Impact of low temperatures on compressive strength of concrete

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Abstract: - Construction process management is based on brief scheduling of the on-site performance of construction works. Therefore, it is frequently necessary to perform concrete works in wintertime when the air temperature is below 0°C. Thus, the necessity of the assessment of low temperature conditions on the compressive strength of concrete should be assessed. The assessment of the concrete compressive strength is usually based on destructive tests of concrete specimen (cubes or cylinders in compliance with procedure stated in EN 12390). However, the environment where the specimen are stored has significant impact on the compressive strength results of the specimen. The impact of the storage conditions of the specimen on their compressive strength results has been assessed in the paper.

Key-Words: - concrete, compressive strength, low-temperature

1 Introduction

Construction process management is based on brief scheduling of the on-site performance of construction works. Therefore, it is frequently necessary to perform concrete works in wintertime when the air temperature is below 0°C. Thus, the necessity of the assessment of low temperature conditions on the compressive strength of concrete should be assessed in order to plan proper procedures of curing of the concrete constructions. The assessment of the concrete compressive strength is usually based on destructive tests of concrete specimen (cubes or cylinders in compliance with procedure stated in EN 12390). However, the environment where the specimen are stored has significant impact on the compressive strength results of the specimen. The impact of the storage conditions of the specimen on their compressive strength results has been assessed in the paper in order to provide recommendations for planning of the on-site specimen preparation and storage procedures.

2 Problem Formulation

Compression strength test is the most common test conducted on hardened concrete, partly because it is an easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength [1].

The assessment of compressive strength gain of concrete constructions is one of the most important problems in the field of management of construction works. Therefore, a range of approaches are used for detection of the compressive strength of concrete. The most accurate and reliable method for detection of compressive strength of concrete is the destructive testing of concrete specimen. The problem arises when the curing conditions of the specimen have to be taken into consideration while assessing the compressive strength. Therefore, the best approach for detection of the strength gain of concrete constructions is to use specimen, which have been bored out from the construction. However, it is not always possible to obtain specimen form the construction, and it is necessary to test moulded specimen that have been prepared from the same concrete as the relevant construction. In such cases, the significance of environmental conditions on the specimen is highly significant.

A common mistake in construction industry is the approach to storage of the concrete specimen. If the specimen are stored apart from the construction and the environmental conditions are different then it cannot be stated that the results obtained from testing of the specimen can be attributed to the properties of the construction. The same can be stated about the surface area vs volume ratio of the relevant construction and the specimen. In case the ratio differs significantly, the obtained results cannot be attributed to the properties of the construction.

Once concrete is placed in the field, its properties are significantly related to its thermal history. The temperature distribution in a cross section of concrete is the dynamic heat balance between the heat generated from the hydration of the cementitious materials and the heat loss to, or gain from, the surroundings [2].

2.1 Development of concrete properties in low temperature conditions

As temperatures drop, concrete sets more slowly, takes longer to finish, and gains desired strength less rapidly. If temperatures dip too low, the mix water may freeze and the final product will be irreparably damaged [3].

Hydration process of the concrete proceeds at a much slower rate when the concrete temperature is low. Temperatures below 10°C are unfavorable for the development of early strength; below 4°C the development of early strength is greatly retarded; and at or below freezing temperatures, down to -10°C, little or no strength develops [4].

Concrete gains very little strength at low temperatures. Freshly mixed concrete must be protected against the disruptive effects of freezing until the degree of saturation of the concrete has been sufficiently reduced by the process of hydration. The time at which this reduction is accomplished corresponds roughly to the time required for the concrete to attain a compressive strength of 3.5 MPa. At normal temperatures and water-cement ratios less than 0.60, this occurs within the first 24 hours after placement. Significant ultimate strength reductions, up to about 50%, can occur if concrete is frozen within a few hours after placement or before it attains a compressive strength of 3.5 MPa. Concrete to be exposed to deicers should attain a strength of 28 MPa prior to repeated cycles of freezing and thawing.

Temperature affects the rate at which hydration of cement occurs—low temperatures retard hydration and consequently retard the hardening and strength gain of concrete.

If concrete is frozen and kept frozen above about minus 10°C, it will gain strength slowly. Below that temperature, cement hydration and concrete strength gain cease [4].

However, concrete generates heat during hardening as a result of the chemical process by which cement reacts with water to form a hard, stable paste. The heat generated is called heat of hydration; it varies in amount and rate for different cements. Dimensions of the concrete placement, ambient air temperature, initial concrete temperature, water/cement ratio, admixtures, and the composition, fineness, and amount of cementitious material all affect heat generation and buildup. Heat of hydration is useful in winter concreting as it contributes to the heat needed to provide a satisfactory curing temperature; often without other temporary heat sources, particularly in more massive elements [4].

2.1.1 Detection of compression strength of concrete specimen

Compressive strength is the most often evaluated concrete property and is used to prescribe concrete. It is used to characterise concrete and to check its constancy and conformity. The standardised method for determining compressive strength is regulated in EN 12390-3 "Testing hardened concrete. Part 3: Compressive strength of test specimens". In this test, specimens are tested up to their rupture in a single-axis compression machine, recording the maximum load supported by the specimen. This value, divided by the cross-sectional area, is used to calculate the compressive strength [5].

Compression test develops a rather more complex system of stresses. Due to compression load, the cube or cylinder undergoes lateral expansion owing to the Poisson's ratio effect. The steel platens do not undergo lateral expansion to the some extent that of concrete, with the result that steel restrains the expansion tendency of concrete in the lateral direction. This induces a tangential force between the end surfaces of the concrete specimen and the adjacent steel platens of the testing machine. It has been found that the lateral strain in the steel platens is only 0.4 of the lateral strain in the concrete. Due to the platen restrains the lateral expansion of the concrete in the parts of the specimen near its end. The degree of restraint exercised depends on the friction actually developed [1].

In case the friction between the specimen and the loading plates is significantly reduced the specimen is almost under a uniaxial compression state. The restriction against lateral expansion of the specimen is approximately constant along the specimen height. Cracks parallel to the loading direction can be observed, and the measured strength is lower than that of the specimen where specimen do not undergo lateral expansion [5].

The procedure of compression test applied for experiments described in this paper has been carried out in compliance with requirements stated in EN 12390 – 3 [6].

The setting of the experiment has been displayed in fig.1 and fig.2.

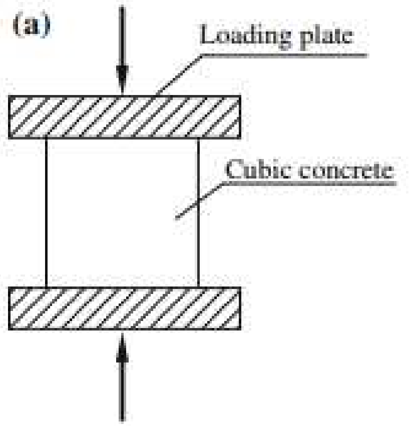

Fig.1. Concrete specimen in loading machine [6]

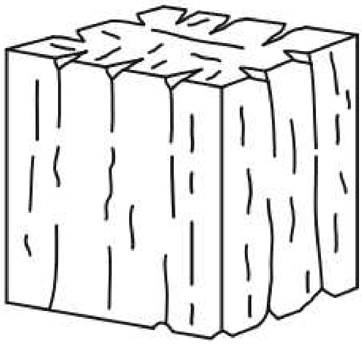

Fig.2. Failure mode of the concrete specimen [6]

3 Description of experiment

In order to evaluate the impact of temperature regime during the curing time of concrete constructions an evaluation of compressive strength of a set of concrete specimen which have been stored in different temperature regimes.

For the relevant experiment, a set of 9 concrete specimen with diameter of 110mm and height of 105mm were prepared as in Fig.3. All specimen were prepared from the same mix of C25/30 concrete with stated density of 2500kg/m^3.

The specimen were divided into three groups – by three specimen in each group. The first group of specimen were stored in laboratory conditions of +18°C in water tank (conditions complying with requirements of EN 12390[7]), the second group of specimen were stored in on-site conditions in a, alternating temperature range -2….+10°C (conditions complying with curing conditions in autumn and spring in northern Europe), while the third set of the specimen were stored in climate camera in temperature range -10….-7°C.

At age of 14 days the compression strength of specimen were determined by procedure stated in EN 12390 [7].

The summary of the results has been displayed in Fig.4.

Fig.3. Concrete specimen

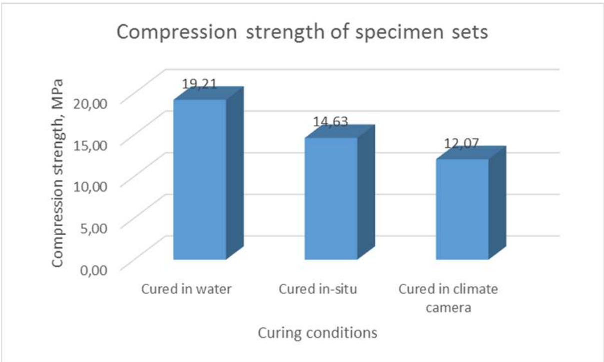

Fig.4. Compression strength of specimen sets

The obtained results display even distribution of the compressive strength of the specimen. The assumptions and results of previous researches that the compressive strength gain of concrete is influenced by the environmental conditions during the curing time of the specimen. The reduction of compressive strength due to the in-situ curing conditions of 23,82% has been determined in the relevant research as well as the reduction of 37,16% of compressive strength for specimen cured in negative temperatures.

The same storing conditions were applies for the second set of 9 specimen, where the specimen were cured in 300x300mm moulds (Fig.5) in order to decrease the ratio between the volume and the surface area of the specimen during its curing time. In such way, the impact of volume/surface radio on strength gain of concrete specimen has been assessed.

Fig.5. Specimen sets cured in 300x300mm moulds

The summary of the obtained results has been displayed in Fig.6. The compressive strength of the specimen cured in moulds excessing size of the test specimen display higher compressive strength than the ones obtained from the first set of specimen and the compressive strength results of the specimen cured in climate camera and in-situ have become closer.

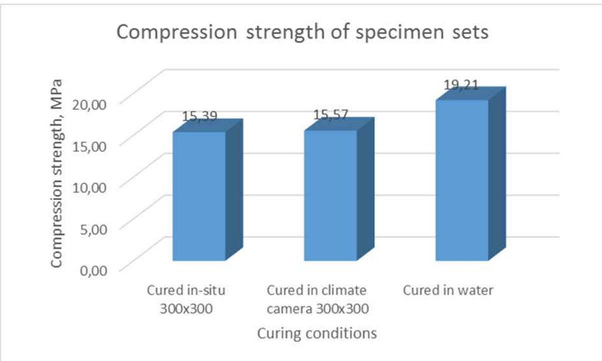

Fig.6. Compression strength of specimen sets cured in 300x300mm moulds

However, the results are still significantly lower than the compressive strength of the reference specimen which was cured in water at temperature +18°C. Such results prove previous assumptions that the volume/surface area ratio has impact on the speed of strength gain of concrete specimen and should be evaluated during quality control issues on site. The particular difference between the results obtained from the reference specimen and specimen cured in moulds can be explained by the negative impact of temperature on hardening of concrete. Nevertheless, the exothermic reaction of concrete binding diminishes the negative effect of low temperatures on strength gain process of concrete specimen.

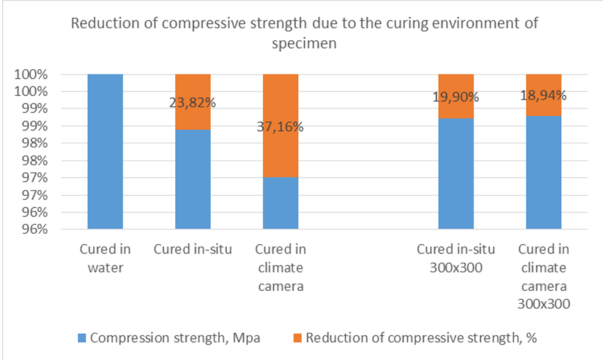

Fig.7. Reduction of compressive strength due to the curing environment, %

Therefore, the compressive strength of the concrete cured in moulds is by 18% higher for the specimen cured in negative temperatures in climate camera and by 4% higher for the specimen cured in-situ than the compressive strength of the relevant specimen of the exact size (first set of the specimen).

4 Conclusion

The hydration heat of concrete has significant impact on strength gain in low temperature conditions. Therefore, the impact of ambient air temperature should be considered in evaluation and interpretation of concrete test results.

It is not acceptable to leave concrete specimen in-situ without curing due to high impact of ambient temperatures on compression strength of the material. The concrete volume/surface area ratio has a significant impact on the settling time and hardening of concrete as well, therefore, the test results obtained from the isolated specimen cannot be referred to properties of the concrete construction due to the differences of hydration heat of the constructions and resulting differences in curing conditions of the material.

Correlation between volume/surface area of the concrete specimen and its compressive strength in certain ages should be determined in order to improve in-situ quality control procedures of concrete technology.

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