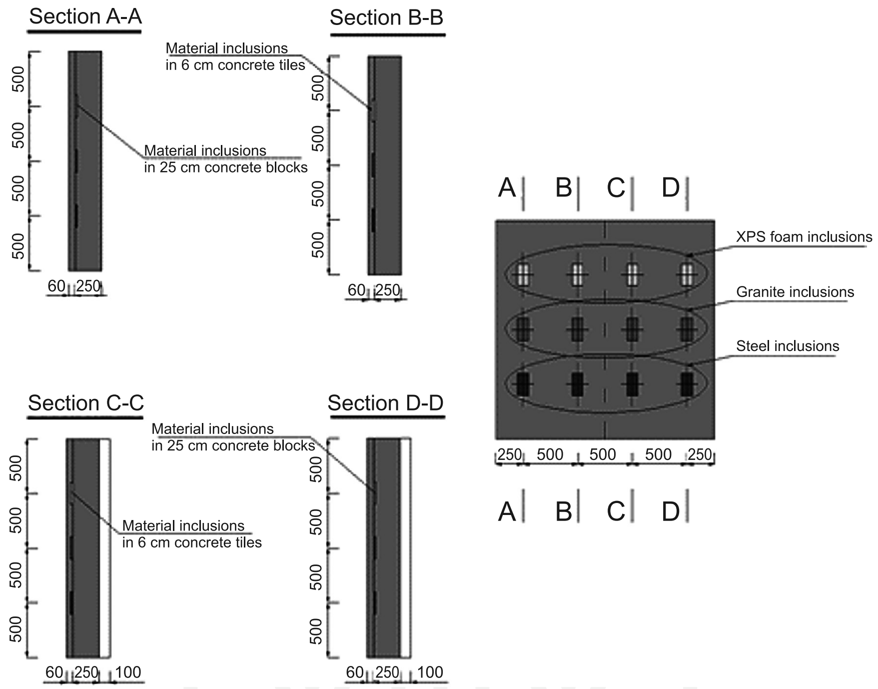

Fig. 3. Placement of XPS foam, granite and steel inclusions in wall made of concrete blocks

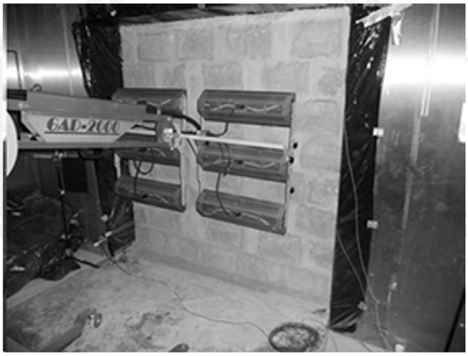

Fig. 4. Heating surface of the test wall by infrared radiators with power 7,2 kW

set in the cooling mode to the air temperature $t_e = -10°C$. The thermograms were recorded with 15 min intervals (with FLIR P65 and FLIR B360 cameras).

Exemplary results of the study performed in climate chambers the concrete blocks wall with material inclusions are shown in Figs. 5 and 6, in which are thermograms of the wall after the infrared radiators were turned off ($t = 0$ min) and during the cooling of the wall after 60, 120 and 250 minutes. Additionally, under the thermograms are shown surface temperatures of the wall along the horizontal lines at the level of material inclusions.

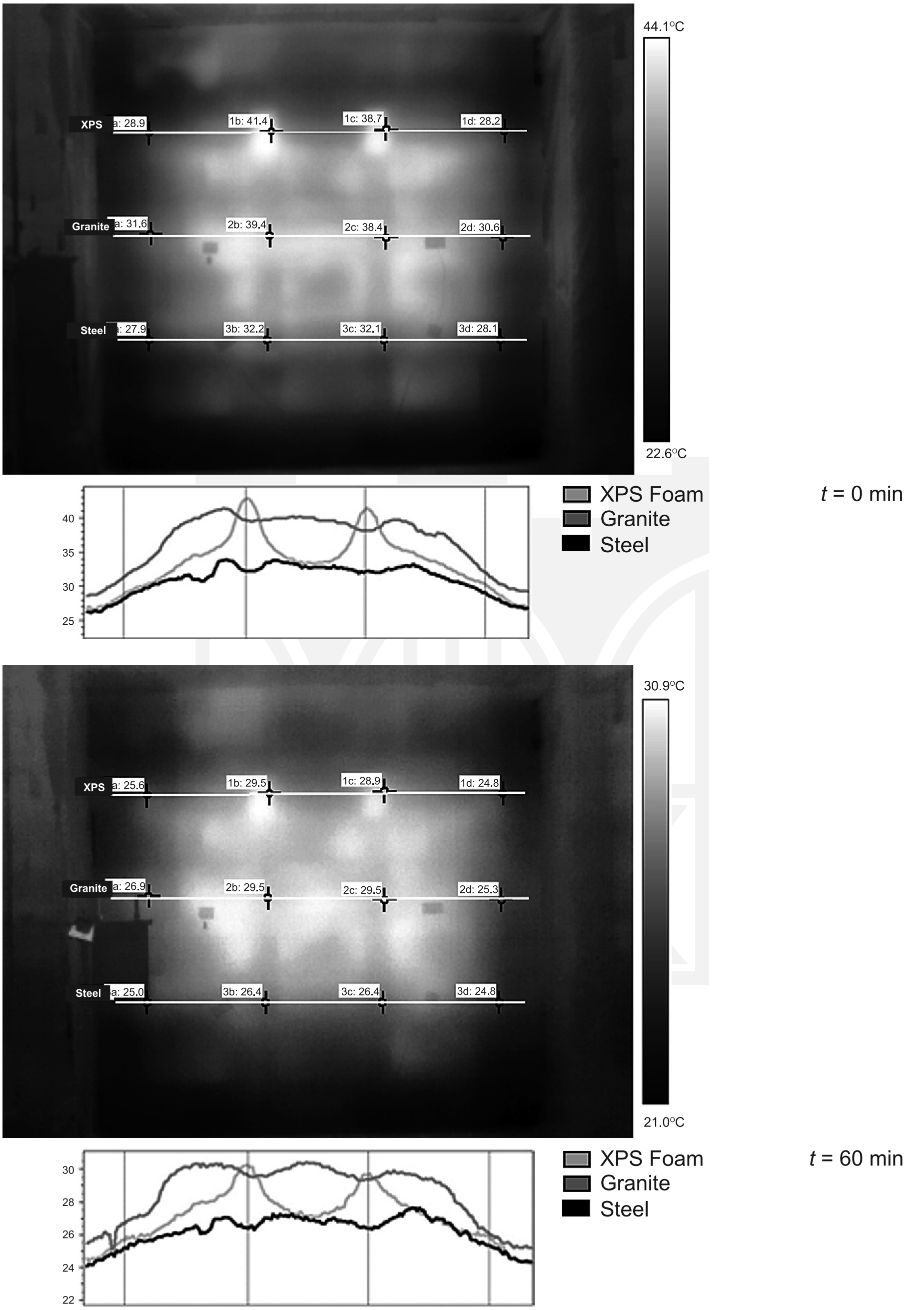

Fig. 5. Thermograms of analyzed wall with surface temperatures in place of material inclusions and temperature distribution along inclusion lines in time of wall cooling ($t = 0$ and $t = 60$ min)

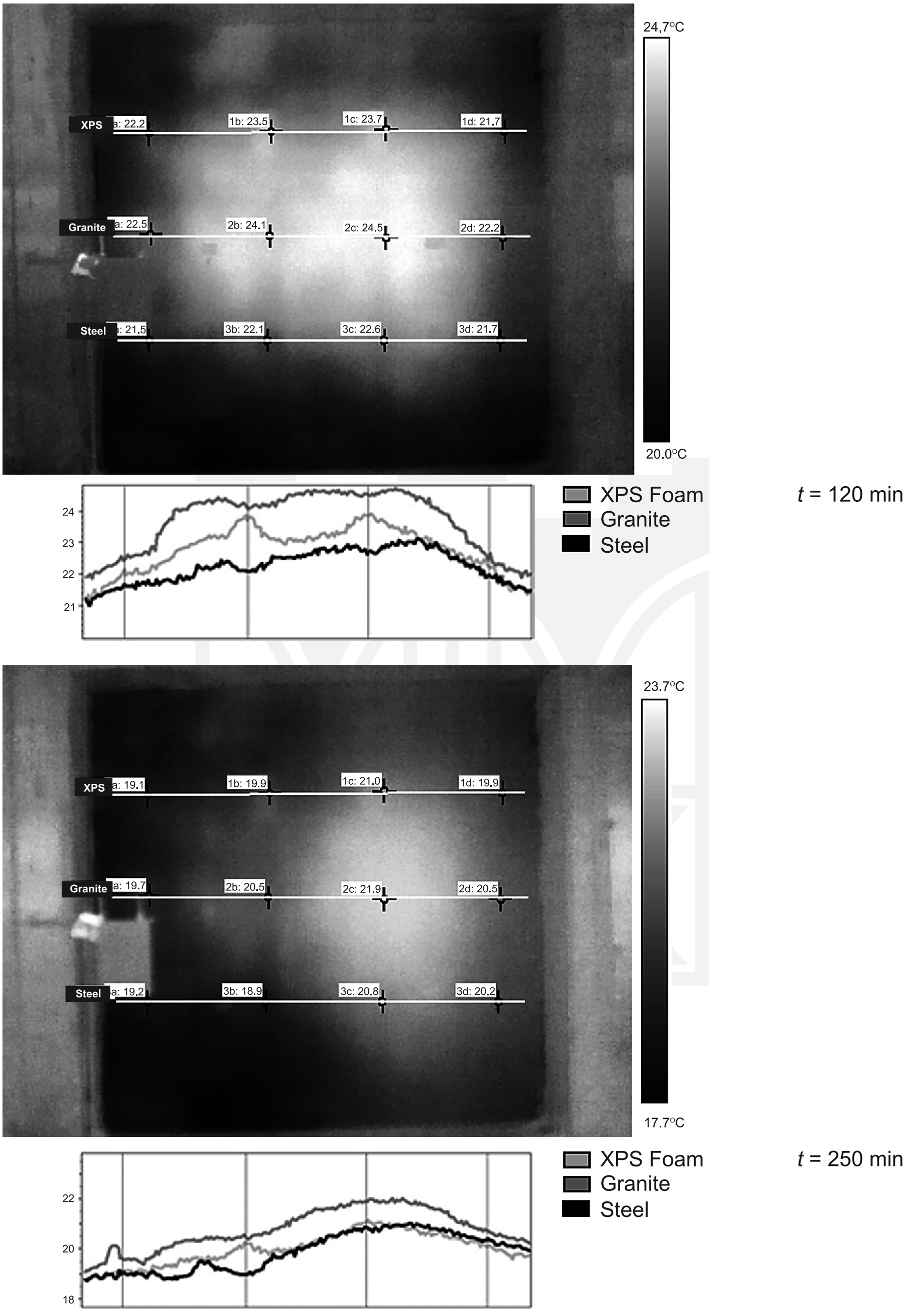

Fig. 6. Thermograms of analyzed wall with surface temperatures in place of material inclusions and temperature distribution along inclusion lines in time of wall cooling ($t = 120$ and $t = 250$ min)

The results analysis leads to the conclusions that:

- The surface temperature of the wall, at the place of inclusions, is depending on the type of material inclusion. For the inclusion material with better thermal properties than wall (e.g. extruded polystyrene) the surface temperature is always between the temperature lines for the inclusions with worse thermal properties than wall (e.g. granite, steel). It is seen in all graphs in the lower part drawings.
- The surface temperature of the wall, at the place of inclusions, for inclusions having worse thermal properties (e.g. granite, steel) is lower than the surface temperature of the remaining wall ('temperature peaks turned down' in the lower graphs on Fig. 5, 6).
- The surface temperature of the wall, at the place of inclusions, for inclusions having better thermal properties (e.g. extruded polystyrene) is higher than the surface temperature of the remaining wall ('temperature peaks turned up' in the lower graphs on Fig. 5, 6).
- The above mentioned temperature trend lasted up to 2 hours after the wall started cooling. From the 3rd hour of cooling, till the end of measurements, the surface temperatures of the wall, in the part of wall with thermal insulation, where inclusions were placed were higher than on in the uninsulated part
- The first clear signs of the material inclusions' impact on the wall surface temperature distribution could be seen at the time the heating was turned off and the wall started to cool down.
- The effect of the material inclusions in the form of different surface temperatures of the concrete wall was still visible in the 3rd hour of measurements. Wherein, the steel and granite inclusions in the wall without thermal insulation can be identified even in the 7th hour of wall cooling.
- This gives the practical conclusion that in the case of walls made of concrete or concrete blocks, to be successful, searches for material inclusions should be done within 3 hours of heating the wall for 40 minutes with infrared radiators (with a capacity of about 7.0 kW). It is also possible to identify these inclusions even after a long time, up to 7 hours, but careful interpretation of the obtained test results is necessary.

These conclusions and observations are formulated for walls with concrete blocks. Probably some other proposals will be for walls with different thermal parameters, such as brick walls or aerated concrete blocks, especially when it comes to seeing temperature differences above materials inclusions.

3. Conclusions

I Infrared thermography is a very powerful and effective tool for locating hidden material defects in the building envelope by searching for surface temperature anomaly distribution on boundary surfaces of walls. In every case, the heat flow through the individual parts of the walls with material inclusions causes differences in the surface temperatures of building partitions, which is correlated with different thermal conductivity, specific heat capacity of materials and their geometries.

Each anomaly in the temperature distribution of the wall surface, identified by infrared camera, should be thoroughly analyzed in conjunction with the design and structure of partitions, the materials used, the conditions of the temperature coercion and the performed examination conditions.

This research, which was carried out for concrete blocks wall with various material inclusions (steel, granite and extruded polystyrene differs in thermal conductivity rate) in climate chambers with use of active thermography in reflective mode allows to get conclusions for practical use:

Principles of applying the method of active thermography in reflective mode to locations of material inclusions being built in masonry or cast concrete walls are as follows:

- the method is effective in locating the material inclusions inside the wall to a distance of 5 to 6 cm from the heated side of the wall surface,
- it is recommended that, for uniform heating of the wall, the infrared heating device should use a few lamps with the total heating power of 6–7 kW, and the wall heating time should not be less than 40–45 minutes made from a distance of about 1.0 m from its surface,
- if the wall has glued sensors, such as thermocouples, attention must be paid that the wall surface temperature does not exceed 70–75°C, due to the attachment stability of thermocouples,
- it is recommended to record the thermograms of the wall cooling in 10 min. steps, and should last, depending on the thermal mass of wall, at least 8 hours.
- analysis of thermograms should be performed in a professional computer software application, such as ThermaCAM Researcher Pro.

The article presents the results of experimental studies. The next stage of research is the analysis of inverse problems of heat conduction. To identify the size and depth of the material of the inclusions in the wall by active thermography in reflective mode, is necessary to use a mathematical model describing the relationship between the time-spatial distribution of the diagnostic output and the diagnostic signal [8, 9].

Theoretical analysis of heat conduction in solids is associated with the solution of the so-called simple and inverse problems of mathematical physics, and the simple problems correspond to numerical modeling and inverse problems with experimental data processing. A simple solution to the problem is to determine the temperature field based on the established model of heat exchange with the defined boundary conditions, adopted geometry and knowledge of the thermo-physical properties of materials. In contrast, the inverse problem of heat conduction is to identify the thermo-physical parameters on the basis of the adopted model of heat transfer, temperature observations at selected measuring points, and knowledge of the distribution of the surface heat flux.

We are currently working on solving the inverse heat conduction problems, in order to identify the location and depth of the thermal properties of the material inclusions in the studied concrete wall and the sensitivity analysis for the experiment.

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