Improvement of openings strength in cryolithic zone

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Abstract
Some experimental results of mine openings improvement in continuous permafrost zone by applying the heat insulation are set forth. Thermal protection problems of frozen rocks at high positive air temperatures in mine openings are considered.
Keywords: MINE OPENING, FROZEN ROCKS, HEAT INSULATION, THERMAL PROTECTION

For reasons of safety the thermal protection must be used for underground facilities of cryolithic zone (continuous permafrost zone). These facilities under operation have freeze-thaw indoor temperature and their rock strength parameters are changed considerably while thawing [1, 2, 3]. As a rule the synthetic materials based on foamed polyurethane and lightweight concretes are used for rocks heat insulation [3, 4, 5]. Theoretical and experimental researches showed that the using of foamed polyurethane coatings is an efficient mean to ensure the specified parameters of thermal conditions in underground facilities of cryolithic zone and in stable mine openings. The results of investigations carried out in experimental opening in mountain mine of southern Yakutia, where the thermal protection made of foamed polyurethane of PPU-4n grade was used, allowed to discover basic regularities of thermal conditions formation in heat-insulated mine openings [4,5]. In particularly it is established that the heat insulation highly reduces the heat-exchange rate between air and rocks. For example, the air temperature difference along the length of mine opening in the heat-insulated area was 0.3 ºC/m while in the area without heat insulation it was almost three times higher – 0.8 ºC/m. Evaluation of test data indicated that the heat insulation reduces the temperature difference along the length of mine opening in average by 0.2 ºC/m. In such a case with the increasing of initial temperature the role of heat insulation also increases greatly. The thermal effectiveness of aeration in experimental opening can be defined by the quantity of heat, which denotes the heat content differential of intake and return air (Q_J) in various areas.

Calculated values (Q_J) in the opening areas with heat insulation and without it are given in Table 1. Obtained values differ essentially from each other giving evidence of more intensive through heating of the frozen rocks in the area without heat insulation.

Table 1. The heat-exchange rate in various areas of experimental opening

Characteristic of the areas	Air-flow rate kg/s	The temperature at the beginning of an area °C	The temperature at the end of an area °C	Relative humidity at the beginning of an area, %	Relative humidity at the end of an area %	Heat-exchange rate, J/s
with heat insulation	1.04 1.01 1.95 1.62	6 16 22 28	4.7 13.8 19.1 24.5	60 58 42 24	70 62 44 24	861 2121 4907 10904
without heat insulation	1.04 1.01 1.95 1.62	6 16 22 28	4.3 12.5 18.2 21.6	70 62 50 28	94 76 62 36	1309 4650 14840 14350

Observations over the temperature field around the experimental opening in order to define the impact of insulating blanket on thermal conditions of rocks were fulfilled. It is established that the heat insulation greatly reduces the rate of heat accumulation process by rock formations and prevents the propagation of positive temperatures into the depth of the solid.

The heat insulation, installed on the roadway sides, which is 5 – 7 cm in thickness, reduces the depth of thaw halo twice. However, the rocks temperature oscillations practically die decay even at 1,5 – 2 meters from the roadway side.

Comparative data evaluation indicates that the heat insulation increases the starting time of rocks around the opening thawing, at that the time of positive temperature appearing in the roadway sides depends on thickness of heat insulation and in-situ temperature of frozen rocks. For example, if the heat insulation depth is 3 cm (T_e = -0,68°C) the thawing of frozen rocks starts in a day but if the depth is 5—7 cm (T_e = -1,1°C) it starts in three days after the beginning of aeration. In the area without heat insulation (T_e = -1,5°C) the thawing of rocks started in 16 hours. The results of experimental researches also suggested that the thawing speed of rocks over the heat insulation is lower than on areas without heat insulation: the speed of thaw halo over the heat insulation 6 cm in thickness is twice lower than on areas without heat insulation. It should be noted that the change rate of thaw halo is high during only the first 10 – 12 days of opening ventilation by the air with positive temperature. As time passes it decreases sharply, at that the speed reduction rate in the heat-insulted areas is much higher.

In accordance with the results of field observations the following conclusions can be made:

1. In the heat-insulted areas the air temperature oscillations are slight as the rate of heat-exchange with rocks decreases sharply.
2. The heat insulation in the roadway side highly reduces mass transfer rate as the immediate contact of air with watered surfaces of opening is avoided.
3. During openings aeration the heat-insulation layer which is in sides highly reduces the heat accumulation process by frozen rocks. For example, the heat insulation 5—7 cm in thickness reduces the thaw depth twice, at that the change rate of thaw halo over the heat insulation is 2 times lower than in the areas without heat insulation.
4. The heat insulation of mine openings is the efficient mean of mine air conditioning, which allows providing required thermo-humidity conditions of air flow and decreases the thawing depth of rocks around the opening.

The disadvantages of foamed polyurethane coatings are their low strength properties and difficulties with overcoating in underground conditions by reason of evolving of harmful gases in large volume when solidifying. In that context we have developed new load-carrying thermal protection coatings based on lightweight shotcrete [4,6,7,8]. The distinction of these coatings is increased thermal resistance at the constant strength. The latter is obtained by making the thermal protection coating laminated, which means that load-carrying solid layers and light heat-insulated layers interstratify. Shotcrete technique allows obtaining such construction within a single cycle by content changing of porous aggregate and sink in charge blending.

The substantial defect of most heat insulation materials and protective structures based on them is almost constant heat conduction coefficient, which varies depending on temperature slightly. When the object with positive temperature is under operation the heat insulation ensures the frozen condition of rock formations and as consequence their strength. But heat insulation hinders rocks cooling when the temperature is lower than phase transformation of moisture in rocks and in-situ temperature of rock formations. Our researches showed [1,3,4] that the thickness of heat insulation, providing safe operating mode of an object at positive air temperature, will be the smaller, and, consequently more efficient economically, the lower the temperature of surrounding rock. Therefore such depth will be economically more efficient. Hence, it is evidently that the traditional thermal protection fulfils both positive and negative roles in considered operating conditions of objects. In the field it involves the necessity of either substantial increasing of the heat insulation depth or using of reinforced support, which leads to additional costs. In such cases the usage of universal thermal protection coating with the variable thermal resistance is the most effectual. When the air temperature in construction is subfreezing the surface heat resistance is minimal, which provides effective cooling of rocks. But when the positive temperature of indoor environment the surface heat resistance increases, moreover the higher is air temperature, the more it increases. While changing the temperature from positive to negative the heat resistance of protective coat decreases and attains the initial value.

For the implementation of this idea we have suggested the original design of elementary coating unit consisting of laminated elements which are interconnected in a certain manner and elements with the linear expansion coefficient, which changes substantially. When the temperature is subfreezing the coating unit poses sufficiently hard-textured laminated material, the layers number of which is determined by the range of possible variation of operation temperature. With the increasing of the temperature laminated material softening takes place due to air gaps appearing between layers, and the heavier is heat flow having an effect on surface, the bigger are air gaps. At that, air gaps diminish or grow in size proportionally to transverse temperature gradient in the coating. Thus, the higher is air temperature in opening, the higher is heat resistance in the unit of such coating. With the decreasing of the temperature the air gaps are reduced, some layers are joined and heat resistance of the surface decreases sharply, which allows efficient cooling of rock formations. The calculation method of universal coating elementary unit has been developed; it allows determining the heat resistance changes depending on heat-flow rate and indoor temperature and also determining the design optimal parameters of coating unit.

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