Influence of Low Temperature on Concrete Properties

Bartosz Mazur 1, Anna Kotwa 1

1 Kielce University of Technology, Al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland

bmazur@tu.kielce.pl

Abstract. The aim of this article is to show the negative effect of the reduced ripening temperature on the increase in compressive strength. Laboratory tests were performed on a concrete mix with a w/c ratio of 0.54. The samples were reformed for 2, 5, 8 hours at +18°C, and then were frozen once to -3°C and -8°C for 24 hours. After this time, the samples matured at +18°C. The greater the early strength, the lower the drop in compressive strength with a single freeze. The greatest decrease in strength was noted for concrete maturing 2 hours and once frozen to -8°C is 52.3%. The greatest impact on durability drops is: freezing temperature, pre-ripening time, type of cement used. Additionally, the methods of protecting concrete against the influence of negative temperatures are described. Laboratory tests carried out indicate a negative effect of the reduced temperature on the increase of compressive strength. The largest decrease in compressive strength in relation to the reference concrete was noted for concrete made of cement CEM II / BV 32.5R maturing for 2 hours in water at +18°C and once frozen in air to -8°C, a fall of 52.3 %. After analysing the test results, it was found that the drop in compression strength depends on the type of cement, the level of freezing temperature and the time of initial maturation. It was found that the lower the freezing temperature and the shorter the pre-ripening time, the greater the drop in compressive strength. The influence of negative temperatures on young concrete is harmful in every case, although this harmfulness has a different degree. It is therefore necessary to protect young concrete against this type of weather conditions. Concrete works under conditions of reduced temperatures are only possible if contractors take appropriate measures to enable binding and hardening of the concrete mix, e.g. by providing thermal protection, so that the young concrete in the element does not freeze. The reduced air temperatures have a negative effect on the setting and hardening of the concrete. The lower the ambient temperature of the concrete structure being made, the lower the concrete temperature and the younger the maturing process of the concrete is slower.

1. Introduction

The process of maturing concrete depends in a significant way on the ambient temperature. The main difficulties are posed by the reduced temperature of the external environment, causing the necessity to apply specific technological measures or, in extreme cases, discontinuation of monolithic concrete works. The main reason is the reduction of the rate of chemical reactions in the cement paste, resulting in a slowing down of the kinetics of the heat of hydration, disrupting the bonding and hardening of concrete. In the case of concrete works at low ambient temperatures, an important issue is the criterion of concrete resistance to the influence of low temperature of the external environment. The influence of the ambient temperature on the maturing concrete depends on the time that has elapsed since the concrete mix was made. In general, it is recommended to delay the effect of the negative temperature on the concrete to a maximum, because the more advanced the hydration process of the cement, the less it
becomes sensitive to the effects of low temperature, including frost. This is due to the mechanical properties of ripening concrete (mainly with strength). Despite adherence to the above-mentioned recommendations from ITB instruction no. 282/2011, the construction of concrete freezes in practice [1].

2. The influence of low temperatures on the properties of concrete

In the literature, we find a description of the concrete destruction mechanism as a destruction caused by the pressure of water contained in the free spaces (pores) of the concrete structure, which under the influence of temperature changes increases its volume. The maximum density that water can achieve is at an ambient temperature of + 4°C. As for its fastest decline, it occurs during the transition from the liquid phase into a solid, i.e. freezing at 0°C.

Freezing water increases its volume by about 10%. Contained in the capillaries during the increase of its volume causes pressure increase, which after exceeding the tensile strength of the pore walls has an impact on the destruction of the concrete structure, e.g. the occurrence of cracks. The number of damages increases in the case of cyclical freezing and thawing of concrete. In addition, the degree of water saturation has a significant effect on the frost resistance of the concrete mix.

Capillary pores contained in concrete form a "system" of interconnected vessels that have a huge impact on the frost resistance of a hardened concrete mix. In order to improve the concrete's freezing resistance, aeration admixtures are used in the mixing phase to break the capillary chains. Thanks to such a phenomenon freezing water in hardened concrete during the increase of its volume has enough free space to fill it without causing destruction of the structure.

Observations of the concrete bonding process carried out over the years show that when the ambient temperature drops below 10°C, the bonding of the concrete mix suddenly slows down. In turn, at the temperature of 0°C, the hydration mechanism is almost absent. Therefore, some countries considered the temperature of concrete maturing to be +10°C, conducting concreting at lower temperatures imposes on the contractor the obligation of proper care and protection of fresh concrete.

In order to characterize the influence of low temperatures on the strength of concrete, three crucial spots are distinguished in the early maturing phase of the concrete mix:

1) The period before the beginning of binding,
2) Time between start and end of binding,
3) Period from the end of setting to concrete strength.

![Figure 1. Effect of freezing of concrete mix during aging on the final strength of concrete [2]](image-url)
Figure 1 shows the effect of once freezing the concrete mix on the final strength of the concrete. The vertical axis determines the degree of harmfulness of infestation of a concrete mix in percent, while the horizontal one determines the degree of concrete maturing. The solid line shows the degree of harmfulness during repeated freezes, in turn interrupted by one-time.

The first phase when the concrete mix will freeze is characterized by frozen mixing water, and hence by increasing its volume. The result of such a phenomenon is the lack of water, which is necessary to carry out correct chemical reactions, i.e. hydration of cement, as a result, it slows down and even stops it. Due to the inhibition of the concrete bonding process, the forming ice does not tear the microstructure of the cement paste. The consequence of this phenomenon is the occurrence of additional pores after frostbite.

In the case of freezing of the leaven before the start of binding, the method recommended for contractors is thawing the concrete mixture and re-vibrating it to eliminate the additional pores formed. By using this method after hardening, the concrete has a slightly lower final strength due to the lower bond strength of cement paste and aggregate.

The drop in temperature in phase 2 between the start and the end of the concrete bond causes the formation of ice crystals, which in turn affect the destruction of newly formed bonds of cement hydration products.

In the third phase, there is enough free water in the concrete mix that when frozen, it can destroy the concrete microstructure resulting in an irreversible drop in the concrete strength.

After elaborating the collected information, it follows that the most serious loss in the strength of concrete has its freezing: after starting the process of binding the concrete mix, but before reaching safe strength.

Analysing figure 1 it can be stated that single freezing of concrete after achieving the so-called Resistance to a single freeze does not cause a significant drop in the final strength of the concrete.

3. Analysis of research
The results of the research concern the influence of the negative temperature influence on the development of the early compressive strength of concrete as well as on the decreases in strength caused by it in relation to the strength of the maturing samples under standard conditions. Samples were pre-matured at +20°C for 2, 5, 8 hours, and then cooled in air to -3°C or -8°C for 24 hours. After this time the samples were ripened in water at +20°C.

Table 1. The composition of the concrete mix

| Components of a concrete mix | Volume [kg/m³] |
|------------------------------|----------------|
| Cement                       | 334            |
| Sand 0-2mm                   | 625            |
| Dolomitic f= 4/8mm           | 581            |
| Dolomitic f=8/16mm           | 581            |
| Water                        | 181            |
| w/c ratio                    | 0.54           |
Cement CEM I 42.5R (designation A), CEM I 32.5R (designation B) and cement CEM II/B-V 32.5R (designation C) were used for the tests.

![Figure 2. Decrease of \( f_{cm} \) in concretes subjected once freezing to a temperature of -3°C](image)

The conducted research indicates that samples frozen to -8°C after the initial maturing period of 2 hours show the greatest decreases in strength compared to samples ripening at +20°C and for cements C - 52.3%, B - 48.2%, C - 38.5%. The greater the early strength, the lower the decrease in strength when freezing once (Figure 2). The greatest impact on the drop in the strength of concrete is: freezing temperature, pre-ripening time, type of cement used. The greatest loss of strength was noted for samples made of CEM II/B-V 32.5R cement, cooled to -8°C, pre-ripening for 2 hours and amounts to 52.3%.

4. Methods of protecting concrete mix against the influence of reduced temperatures

The process of binding concrete mix is a chemical process, where low temperatures significantly slow down the reactions occurring in it, while high temperatures accelerate, which is why young optimal concrete must be guaranteed maturing temperature. Laying the concrete mix at sub-zero temperatures is possible after applying appropriate, and at the same time necessary, protections that will ensure the proper course of the bonding process.
4.1. Modification of the composition of the mixture

4.1.1. Decrease in w/c ratio. The ratio of mixing water to cement has a significant impact on the concrete mix resistance to freezing. With its decrease, the number of capillary pores contained in the concrete structure decreases, resulting in a growing hydrostatic resistance. In this situation, the small amount of water contained in the concrete has no place to transform into ice.

The use of plasticizing admixtures makes it possible to produce concrete with a reduced amount of water at an unchanged w/c value, which is desirable when freezing. In addition, a reduced degree of w/c gives a better tightness of the concrete structure and causes a slower absorption of water. Maintaining the w/c ratio below 0.4 enables the construction of concrete with good frost resistance. This applies mainly to porosity, distribution and pore size, permeability, capillary rising and water absorption.

4.1.2. Choosing the right cement. The content of alkali (K₂N, N₂O, soluble sulphates) with a value of over 0.8% in cement has an effect on the difficulty in aeration of the concrete mix. The degree of grinding of cement is also important, because it cannot be too big, because finely ground cements cause difficulties in aeration.

Cements with a high content of alite and sulphate-resistant cements are classified as frost-proof. In turn, pozzolanic and metallurgical cements show much less resistance to freezing. In general, the cement constituents have a significant impact on the proper functioning of aeration admixtures.

4.1.3. Selection of the right aggregate. When making frost-proof concrete, the decisive parameter is the capillary porosity of the aggregate. Its texture, the presence of pores and the ability of individual grains to absorb freezing water at operating temperatures are of significant importance.

4.1.4. The use of cement with high heat of hydration. It may seem that if this heat is released and the concrete itself does not appear warm or even hot, it is not too much. This is only an illusion that does not indicate that young concrete does not emit heat.

Should learn to use the potential that high-grade cement gives us to not be afraid of concrete even on colder days. The amount of heat that the young concrete gave us with the right relation to the other ingredients is enough to carry out the correct binding process.

4.1.5. Application of aeration admixture. The best method to break the capillaries contained in a concrete mix is to use an aerated admixture, which introduces into the structure a network of evenly dispersed small, spherical air bubbles of approximately 10 - 300 μm. Additional free spaces introduced by the admixture take over the excess of water pushed out of the ice formation area during the freezing of concrete.

In addition, aeration causes the concrete mix to be more cohesive, sedimentation is reduced and the mixing water does not separate from the concrete. In addition, it limits the segregation of components during transport and mixing, improves the workability, consistency and viscosity of concrete. Aeration has the effect of increasing the porosity, and thus reducing the compressive strength. It is assumed that 1% of additional air causes a loss of strength by approximately 5.5%.
4.2. Application of heat preservation method

The heat conservation method can be used at temperatures between +5°C and -5°C. It consists in heating the concrete components to a temperature of 40°C to 60°C and protecting the newly laid mixture against too rapid heat loss through the use of mats, tarpaulins, etc. Until the increase of the safe limit of compressive strength of concrete.

4.3. Application of the method of heating ingredients

By using double-walled formwork, you can heat molded young concrete using steam or hot water. Heated ingredients are placed in the boarding and then heated until the concrete is properly fixed and hardened. In addition, the concealed elements of construction are covered with foil, tarpaulins and the warm air from the heating aggregates is blown over their surface.
4.4. The use of chemical admixtures
This method consists in using instead of heating the components of the concrete mix, that is water and aggregates, chemical additives, i.e. chemical admixtures. It can be used at temperatures from -5°C to -15°C. It is used for concreting such elements as: ceilings and roofs.

4.5. The use of electro-heating
Thanks to the application of this innovative method of protecting concrete against excessive heat loss, the concrete mix can be laid at temperatures down to -15°C. It consists in fixing the reinforcement both vertically and horizontally with tying wire or a plastic belt of heaters. The distance between them is usually between 20cm and 35cm. One 25m long heater is enough to heat 1m³ of the concrete mix. The ends of the heater are connected to the lines feeding the entire heating system through plastic connectors, which must be insulated to protect against the ingress of water coming from the concrete mix.

It is important to strike the construction elements at the right time after heating and partial cooling. Otherwise, if directly after switching off the heating element was struck, it would be exposed to increased stress in the concrete, and hence the reduction of its strength and destruction of the resulting structure, [6-10].
5. Conclusions

Laboratory tests carried out indicate a negative effect of the reduced temperature on the increase of compressive strength. The greatest decrease in compressive strength in relation to the reference concrete was noted for concrete made of cement CEM II/B-V 32.5R ripening for 2 hours in water at +20°C and once frozen in air to -8°C, drop was 52.3%.

After analysing the test results, it was found that the drop in compressive strength depends on the type of cement, the level of freezing temperature and the time of initial maturation. It was found that the lower the freezing temperature and the shorter the pre-ripening time, the greater the drop in compressive strength.

The influence of negative temperatures on young concrete is harmful in every case, although this harmfulness has a different degree. It is therefore necessary to protect young concrete against this type of weather conditions. Concrete works under conditions of reduced temperatures are only possible if contractors take appropriate measures to enable binding and hardening of the concrete mix, eg Providing thermal protection so that the concrete in the element does not freeze. The reduced air temperatures have a negative effect on the setting and hardening of the concrete. The lower the ambient temperature of the concrete structure being made, the lower the temperature of concrete and the process of maturing concrete is slower [11].

References

[1] Instrukcja ITB nr 282/2011, Wykonywanie robót budowlanych w okresie obniżonych temperatur. Performing construction works during low temperatures. Warszawa 2011.
[2] Pawelska-Mazur M., Warunki betonowania w obniżonych temperaturach, na przykładzie pomorza. Conditions of concreting at reduced temperatures, on the example of a pomorze. Building review. Przegląd budowlany. Warszawa 2011.
[3] Czołgosz R., Domieszki chemiczne stosowane przy produkcji betonu nawierzchniowego. Chemical admixtures used in the production of surface concrete, Inżynier budownictwa. Warszawa 2013.
[4] Bajorek G., Roboty betonowe w okresie zimowym - czy domieszki rozwiążą problemy? Concrete works in winter - will the admixtures solve problems? Inżynier budownictwa. Warszawa 2012.
[5] Stępczak M., Laskowski K., Mrozooodporność betonu i betonowanie w okresie obniżonych temperatur. Frost resistance of concrete and concreting during low temperatures, Politechnika Wrocławska 2011.
[6] Kuniczuk K., Wpływ niskich temperatur. The influence of low temperatures. Builder. Warszawa 2011.
[7] Bajorek G., Bobrowicz J., Problemy prowadzenia robót betonowych w warunkach zimowych. Problems of conducting concrete works in winter conditions. Konferencja dni betonu. Wisła 2006.
[8] Rusin Z., Technologie betonów mrozooodpornych. Polski cement. Kraków 2002.
[9] Bajorek G., Wspomaganie robót betonowych w okresie zimowym domieszkami do betonu. Supporting concrete works in the winter with admixtures for concrete. Konferencja dni betonu – tradycja i nowoczesność. Wisła 2006.
[10] Bajorek G., Betonowanie zimą. Budownictwo, technologie, architektura. Concreting in the winter. Construction, technologies, architecture, Polski cement. Kraków 2007.
[11] Kotwa A., Wpływ ujemnej temperatury na właściwości młodego betonu. The influence of the negative temperature on the properties of young concrete. Praca doktorska, Kielce 2011r.