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Influence of temperature factor on the speed of strength gain of modified concrete of workings support

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Abstract. The article analyzes the influence of the temperature of the medium on the speed of strength gain of concrete of workings support. For these purposes, comparative tests of concrete samples at the age of 0.5, 1.0 and 3 days were carried out. As a result of data processing, the dependences of the strength of concrete of support at an early age at different hardening temperatures were obtained. A method for predicting of concrete strength considering the temperature and parameters of the technological cycle of attachment was developed. With this technique, it is possible to more accurately determine the parameters of concreting, reduce the time of Stripping of monolithic support and increase the speed of penetration of workings.

1 Introduction

The temperature factor has a significant impact on the efficiency of construction and operation of underground facilities. During operation, changes in temperature can lead to increased corrosion of the support and surrounding rocks. As a result of such changes, the safety margin and durability of structures are reduced, there is a need for expensive repairs [1-7]. Redistribution of stresses in the "support – array" system with temperature change [8-13] can lead to deterioration of geomechanical situation in the workings, crack formation and opening, formation of local areas of damage and excessive deformation of the support.

During construction, the temperature has a significant impact on the process of gaining strength of concrete of support. Currently, modified concretes with high performance properties are widely used for fixing underground structures. Production of such concrete in Russia is based on the use of concrete modifiers MB series. The inclusion of these modifiers in the concrete composition allows providing:

- high compressive strength of concrete (up to 80-100 MPa) and more;
- high-strength of concrete in tension up to (6 - 8 MPa), and more;
- low water permeability equivalent to concrete grades W12-W20 and more;
- low shrinkage and creep;
- high frost resistance equivalent to concrete grades F400 - F 500 and more;

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- increased corrosion resistance and durability.

Also one of the important advantages of modified concrete is a quick set of strength at an early age. With regard to the fastening of vertical barrel, it creates the prerequisites for accelerated Stripping of the stowage support and increasing the technical and economic indicators of the fastening.

However, most of the studies of the strength of modified concrete is carried out under normal conditions at a temperature of 20 + 2 °C, which does not meet the real conditions of the construction of the support in underground conditions.

2 Statement of research objective

To quantify the effect of temperature factor on the dynamics of strength gain of modified concretes, the samples of modified concrete of three compositions were tested for compression at different temperatures of the concrete mixture.

The following materials were used for the preparation of concrete:

1. Portland Cement M500 D0 (C) with activity at a steaming of 38,0 MPa, the density of the cement paste is 25%, the mineralogical composition of: C_3S=65%; C_2S=19%; C_3A=6%; C_4AF=10%; $CaSO_4 \cdot 2H2O$=4%, which corresponds to GOST 10178 and to GOST 30515.
2. Large aggregate (Cr) – crushed granite, fractions of 5-20 mm.
3. Fine aggregate (S) – quartz sand, the module of fineness Mf=2,5.
4. Tap water (W).
5. Modifier concrete MC-50 (MC).

The characteristics of the studied compositions are presented in the table 1.

Table 1. Characteristics of concrete mix compositions and properties

No	Composition of concrete mix					Characteristics of concrete mix				
	C, kg/m^3	MC, kg/m^3	S, kg/m^3	Cr, kg/m^3,	W, l/m^3	SC*, cm	γ, kg/m^3	W/S	W/C	MC/C
1	320	55	690	1120	170	22	2355	0,45	0,53	0,17
2	360	45	705	1120	170	20	2400	0,42	0,47	0,13
3	380	35	730	1090	170	18	2405	0,41	0,45	0,09

*Note: in table marked with: SC – Slump measurement; γ – the density of the concrete mix; W/S – water-solid ratio (ratio of water flow to the sum of cement and modifier flow).

The cubic strength of concrete for compression was determined on the samples of 100x100x100 mm at the age of 0.5, 1.0 and 3.0 days in accordance with state standard 10180, except for the hardening temperature, which was varied in the range 10 to 30 °C.

3 Research result

The results of determining the strength of the modified concrete of support at an early age are presented in table. 2.

Table 2. Compressive Strength of modified concrete at an early age at different hardening temperatures

Hardening temperatures	Composition number	Average strength, MPa, at the age of		
		12 h	24 h	3 days
10°C	1	0,8	5,5	18,8
	2	1,0	6,7	23,2
	3	1,4	7,1	24,4
20°C	1	5,6	13,7	22,8
	2	8,2	16,6	27,5
	3	6,6	17,3	28,9
30°C	1	16,4	21,0	27,2
	2	20,2	25,9	33,5
	3	21,7	26,6	35,0

Figure 1 shows the graphs of the dependence of relative strength of concrete (in parts of the project strength) from the time of hardening at different temperatures. The graph shows the average data obtained from the tests of the three compositions.

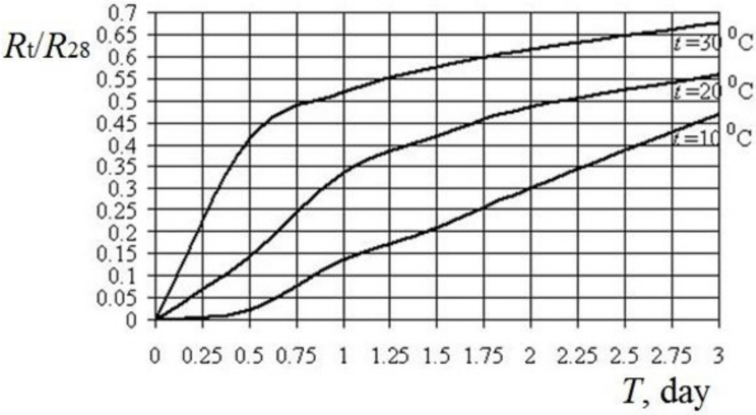

Fig. 1. The graphs of the dependence of relative strength of concrete from the time of hardening at different temperatures.

Analysis of the data shows that the deviation of the concrete hardening temperature from the normal one leads to a significant change in the speed of strength gain of the modified concrete. At t = 10 ºC only after 12 hours of hardening concrete gains strength, close to the Stripping. In General, after 12 hours of hardening, the strength of concrete on average is 2.5% of the project one, at the age of 1 day = 14%, and at the age of 3 days – 47% of the project strength.

Concrete hardening at T = 30 ºC is characterized by the intensification of concrete strength gain: after 12 hours of hardening, the strength is 41%; after 1 day – 52%; after 3 day – 67% of the project one.

Consider the method of accounting for the temperature factor on the example of vertical mine shaft.

In the period of sinking vertical shafts are dead-end workings. The air temperature in the vertical shafts of the mine varies both in depth and in cross-section. It depends on the temperature of rocks and atmospheric air on the surface, the amount of air supplied to the bottom-hole space for ventilation, heat dissipation during blasting and operation of equipment, water cut and other factors [14-18]. In this case, the depth of the mine shaft plays a decisive role.

So with depth there is an increase in air temperature, which occurs mainly due to the thermal conductivity of rocks and the intensity of heat release from them, as well as due to the compression of air when it is lowered into the mine shaft. For the conditions of the Eastern Donbass mines, the temperature of rocks to a depth of 16.4 m, where a layer with a constant temperature of 10°C lies, varies depending on the air temperature on the earth's surface. The temperature of rocks below the layer with a constant temperature at a geothermal gradient of 33 m / °C is

$$t_p = 10 + (H - 16.4)/33, \quad (1)$$

where H – the depth at which the temperature is determined, m.

When the air in the mine shaft is lowered due to adiabatic compression, the air temperature rises by about 1°C for every 100 m of the mine shaft depth. The increase in air temperature in the mine shaft is also due to the heat generated during the operation of machines, especially machines with electric motors. For example, according to Shakhtinsky research and design coal Institute, fan “Prokhodka 500-2m" can increase the temperature of the surrounding air by 8 - 10° C. The increase in air temperature in the mine shaft is also due to the heat generated during blasting [19].

At the same time, it should be noted that the sinking of the mine shaft is accompanied by some processes in which heat is absorbed. Among these processes, the evaporation of water is of great importance. It is known that the evaporation of 1 g of water reduces the temperature of 1 m^3 of air by about 2°C.

Air entering the barrel from the surface usually has low humidity (about 50-55 %). The air coming from the surface is saturated with moisture and absorbs a large amount of heat, which contributes to a significant overall cooling.

Similarly, when the expansion of compressed air, exhaust mechanisms, there is a significant cooling. So, 1 kg of compressed air with free expansion reduces the temperature of 1 m^3 of air by 2.4°C.

Water falling from the upper horizons to the bottom of the barrel also contributes to air mixing and air cooling.

So, the air temperature in the passable barrel depends on variety of factors that are difficult to express a single dependence and most accurately it can be determined by direct measurements.

Generally the temperature of the air in the barrel should be considered in terms of the impact on the temperature change of the concrete mixture and concrete after laying it behind the formwork and after determining the optimal time of Stripping.

To predict these parameters, we propose to use the B. G. Skramtaev's equation of heat balance [20]. Apply to the fastening of vertical mine shafts, this equation can be represented as follows

$$\tau = \frac{\gamma \cdot C\left(t_{in} - t_f\right) + \alpha \cdot C \cdot H \cdot R}{86.4 \cdot K \cdot M_p\left(t - t_b\right)}, \quad (2)$$

where γ – volume weight of concrete mix, kg / m^3;

C – specific heat of concrete, kJ /(kg °C);

t_{in} – initial temperature of the laid concrete mix, °C;
t_f – final (calculated) temperature at the time of Stripping, °C;
α – the intensity factor of heat dissipation;
C – cement consumption per 1 m^3 of concrete, kg;
H – heat dissipation of 1 kg of cement during 28 days of hardening at 20 °C, kJ/kg;
R – the Stripping strength of concrete in % of the project one;
M_p – surface modulus of the support sinking, m^{-1}

$$M_p = \frac{F}{V};$$

F – total cooled surface of the sinking, m^2;
V – the volume of concrete of the support sinking, m^3;
t_c – the average temperature of concrete for the time τ, determined by the formula

$$t_c = t_f + \frac{t_{in} - t_f}{1.03 + 0.181 \cdot M_p + 0.006\left(t_{in} - t_f\right)};$$

t_b – average air temperature in the barrel for the time τ, °C;
K – the heat transfer coefficient of the formwork, $W/m^2 \cdot °C$, is determined by the formula

$$K = \frac{1}{\frac{1}{\alpha_i} + \frac{\delta_i}{\lambda_i}};$$

α_i – heat transfer coefficient at the outer surface of the formwork, $W/(m^2 \cdot °C)$;
δ_i – the thickness of the formwork section m;
λ_i – the coefficient of thermal conductivity of the formwork material, $W/(m^2 \cdot °C)$.

3 Research result

The use of the proposed method at a certain temperature in the barrel will allow to determine the parameters of concreting more reasonably. In turn, it creates the conditions for the optimization of the tunneling cycle, reducing the time of Stripping of the support and increasing the speed of penetration of workings.

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