Design of the construction and research of vibrations and heat transfer of mine workings

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The creation of safe conditions for the operation of underground facilities is one of the main tasks of ensuring the stability of mine workings. Today, in conditions of great depths and external dynamic loads, it is necessary to ensure not only the strength of the linings but also their resistance to seismic, vibration, and thermal effects. The solution of this problem is the usage of multi-layer combined linings, which expand the possibility of using various materials for fastening openings in difficult mining and geological conditions.

This paper presents a study to determine the usage of concrete for standing support of walls and roof in a mine. It deals with the research of vibrations and heat transfer of mine workings. The construction of a three-layer vibration-resistant rigid-pliable lining for mine workings has been developed. Its pliable outer layer is made of foam concrete reinforced by PET fiber, the inner layer is the sprayed concrete layer with PET-fiber reinforcing, and the middle layer is a closed concrete ring of the rigid lining.

In the article, the mathematical model of impact-wave deformation of the lining ring from external seismic and impulse loads is formalized. The course of temperature fields above the heated sample is also studied.

Key words: *vibration, heat transfer, mine workings, concrete lining.*

Introduction

In the mining operations within mines are used large quantities of concrete products, primarily in roof supports. Other uses are for walls, floors, rail ties, and also for small temporary buildings, props, and blocking for machinery (Budaj et al., 2018). Concrete is used to support mine roofs. Concrete props are loaded perpendicularly to the roof and floor for maximum strength. Props are used in faces, mine entries, and along haulage corridors (Stone et al., 1985). Standing supports in the form of posts and wood cribs have been used since the earliest days of underground mining and remained the most common form of support in coal mines until new support products were developed in the early 1990s (Barczak, 2005). Roof support is essential to the safety of every underground miner. It has three primary functions: first, to prevent major collapses of the mine roof; second, to protect miners from small rock falls that can occur from the immediate roof skin; and third, to control deformations, so that mine openings remain serviceable for both access and escape, as well as for ventilation of the mine workings.

Application of concrete is necessary to resist instead of vertical load stress, maximum horizontal stress, and the minimum horizontal stress underground. The roof load is the vertical force that applies to roof support most directly. Longwall mining concrete and pillar recovery can concentrate large vertical loads on gate entries and pillar lines. Appropriate wood and concrete pillar sizing are essential for limiting the roof stresses and deformations to levels that can be handled by roof support. The correct column can greatly reduce the loads applied to the roof. Vertical supports column, like concrete, wood, or longwall shields, develop loads in response to the convergence between the roof and floor (Mark and Barczak, 2000).

There are localities where wood is not only unusual but where the wooden types available are not suitable for even light ground support. Concrete sets deserve consideration for these localities. Wood props are sometimes used where the roof above the seam consists of relatively massive rocks that do not cave easily. In most circumstances, wood props are not suitable for coal faces where the system of work is such that they would have to be advanced during each cycle (Wing, 2002).

The usage of concrete sets is appropriate for light ground support when suitable wood is difficult to get. Because this substitution of concrete for wood may be principally an economic problem, the relative costs must be carefully compared. Concrete supports column for mines serve a purpose much different from those for ordinary concrete structures. Concrete is used as a substitute for wood when the latter is difficult to obtain in quantity or when mine conditions are conducive to rapid deterioration of wood. Reinforced concrete is unlikely to fail instantly (Michaud, 2017). Foam concrete blocks and lightweight aggregate blocks also can be used to build roadside packs. Without reinforcement, packs built of these materials are liable to collapse under relatively

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small loads. The number of concrete supports column under each bar should be sufficient to maintain the required support density over the width of the face working (Wing, 2002). Before 1980, timber was the dominant support material with wood cribs and timber posts used exclusively for tailgate and breeder support. Concrete, with the compressive strength and material modulus an order of magnitude higher than wood, had to provide superior roof support as was thought at the time (Barczak, 2005).

This paper presents a study to determine the usage of concrete for standing support of walls and roof in a mine. It deals with the research of vibrations and heat transfer of mine workings.

Analysis of the problems

As a rule, the problem of ensuring the strength of all types of linings is solved. However, at present, the volume of mine workings carried out in complex geological conditions (high seismicity, neotectonic phenomena, etc.) is continuously increasing. In this case, an additional requirement for resistance to seismic and vibration effects should be presented to the linings, which is not reflected in any regulatory document.

During operation, linings are exposed to natural (seismic activity) and man-made (caused by human activity: blasting and construction work, traffic) vibrations. Vibration can cause damage to the lining, reducing its operational reliability: decrease stability, degrade the carrying capacity.

Natural and man-made vibrations, perceived by the constructions of the linings, differ in their nature. Vibration from natural sources is concentrated in the lower frequencies, characterized by high power in the source and extends over long distances.

Vibration can cause significant damage, so in places of constant or expected action of vibration sources, special requirements should be placed on the lining structure:

- the lining material must be resistant to dynamic loads;
- structural lining elements must be interchangeable;
- fastening elements of the lining should not only ensure the rigidity of the connection but also dampen vibration.

At great depths, traditional single-layer supports (metal, concrete, ferroconcrete) are ineffective, because the main material of the structure of the lining forms an almost rigid structure, and with intensive displacements of the contour rocks, the production is destroyed. Under the conditions of dynamic action, fiber-reinforced concrete structures are the most effective.

Materials and methods

Overview of existing types of the lining of horizontal mine workings and requirements for them

In recent years, the approach to safety at underground facilities has changed significantly. Mines are becoming deeper and deeper, which poses a serious challenge for the industry to control mine workings at elevated temperatures, strains, and pressures. To solve these problems, it is necessary to introduce not only a more advanced technique but also advanced technologies for mine working and consolidation of rocks.

The main means of ensuring the sustainability of mine workings throughout the entire service life is the erection of lining.

The lining of mine workings performs a number of important functions to protect the underground structures from rock falls, to ensure the design dimensions of workings, the perception of external and internal loads, to prevent the destruction of rock mass from weathering. There are many lining structures that are successfully used in large depths. In the modern classification of the lining of mine workings, the main classification feature determining the type of lining is its purpose, that is, for which group of underground workings lining is intended (Baklašov and Kartozija, 1984). On this basis, the lining can be divided into the lining of capital (overburden), preparatory, and treatment workings.

In accordance with the current classification, all currently existing lining of capital and preparatory mine workings are divided into three classes according to the main structural and technological features: frame, solid and anchor (Aksenov et al., 2012). In turn, the linings of the first two classes depending on their contour are divided into two subclasses: with an open and closed contour. Besides, the solid lining can be monolithic and prefabricated. The class of anchor linings is also divided into two subclasses: with the fastening of anchors in the bottom part of the well (with distance lock devices) and with the fastening of anchors along the entire length of the well or a significant part of it.

Each of the subclasses of the frame and solid linings is divided depending on the conditions and nature of the interaction of the lining with an array of rocks and constructive solutions into groups: rigid, pliable, hinged, hinged-and-pliable. In addition, each of these subclasses, as well as classes of anchor linings, depending on the material used for their manufacture are metal, wood, concrete, reinforced concrete, polymeric and mixed. The subgroup of lining determines the material of the main (bearing) structure or element of the lining.

By the nature of the work, linings are enclosing, insulating, and bearing. Fencing linings are designed to protect people and equipment from accidental local dumping of pieces of rock. Insulating linings are designed to protect the outcrops of rocks in the workings from weathering, waterlogging, leaching and cracking. Bearing linings have the main purpose to perceive the load from the mountain pressure.

According to the deformation characteristics linings can be rigid (offset up to 50 mm), little pliable (up to 100 mm), pliable (up to 300 mm) and very pliable (more than 300 mm).

By the structure, linings can be single-layered and multi-layered.

According to the methods of erection, linings are ordinary and special (hammered, crushed, submerged, lowered, pre-compressed, etc.).

By the ability to move linings can be stationary and mobile.

In accordance with the main regulatory documents, the mining lining must meet a set of technical, economic, and functional requirements:

- to withstand the pressure of rocks without breaking and to ensure the working condition of the production throughout the entire service life;
- to be technological (simple to manufacture), transportable, easy to use during construction in the mine, available in service during operation;
- not to interfere with the implementation of production processes in the development;
- to be resistant to corrosion and decay;
- to ensure minimum material and labor costs for the construction and operation of the lining.

Influence of vibration on the lining

Vibration is a mechanical oscillation: a combination of impact and alternating load. Tension or compression deformations occur when oscillations propagate in a solid. Wave motion is an oscillatory process in which the oscillation energy is transmitted in the direction of wave propagation. The cause of the oscillatory process is constant or single external influences. As a rule, single external oscillations are harmonious and obey the sinusoidal law. Oscillations are constant with a constant impact of forces; oscillations turn into damping when the action of forces ceases.

If the solid in which the oscillation process takes place is based on an elastic base, then the vibrations are reflected from this base, and the waves go in opposite directions. The phenomenon of resonance, that is, the summation of the vibrational wave energies may occur. Resonance can also occur under the action of a variable in time, but constant in duration load. The impact of an impulse can create waves that go parallel to each other and overlap, increasing the amplitude of the oscillatory process. Resonance is undesirable for the construction, as it leads to the destruction of the construction of any strength (Gao et al., 2018).

Direct and reverse impulses (compression and tension) of the oscillatory process alternate each other. Alternating loads appear in the solid, which leads to the phenomenon of material fatigue and destruction of its structure. Fatigue always occurs, but the time of steady state may be different. It depends on the strength of the impulse of the oscillating wave impact and the strength characteristics of the construction. These elements are determined only by experience (Lu and Zhao, 2013).

To ensure the strength of the concrete lining, the stresses arising in the construction must meet the following condition:

$$\sigma = \frac{R_{im}}{A_{im}} \leq [\sigma], \tag{1}$$

where R_{im} is the impact force; A_{im} is the area of the impact: for the lining of a circular cross-section $A_{im} = \pi d \frac{\lambda}{2}$, where d is the diameter of the lining, λ is the wavelength of the impact; $[\sigma]$ is the permissible tensile or compressive stress for the concrete lining.

The impact force can be determined in two ways.

1. Based on the theory of oscillations of mechanical systems, harmonic oscillations are described by the equation (Birger, 1968):

$$x = A\sin(\omega t + \varphi), \tag{2}$$

where A is the oscillation amplitude; $\omega = \frac{2\pi}{T}$ is the circular oscillation frequency, where T is the oscillation period; t is the current time; φ is the initial phase.

With harmonic oscillations the speed and acceleration also change according to the harmonic law:

$$\upsilon = A\omega\cos(\omega t + \varphi); \tag{3}$$
$$a = -A\omega^2\sin(\omega t + \varphi) = -\omega^2 x. \tag{4}$$

According to Newton's second law:

$$F = ma = -mA\omega^2\sin(\omega t + \varphi) = -m\omega^2 x. \tag{5}$$

2. Evaluation of the concrete quality can be carried out by the impact wave method, which is based on measuring the velocity of propagation of longitudinal waves in it, caused by mechanical impact. In its physical essence, the impact wave method is based on using of the dependence "R_b – v_{im}", where R_b is the indicator of the concrete compressive strength; v_{im} is the speed of the impact wave.

According to the condition, the impact force must be such as to ensure the creation of a sound impulse in the construction, but not even cause a local violation of the concrete structure. The generated sound impulse propagates at a certain speed in concrete. To determine the speed on the surface of the investigated construction, it is necessary to install two sound receivers sequentially at a given distance. The sound impulse received by the first receiver is converted into an electrical signal, which turns on the microsecond meter after amplification.

When it reaches the second sound receiver, the sound wave, in the same way, turns off the microsecond meter, which will record the distance between the two sound receivers by the sound pulse.

The speed of the sound wave of a mechanical impact is calculated by the formula:

$$\upsilon_{im} = \frac{l}{t_{im}}10^3, \tag{6}$$

where l is the distance between the sound receivers; t_{im} is the time of propagation of the impact wave.

The strength is determined on the basis of the dependence "R_b – v_{im}".

The value of R_b for concrete can be calculated by the following formulas:

for $R_b \leq 30 MPa$

$$R_b = q\upsilon_{im}^4; \tag{7}$$

for $R_b > 30 MPa$

$$R_b = \frac{R_0\upsilon_{im}}{8,87\upsilon_0 - 7,87\upsilon_{im}}, \tag{8}$$

where q is the coefficient calculated as $q = \frac{R_b^{act}}{\upsilon_{im}^4}$, where R_b^{act} is the actual compressive strength of concrete; R_0 is the strength of concrete at the construction site, where the maximum velocity of the impact wave v_{max} was found not less than at five sites; v_0 is the initial velocity of the impact wave.

The proposed vibration-resistant structure of the lining

A promising construction that extends the use of various materials for securing workings in difficult conditions is a multi-layer combined lining.

For effective sound absorption and vibration isolation, the following lining construction is proposed (Fig. 1).

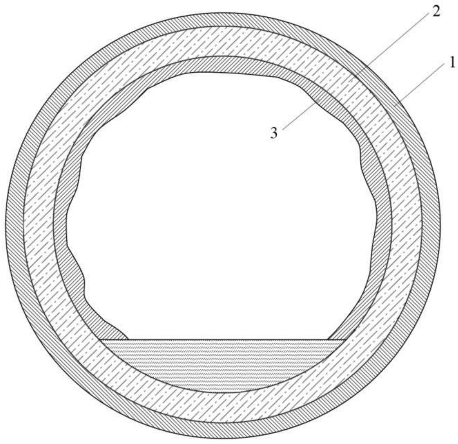


Fig. 1. The proposed construction of a fiber-reinforced lining: 1 is the layer of reinforced foam concrete; 2 is the layer of precast fiber concrete; 3 is the sprayed concrete layer.

The lining has a circular cross-section, which is the best option both in terms of structural parameters, providing durability and reliability, and in ease of manufacture.

The design of the lining is three-layered, consisting of three shells with a layer of moving material between them. The middle layer (2) is load-carrying and has a rigid structure. The outer (1) and inner (3) layers are pliable and vibration-proof, providing sufficient resistance to the displacement of the output circuit in the formation of fracture zones. The material for the load-carrying layer (2) is selected depending on the geological conditions and is calculated by the formulas (1)-(8). The materials used to create a pliable layer must meet the requirements of sufficient strength and the ability to resist loading, sufficient cheapness, the ability to work for a given service life of production, as well as technological applications in real conditions. In the proposed lining construction as the material of the outer layer (1), it is recommended to use non-autoclaved foam concrete reinforced by polyethylene terephthalate fibers (PET fiber) (Domnina and Pivarciova, 2019; Qaizada et al., 2016). This layer is intended for damping natural and human-made vibrations, and one of the conditions for its creation is that both the material of the layer and the reinforcement must dampen vibrations. Foam concrete absorbs sound and vibration well without reflection due to the cellular structure. PET fiber is a high-strength polymer material (Sviatskii et al., 2018). The polymers simultaneously possess the properties of both liquids and solid elastic and plastic bodies. Plastic deformations absorb impact load by changing their own shape, and they do not return to their original shape and size. Plastic materials during operation accumulate changes in shape before losing steady state as supporting structures, and they must be calculated for a certain number of strokes, after which they are not workable. It is necessary to take into account, plastic deformation due to large forces often turns into deformation of fluidity, in which the action of the impact force is not felt, there is only the movement of the compressed layer. However, when elastic barriers are reached, the impact may remain noticeable, so it is more advantageous to use plastic deformations rather than fluidity deformations. Plastic deformations absorb impact without return.

The middle layer of the lining (2) is proposed to be made of heavy concrete. The lining construction is assumed to be in block design.

The usage of the sprayed concrete as the inner layer of lining (3) allows simplifying the process of attaching a pliable layer on the walls of the middle layer significantly. As a pliable element, sprayed concrete with PET fiber inclusions can be considered. The significant difference of such an element is that the bearing element in the composite is the matrix, and the pliable element is the inclusion of fibers. After the stresses in the matrix reach their limit values, the matrix is destroyed, and the pliable elements, in this case, they are PET fibers, provide the movement of the contour of production on the technologically acceptable value.

As a moving material between the layers, it is proposed to use graphite deposition with a thickness of up to 5 microns. The purpose of graphite is to reduce friction between concrete layers.

Impact-wave model of ring deformation from external seismic and impulse loads

In our case, the most realistic model of impact deformations is presented in Fig. 2. It is convenient to consider a separate layer of lining as a rod along the line of action of the impact force P_z: $L = d_r$, where d_r is the diameter of lining ring. Since the speed of passage of an impact wave is close to the speed of sound, and the rate of deformation of the layer of lining as a ring is too slow, it can be neglected. During this time, the impulse will have time to deform the entire material of the layer, and the shape of the ring will not change. If the impulses come with great frequency, the ring can break from the fatigue of the material, and not from changes in its shape.

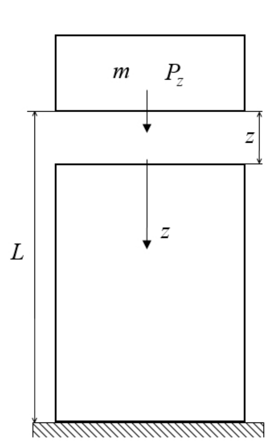


Fig. 2. Impact scheme: L is the length of the rod, v is the speed of the impact force, m is the mass of the soil.

Between the impact force and the rod, there is an element with a certain compliance δ. In our case, this element is the outer layer of the lining (1) made of fiber foam concrete). Since plastic deformation goes layer by layer, the next stage of the continuation of the impact deformation repeats the first one with the only difference that the length of the rod becomes less by the amount of plastic deformation of the previous layer Δz. The impact speed remains constant. The work of the impact force is not only on the course of deformation but also on the heating of the deformable layer of material (Virieux et al., 2012).

So the mathematical model of impact -wave deformation of the lining ring from external seismic and impulse loads can be represented by (Repko, 2005):

$$\left.\begin{aligned} & P_z = \frac{v}{\delta k_1 c} \cdot e^{-k_2 cT} \cdot \sin k_1 cT; k_1 = \sqrt{\frac{1}{E \cdot F \cdot \varsigma \cdot L \cdot \delta} - \frac{1}{(2EF\delta)^2}}; k_2 = \frac{1}{2EF\delta}; \\ & P_{-z} = \frac{\frac{\pi \cdot l}{W}\tau_n \cdot v(L-W)}{v^2 \cdot \Delta T_0 - W \cdot v} \cdot z^2 + \left[\frac{\tau_n \cdot \pi \cdot l \cdot (L-W)}{W} - \frac{\pi \cdot l \cdot \tau_n \cdot v(L-W)}{v^2 \cdot \Delta T_0 - W \cdot v}\right] \cdot z; \\ & \frac{cT}{L} = \pi\sqrt{\varsigma}; W = \frac{4(1-v^2)P_z}{\pi \cdot b \cdot E} \cdot \frac{\pi}{2}; l(P_z = 0) = 0; \\ & U_m = \frac{mv^2}{2}; \tau_n = [\tau_n]; \tau_{\min} = 0{,}01[\tau_n]; z = v \cdot T; \\ & \Delta\theta = \frac{z_0 - \left[\left(1 + \frac{vP_z}{2abE}\right)z_0 - \frac{P_z}{bE} - \frac{v}{2}\frac{P_z^2}{a \cdot b^2 \cdot E^2}\right]}{\beta \cdot z_0} \le [\theta], \end{aligned}\right\} \qquad (9)$$

where P_z is the impact force;

v is the speed of the impact force;

δ is the coefficient of compliance of the outer fiber foam concrete layer;

c is the speed of the impact wavefront;

T is the compression time per a single stroke;

E is the modulus of elasticity of concrete;

F is the cross-sectional area of the rod;

ς is the mass equivalent to the part of the mass enclosed in a strip of positive or negative impact wave of the oscillatory process of the soil;

L is the rod length;

P_{-z} is the impact resistance force;

l is the width of the load bearing support;

W is the volume of the compressible lining layer;

τ_n is the ultimate shear stress occurring in a lining layer;

ΔT_0 is the duration of one impulse;

z is the impact half-wave length: $z = \frac{\lambda}{2}$;

cT is the length of the passage of the impact wave;

a, b are parts of the impact area;

U_m is the impact energy;

m is the mass of the soil located in the strip of positive or negative impact wave and transmitting vibration to the structure of the lining;

$[\tau_n]$ is permissible ultimate tangential stress;

τ_{min} is minimum tangential stress;

$\Delta\theta$ is the temperature difference before and after impact;

z_0 is the value at which the maximum tangential stresses τ_{max} occur at the impact force P_z, leading to plastic shear;

β is the coefficient of volumetric thermal expansion of concrete;

$[\theta]$ is the permissible temperature in the impact zone.

Using the task (9) the stresses arising from vibrations and the heating temperature of concrete rings from the action of impact waves are determined. It is necessary not only for the modeling of strength and stability of constructions to vibration but also to establish the safety of explosive proportions of combustible gases in the mine.

Fatigue issues require a separate approach. It is necessary to conduct a number of experiments to determine the fatigue of concrete, and the results of the experiments should be compared with the conditions of the passage of impact waves in specific mines.

Visualization and analysis of concrete temperature fields

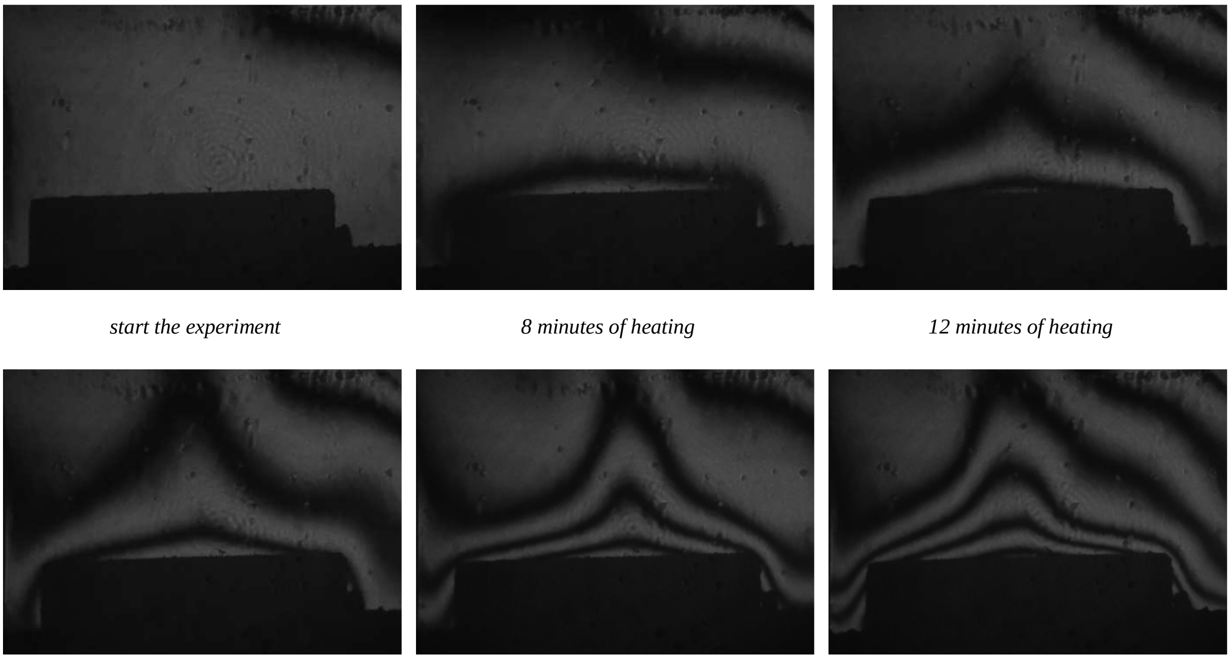
Monitoring of the stress resulting from the heating temperature of the concrete rings from the impact of the impact waves is necessary to determine the safety of explosive proportions of combustible gases in the mine (Xiaobing and Xueping, 2011).

Therefore, part of the research was devoted to the visualization and analysis of temperature fields over heated samples of concrete reinforced with polyethylene terephthalate (PET) fibers, which are obtained by recycling polyethylene terephthalate waste.

Holographic interferometry was used to visualize the temperature fields. This method has been able to detect temperature fields without touching and to monitor and record in real time the on-going process in the boundary layer at the concrete interface – the ambient environment. By a quantitative analysis of the images of holographic interferograms, the temperatures of the isothermal curves above the heated samples were determined.

The goal was to gain new knowledge about the thermal properties of concrete. The samples of size 40×40×15 mm were used to measure heat transfer. An infrared emitter with a power of 225 W was used as a source of heating.

In Fig. 3, we can see the course of temperature fields above the heated sample. We can observe a uniform increase in the thickness of the thermal boundary layer. Interference strips represent isothermal thermal field curves. By a quantitative analysis of holographic interferograms, the temperatures of the isothermal curves were determined. For more information about the method used and the relationships used, see the literature (Pivarciova and Cernecky, 2011; Černecký et al., 2014).



start the experiment — *8 minutes of heating* — *12 minutes of heating*

14 minutes of heating — *22 minutes of heating* — *31 minutes of heating*

Fig. 3. Holographic Interferograms of concrete temperature fields.

In Fig. 4, there is a graph showing the temperature above sample calculated from holographic interferograms.

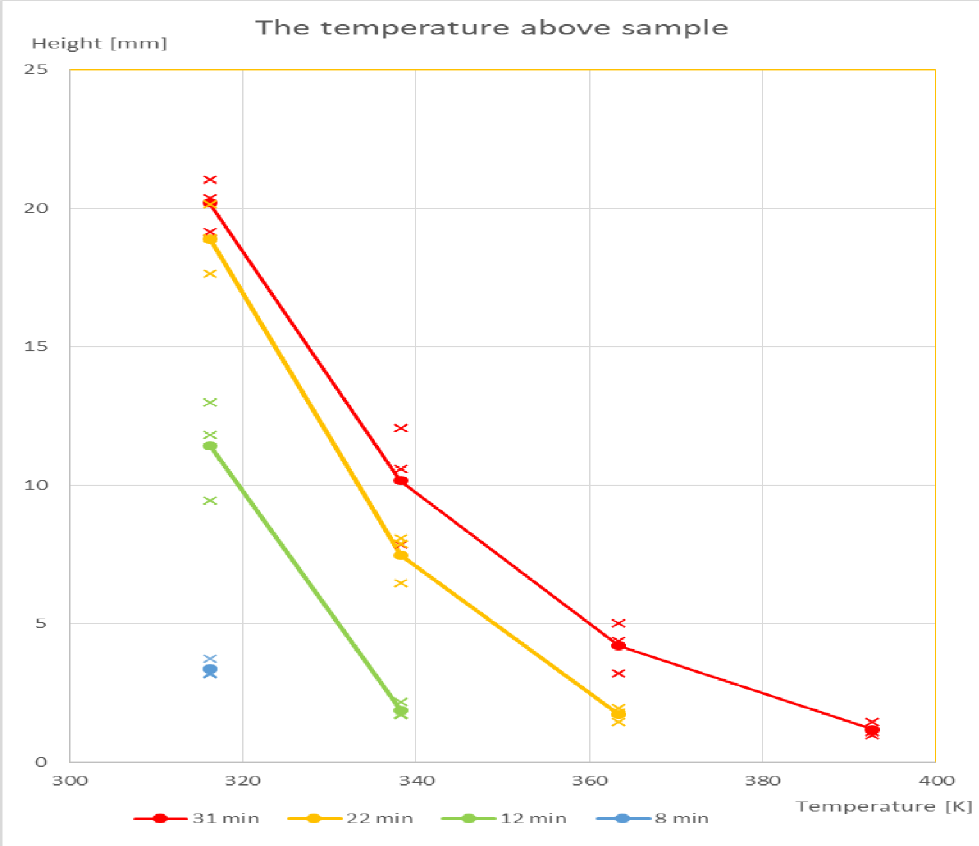


Fig. 4. Temperature above sample.

Heat transfer is a combined case of heat sharing between two fluid-separated walls. From warmer fluid to solid wall, heat passes through convention, conduction, and radiation; solid wall transmits heat through conduction and from the wall to the cooler fluid again by convection, conduction, and radiation.

Along the solid wall in the direction of the liquid stream, a thin layer of fluid is formed, called the thermal boundary layer. It is formed by the adhesion of the fluid molecules to the surface of the solid body. Sharing of heat in this layer is only convection as if the fluid was still. The large temperature gradient in the boundary layer results from the low thermal conductivity of the fluids.

In the transport process, it is also difficult to find that their mathematical analysis is only possible with a number of simplifications, but it also gives rise to systems of differential equations which in many cases cannot be solved. Due to the complexity of the theoretical solution of transmission phenomena by mathematical and modeling methods, which always presuppose certain simplifications, optical methods can be used to solve these problems.

One possible application of holographic interferometry is to visualize the temperature distribution. The interference method allows not only to evaluate the observed phenomena quantitatively, but also gives a comprehensive picture of the size and shape of the temperature fields at a given time, and the measured values are not influenced by the sensor. Another advantage of this method in real-time is the possibility of recording the entire time course of heating. This method allows monitoring the temperature field as a whole, not just local variations, as measured by thermocouples.

The demonstration of the temperature field in the neighborhood of the heated oven in the case of natural convection of air is shown in Fig. 5. In the interferogram image, the temperature boundary layer is visible, in which the air flows upwards. Behind the boundary layer is the surrounding environment with constant air temperature. The thermal boundary layer gradually evolves around the circumference of the oven and extends towards the top. This expansion of the boundary layer causes a reduction in the temperature gradient as well as a reduction in the heat transfer parameters.

An experimental and numerical investigation of the influence of insulation defects on the thermal performance of walls is deal work (Nardi et al., 2019).

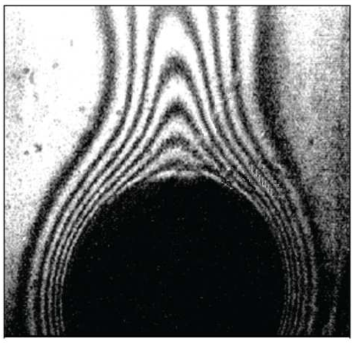


Fig. 5. Demonstration of the holographic interferogram of the temperature field in the surroundings of the heated oven in the case of natural convection of air.

Results and Discussion

In our research, we proposed a new construction of a three-layer vibration-resistant rigid-pliable lining for mine workings. Multi-layer concrete constructions are good because they simultaneously have high strength, wear-resistant, sound insulation, and low thermal insulation properties.

Depending on the purpose and conditions of operation, multi-layer concrete constructions can be used as road surfaces in Siberia and the Far North and airfield coatings. Rational distribution of materials in depth should be established on the basis of the laws governing the formation of a stress-strain state of the structure.

They can also be a solution to the problem of sound insulation of compressor stations and busy highways (usage as enclosing panels). In recent years sound insulation instructions and standards have been updated. The main factor in the updated instructions affecting modern construction is the tightening of the requirements for isolation from impact noise. Problems of reduced stress in mining are also devoted to work (Baranov et al., 2017).

Thanks to the developed mathematical model (9), we can also predict impact-wave and heat deformations of the lining ring from external seismic and impulse loads. In the future, it is necessary to build the methodology for refining the mathematical model based on the calculated experiment.

The course of temperature fields above the heated sample is also studied. As we can see in Fig. 3, the thickness of the thermal boundary layer increases uniformly. The results of the interferometric visualization of the temperature fields are represented by the images of interferograms. Based on holographic interferograms, the temperature above the samples was calculated (Fig. 4). In the future, we can conduct a qualitative and quantitative analysis of interferograms, which will allow us to determine the local heat transfer coefficients α necessary for subsequent calculation of the heat conductivity coefficient λ.

Conclusions

The creation of safe conditions for the operation of underground facilities is one of the main tasks of ensuring the stability of mine workings.

Today, in conditions of great depths and external dynamic loads, it is necessary to ensure not only the strength of the linings but also their resistance to seismic and vibration effects. The solution of this problem is the usage of multi-layer combined linings, which expand the possibility of using various materials for fastening openings in difficult mining and geological conditions.

At this stage of research, the construction of a three-layer vibration-resistant rigid-pliable lining for mine workings has been developed. It is distinguished by the fact that the pliable outer layer is made of foam concrete reinforced by PET fiber, and the inner layer is the sprayed concrete layer with PET-fiber reinforcing. The middle layer is a closed concrete ring of rigid lining, ensuring the stability of the mine workings during given service life.

Further researches are aimed at exploring the prospects of creating mixed multi-layer types of linings.

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