The effect of the mobility of the concrete mixture on the air content and frost resistance of concrete

S M Tolmachov\textsuperscript{1,4}, G V Brazhnik\textsuperscript{2}, O A Belichenko\textsuperscript{1} and D S Tolmachov\textsuperscript{3}

\textsuperscript{1} Department of the Technology of Road Building Material and Chemistry, Kharkov National Automobile and Highway University, Yaroslava Mudrogo st. 25, 61002 Kharkov, Ukraine
\textsuperscript{2} Kharkiv State Automobile and Road College, Kotelnikivska st. 3, 61000 Kharkov, Ukraine
\textsuperscript{3} LLC “Modern infrastructure technologies”, Gvardijciv-Shyroninciv st. 33, office 84, 61170 Kharkiv, Ukraine

\textsuperscript{4} Email: Tolmachov.serg@gmail.com

Abstract. In the technology of building roads, bridges, buildings and structures, concrete mixtures of different mobility are used. It depends on the complexity of the design, equipment and technical requirements. The main requirement for any product or design is high durability. The main index of durability is frost resistance. To increase the frost resistance of concrete, an additional network of air pores is created. This network is formed through the use of air-entraining additives and when the concrete mix is mixed. Different quantity of air may enter in concrete mixes of different mobility. But an increase of the quantity of air involved leads to a decrease of concrete performance. Therefore, it is necessary to know the volume of air bubbles and how they change the properties of concrete. The work shows how the mobility of concrete mixtures affects on the amount of air involved. The results of studies of frost resistance of concrete made from mixtures of different mobility are presented.

1. Introduction

It is known that to increase the frost resistance of transport concrete, air bubbles are additionally involved in the concrete mixture. For this, air-entraining chemical additives are usually used [1, 2]. Moreover, the content by volume of air involved is very important [3, 4].

Studies conducted in this direction by various scientists have shown that every percent of air reduces concrete strength by 5 to 12\%. Therefore, the recommended amount of additional air involved in the concrete mix in different countries is limited to 3 to 7\% [5].

This amount depends from the maximum size of the aggregate used, the type and amount of chemical additives, type of cement. Studies by various scientists have shown that the greatest decrease of concrete strength corresponds to the content of air involved at the level of 4 to 6\% [6 – 10]. It also shows [10] that the additional amount of air not only reduces the strength, but leads to a deterioration of the performance properties of concrete (Table 1). With an increase of the air content in the concrete mixture, the water uptake and wearing value of concrete increases, for example.

From the presented results it is seen that with an increase of the amount of air involved, the compressive strength of concrete decreases significantly. In the range from 1.6 to 4.1\% of the air involved, the compressive strength of concrete is reduced by 9.5\% for each percent of the air involved. In the range from 4.1 to 6.0\%, the compressive strength is reduced by 9\% for each percent of the air involved.
Table 1. The influence of air-entrainment on the performance properties of concrete [10].

| №  | Air-entrainment, % | Compressive strength, MPa | Water uptake % |
|----|-------------------|---------------------------|---------------|
| 1  | 1.6               | 55.4                      | 2.5           |
| 2  | 4.1               | 42.3                      | 2.6           |
| 3  | 6.0               | 35.1                      | 2.8           |
| 4  | 8.0               | 29.5                      | 3.1           |
| 5  | 9.5               | 27.6                      | 3.4           |
| 6  | 12.0              | 23.4                      | 3.8           |

With a further increase of the amount of air involved, the reduction in compressive strength is from 4.3 to 7.9 % for each percent of air involved. Simultaneously with the increase of the content of entrained air, the water uptake of concrete proportionally increase. Therefore, the content of air involved in the concrete mixture is an important parameter that allows you to adjust the properties of concrete. The air that is contained in the concrete can enter in it by two ways. The first way is the action of air-entraining chemical additives. The second - air can enter into the concrete mixture when it is mixed in a concrete mixer.

For the construction of canals, bridges, and more recently for road surfaces, concrete mixes of high mobility are used. High mobility concrete mixtures are also used for the construction of multi-story buildings. Air-entraining additives are not always introduced into their composition. In such mixtures of varying mobility, air bubbles are drawn into the mixture by concrete mixer blades during mixing of the concrete mixture.

There are no studies in the literature that show how the mobility of the concrete mixture and the content of air involved are related. Of particular importance for transport concrete is their frost resistance, since this is the main index of durability, which depends from the amount of air involved.

Therefore, studies are relevant that will establish how the mobility of the concrete mix affects on the content of air involved and frost resistance.

2. Materials and methods of research

Were used: the cement of the PC I-500-N (CEM I 52.5N) of the Balakleya plant, crushed stone fr. 5-10 mm, and fr. 10-20 mm, quartz sand with a size modulus $M_{cr} = 2.2$. In concrete mixtures were added chemical additive – superplasticizer Fk-88 produced by the Germany company MC-Bauchemie (0.8 % of the mass of cement).

The compressive strength of concrete was studied on samples-cubes with a size of 7x7x7 cm.

The testing of road concrete for frost resistance were carried out according to the basic procedure. There are two methods for testing road concrete for frost resistance: basic and accelerated. According to the basic procedure, samples made of concrete with a size of 70x70x70 mm are saturated in a 5 % solution of sodium chloride for 4 days, then each sample is weighed and numbered. Before the commencement of the freeze-thaw test, the test specimens are tested for compressive strength. The main samples that are subjected to freezing-thawing are placed in the freezer, where they are frozen for 4 hours at a temperature of $-18 \pm 2 ^\circ C$. After this, the samples are immersed in an aqueous solution of sodium chloride, where the samples are thawed at a temperature of $+18 \pm 2 ^\circ C$. Such a freeze-thaw is considered as one cycle.

Evaluation of the conformity of frost resistance of concrete to the design mark is carried out by comparing the change in the strength of the samples after the test and before it. If the reduction in the strength of concrete samples after testing is no more than 5 %, then it is considered that concrete has withstood the required number of freeze-thaw cycles and corresponds to a certain grade. The second controlled value is the loss of mass of samples after the test and before it. If the weight loss of concrete samples after the tests did not exceed 3 %, then it is considered that the frost resistance of concrete corresponds to the required grade. Both these conditions must be fulfilled simultaneously.

In our research applied the standard method of determination of water absorption of simples was applied, in accordance with DSTU B V.2.7-170:2008 [11]. According to this method, in order to
determine water absorption, samples were dried to constant mass at the temperature of 105±10 ºС. Then they were cooled at the temperature of 18±2 ºС and submerged in water at the same temperature. Samples were periodically taken out from water and weighed. According to the last weighing, in 24 hours after water-logging of samples, water absorption of mortar (concrete) on mass was determined. We used an Eq. (1):

\[ W = \frac{m_2 - m_1}{m_1} \times 100\% \]  

(1)

where \(m_1\) is the mass of the sample dried to constant mass; \(m_2\) is mass of sample that had been in water for 24 hours.

The mobility of the concrete mixture was determined DIN EN 12350-2 [12] by the indicator precipitation cone molded from concrete mixture.

The volume of air content was determined in accordance with DIN EN 12350-7 [13] using a poromer device.

3. Experimental research

Studies were conducted in which the mobility of concrete mixtures was changed. To exclude the effect of chemical additives on air entrainment, experiments were carried out on concrete mixtures without chemical additives. The cement content in concrete mixtures remained constant. To increase the mobility of the concrete mixture, water consumption was increased, and the water-cement ratio. The composition of the mixture was adjusted so that with an increase in water consumption, the content of coarse and fine aggregates was proportionally reduced. The initial composition of the concrete mix: cement – 380 kg/m\(^3\); sand – 580 kg/m\(^3\); crushed stone fr. 5-10 mm – 530 kg/m\(^3\); crushed stone fr. 10-20 mm – 790 kg/m\(^3\).

The mobility of concrete mixtures was changed from S1 to S5 (Figure 1). Studies have shown that when the mobility of the concrete mixture increases from S1 to S3, the content of entrained air increases slightly. But increasing the mobility of the mixture to S4 leads to a sharp increase of the content of air involved from 2.6 % to 4.8 %. Concrete mixtures with such mobility are usually used on the building of sites, walls, elements of bridge, and so on. Recently, they began to be used in road construction for the building of concrete pavements. It was also shown that with an increase of the mobility of concrete mix to grade S5, a decrease of the content of entrained air occurs compared with concrete mix with mobility S4. This decrease is quite significant from 4.8 % to 3.5 %.

![Figure 1. Dependence of the content of entrained air on the mobility of the concrete mixture](image-url)
The main danger for transport concrete is the simultaneous action of negative temperatures and aggressive salts [14, 15]. Studies were carried out on the frost resistance of concrete made from mixtures of different mobility (Figure 2). During testing, the samples were saturated in an aqueous solution of sodium chloride. Thawing of the samples was also carried out in an aqueous solution of sodium chloride.

![Figure 2](image_url)  
**Figure 2.** The dependence of the coefficient of frost resistance of concrete without additives from mixtures of different mobility on the number of freezing and thawing cycles: 1) mobility S1; 2) mobility S2; 3) mobility S4.

Studies have shown that, despite the high content of entrained air in the concrete mixture, the mobility of which corresponds to the S4 grade, the frost resistance of concrete that was made from this mixture is much lower than the frost resistance of concrete from less mobile mixtures. The frost resistance of this concrete does not match the F100 frost resistance brand. In mixtures, the mobility of which was S1...S2, the content of entrained air was 2 times lower. But the frost resistance of these concretes corresponded to the frost resistance brands F150...200.

The reason for the low frost resistance of concrete, which contains the amount of air involved (4...6 %) necessary for high frost resistance, can be explained. In the manufacture of high-mobility concrete mix S4, a large number of large air bubbles (up to several mm in diameter) are involved. These bubbles form a structure consisting of large pores that do not increase frost resistance, but reduce the strength of concrete. The content of entrained air in mixtures with lower mobility (S1...S3) is smaller in value. However, these air bubbles are smaller and to a lesser extent reduce the strength of concrete. At the same time, such pores have a better effect on the frost resistance of concrete. Therefore, we can say that the concrete with the mobility S4 is the most dangerous for the strength and frost resistance of concrete.

Chemical additives superplasticizers are necessarily introduced into the composition of transport concrete. It is known that with the introduction of superplasticizer into the concrete mix, the amount of water can be significantly reduced. Therefore, MC Bauchemie - Fk 88 superplasticizer was introduced into the concrete mixes of different mobility. Samples were made from these mixtures, which were also tested for frost resistance (Figure 3).
Figure 3. The dependence of the coefficient of frost resistance of concrete with the addition of FK-88 of different mobility on the number of freezing and thawing cycles: 1) mobility S1; 2) mobility S2; 3) mobility S4.

Studies have shown that with the introduction of a superplasticizer, the frost resistance of concrete increases, regardless of the mobility of the mixtures from which the concrete was made. For example, with the mobility of the concrete mixture S4 (P4), the frost resistance of concrete reaches the F200 grade. With the mobility of the mixture S2 (P2), the frost resistance grade corresponds to F300 and with the mobility of the mixture S1 (P2), the frost resistance grade corresponds to F350. It is likely that the increase in frost resistance occurs not only because of the decrease of W/C, but also because of the additional air involved [16].

4. Conclusions
1. It is shown that to increase the frost resistance of concrete, 4 to 6% of supplementary air is introduced into the concrete mix, which reduces the compressive strength of concrete by 9.0 to 9.5% for each percent of the air involved.
2. It was found that the amount of air involved changes with increasing mobility of the concrete mixture. The greatest air entrainment, in an amount of 4.8%, was observed in concrete mixtures without chemical additives, the mobility of which corresponded to grade S4.
3. It has been experimentally proven that, despite optimal air entrainment, concrete made from concrete mixtures of the S4 brand have the lowest frost resistance compared to concrete made from less mobile mixtures. This is due to the formation of large open porosity in concrete from mixtures of S4.
4. It is shown that the introduction of superplasticizer into the concrete mix allows increasing the frost resistance of concrete made from mixtures of any mobility by 1 or 2 grades.

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