

Feasibility of active and passive thermal control application for defect identification of building materials and products, enclosures of construction objects

Denis Karpov^{1,*}, Daniya Zaripova², and Mikhail Pavlov¹

¹Vologda State University, Lenina Street 15, Vologda, 160000, Russia

²Kazan State Power Engineering University, Kazan, Russian Federation

Abstract. This paper considers one of the most promising and modern methods of non-destructive testing - thermal control. The possibilities and advantages of thermal control for identifying defects of various building materials and products, enclosures of buildings and structures are presented. Brief characteristics of the main defects of building materials, products, and structures are presented. The basic principles of identifying hidden (invisible) and explicit (visible) defects are briefly considered and the practical results of construction defect identification of objects for various purposes using thermal imaging equipment are presented. The zones of thermal temperature anomalies are localized during qualitative analysis of thermograms (the method of active thermal control). The considered example is a fragment of a building enclosure made ceramic bricks with artificially created technical defects. For some enclosures of building structures and constructions, explicit thermal defects were identified from thermal imaging, their qualitative analysis was carried out, and recommendations for their elimination were proposed (method of passive thermal control).

1 Introduction

Non-destructive testing (NDT) is designed to check the reliability of the test object, its individual elements and structures using gentle methods that do not require cardinal dismantling or temporary disabling [1-4]. NDT is based on the methods and means of control the physical principles of which do not worsen the serviceability and do not violate the integrity of the controlled objects [5-7].

The current regulatory documents laconically define NDT as a control that does not destroy. Depending on the physical processes which it is based on, NDT is subdivided into 10 main types (magnetic, electrical, vibration, etc.), one of which is temperature control (TC), which is the theme of the present paper [5,8-10].

TC implies monitoring of temperature fields and contrasts, heat fluxes of any materials to detect faults and defects [11-14].

The choice of instruments and tools for NDT depends on the tasks set, the selected method and parameters of the test object (damage, thickness of wall or coating, etc.). For example, TC based on the conversion of infrared radiation into the visible spectrum is performed using the following equipment: thermal imager, pyrometer, data loggers, temperature and heat flux density meters, various mechanical means (thermal pencils, heat-dissipating paste, high-temperature paint, etc.) [5,6].

TC is classified into active and passive, as well as into stationary and non-stationary (dynamic). The main characteristic of active TC is the thermal stimulation of the controlled object by an external energy source. By using active TC in construction defectoscopy, information about defects is contained in local thermal temperature anomalies on the surface of the test object. The temperature field formed during the operation of the control object is the main characteristic of the passive TC.

Defects to be identified can be latent (invisible, implicit) and explicit (visible).

Brief description of the main defects of building materials and products.

Durability, reliability and safety of buildings and structures from which they are built depend on the quality of building materials and products. Insufficient quality control of building materials and products at the stage of their manufacturing can lead to violations of the composition, dimensions, etc. The quality of building materials and products is regulated by regulatory documents.

For example, the poor quality of the raw materials: concrete, brick, mortar, lack of a constructive solution or violation of the production technology is a potential cause of defects in reinforced concrete and stone structures.

The use of low-quality building materials and products or violation of their manufacturing technology can cause defects in buildings and structures during their

* Corresponding author: karpov_denis_85@mail.ru

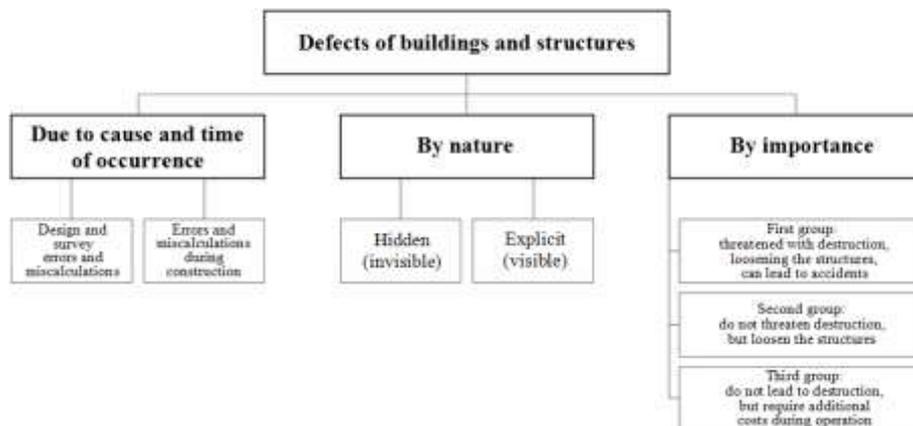


Fig. 1. Classification of defects in buildings and structures.

construction. Defects can be also identified when working in winter, in hard-to-reach places and while checking such places (joints, places of high saturation with reinforcement, etc.). Disadvantages of concrete heating, violation of the temperature and humidity treatment, early freezing, poor-quality care of freshly prepared material, both in warm and cold periods of the year, can be the reason for the poor quality of this building material.

Low frost resistance due to poor-quality composition and preparation of the clay mass, improper firing, non-compliance to individual technological stages of brick production, can result in significant disadvantages. With the further use of such a piece building material, for example, when laying it in a structure, in conditions of negative temperatures, the brick will delaminate and collapse.

Loss of stability and loss of hermeticity are the most frequent defects arising from insufficient control over the quality of work during erection of monolithic structures from reinforced concrete.

Figure 1 shows a general classification of defects in buildings and structures.

Works [5-7] consider typical defects and damages of external walls, types and characteristics of defects in wall fencing made of panels, types and characteristics of

defects in enclosures of buildings and structures.

2 Materials and methods

Basic principles of identifying hidden (invisible) defects of various control objects. Pulse TC options are the basis of many active TC procedures. During pulse TC, the object is thermally stimulated by a pulse of thermal energy. This pulse has certain duration, and includes the fixation of temperature fields on all surfaces of the test object. These actions in case of pulse TC are performed during the action of the pulse itself (stage of thermal stimulation) and during finishing the pulse action (stage of free cooling). The procedures themselves can be performed in different ways, which depends on the physical implementation of thermal stimulation or on the features of processing temperature-flow information. A large number of TC procedures depend on the method of extracting quantitative and qualitative information about latent defects from the main function associated with temperature and time $t(x, y, \tau)$. This function gives an idea of the temporal (τ) and spatial (x, y) characteristics of the excess temperature at each point of the control object, is fixed for the number of thermal images obtained (Figure 2) and depends on some technical characteristics (detector size, temperature sensitivity)

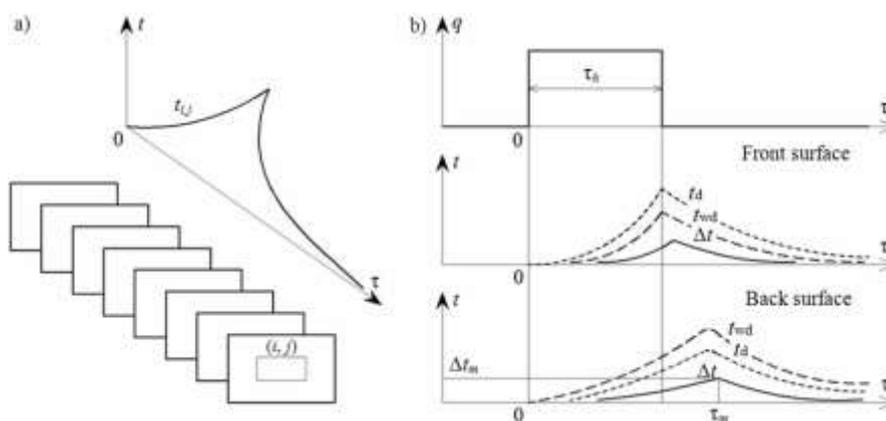


Fig. 2. Main temperature functions of active TC: a) formation of a sequence of thermal images and functions $t(i, j, \tau)$; b) heating pulse and formation of a temperature signal Δt .

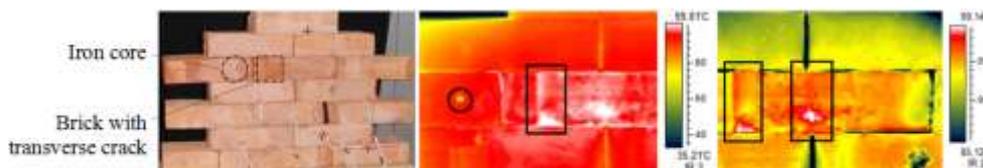


Fig. 3. Fragment of enclosure made of piece building products (ceramic bricks) with defects and thermograms with zones of localization of thermal anomalies.

thermal imaging equipment, responsible for the quality of thermal images: $t(i, j, \tau)$ [5,6].

Figure 2 shows standard functions of the form $t(i, j, \tau)$ for regions with a defect (d) and without a defect (wd).

During the process of thermal stimulation of the front surface of the control object, the excess temperature t increases from zero and reaches a maximum at the end of the thermal pulse of duration τ_n . The maximum excess temperature t with a shift relative to the end of the thermal stimulation is observed on the back surface of the test object. With an increase in the thickness of the test object and a decrease in its thermal diffusivity, an increase in this shift is observed.

During the cooling phase, the temperature drops to ambient temperature (or to zero for excessive heating temperatures). This occurs due to the heat exchange of the controlled object with the environment.

The temperature signal is the key concept of TC and is defined as the temperature difference between the investigated point (zone) of the control object and the point (zone) taken as defect-free:

$$\Delta t(x, y, \tau) = t(x, y, \tau) - t_{df}(x, y, \tau) \quad (1)$$

The temperature signal from an internal defect reaches its maximum value Δt_m at time τ_m . This occurs in the process of dynamic thermal stimulation (cooling).

It is known from the NDT theory that the highest statistical reliability of the obtained results is provided at the maximum possible signal-to-noise ratio. In dynamic tests, this occurs at the optimum moment of observation (fixation of information). In the first iteration, $\tau_m(\Delta t_m)$ is the optimal observation time. Under this condition, it can be assumed that instead of recording a sequence of thermal images at time τ_m , one thermal image can be recorded.

Basic principles of identification of explicit (visible) defects in construction materials and products, enclosing structures of buildings and structures. The basic rules for conducting thermal imaging for the purpose of detecting explicit (visible) active or passive thermal defects are widely presented in [5-7]. The main task of searching for such defects is reduced to detecting places of thermal temperature anomalies (local changes in the distribution of thermal radiation of the test object, interpreted as deviations from the norm). To implement such tasks, thermal imaging equipment is used, which is currently becoming more and more popular and accessible for solving construction defectoscopy issues.

3 Results and discussion

Consider a variant of the active TC of a fragment of a building enclosure made of piece building products (ceramic bricks) with artificially created technical defects in the form of a heat-conducting connector (metal rod) and a vertical crack (Figure 3). After thermal stimulation of this enclosure by external sources of thermal energy in the form of electric infrared emitters, thermal imaging, qualitative analysis of thermograms, we conclude: in the area of the connector connection, the concentration of thermal radiation (temperature field) is recorded, which is different from the thermal radiation (temperature field) of neighboring areas, which is a thermal temperature anomaly. We can state the presence of an explicit defect. In the area of the vertical crack, filled with air, the concentration of thermal radiation (temperature field) is recorded, which is different from the thermal radiation (temperature field) of neighboring areas, which is a thermal anomaly. We also state the presence of an explicit defect.

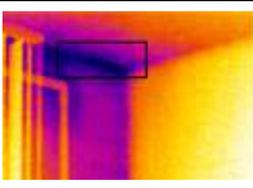
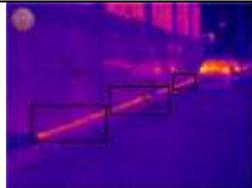
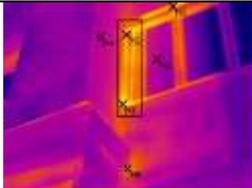
The passive TC option is presented as the results of thermal imaging of several building enclosures with identified explicit thermal defects (Table 1). Thermograms were obtained for construction projects for various purposes located in Vologda (Russia). Thermal imaging was performed using the well-known SDS HotFind-D and Testo 875-2 thermal imagers.

4 Conclusion

The high demand for NDT methods is explained by the advantages of the methods themselves, as well as their compliance with modern civil and industrial safety requirements.

The building defectoscopy of materials and products, various enclosures of structures and buildings with the involvement of thermal imaging equipment is considered. Its practical results are presented using two examples. The first one is a fragment of a building envelope made of piece building products in the form of ceramic bricks with artificially created technical defects. Zones of thermal temperature anomalies are localized according to the qualitative analysis of thermograms. The second one is the example of enclosing building structures. The results of thermal imaging were used to identify explicit thermal defects, their qualitative analysis was carried out and recommendations for elimination were proposed.

Table 1. Obvious thermal defects of building and structure enclosures.

		
Thermal anomaly at the horizontal junction of the roof and the enclosing external structure. External thermal insulation is recommended.	Thermal anomaly at the vertical junction of the wall panels of a typical panel apartment building. External thermal insulation is recommended.	The zone of potential condensation formation at the junction of the outer and inner walls, the floor slab. External thermal insulation is recommended
		
Thermal anomaly at the vertical junction of the wall panels of a typical panel apartment building. External thermal insulation is recommended.	Thermal anomaly at the horizontal junction of the vertical outer enclosures and the foundation. External thermal insulation is recommended.	Thermal anomaly at the vertical junction of the window block and the external enclosing structure. External/internal insulation is recommended

The obtained results confirm the known capabilities of TC for identification of defects of various building objects and their individual elements.

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