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Studying the Durability and Evaluating the Quality of Concrete and Related Tests

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Abstract
Concrete durability corresponds to its age or service life in certain environmental conditions. It is obvious that with the change of environmental conditions governing concrete, the concept of concrete durability also changes. Finding out the concrete durability in different conditions requires being in these conditions and spending considerable time, and usually it is not possible to conduct research in real conditions or it is out of the interest of those involved. In order to determine whether a concrete works properly and optimally in such conditions, short-term tests are needed in which the aggressive factors are intensified (accelerated). Sometimes, some short-term tests related to durability and exposed to a factor other than the intended factor are used and according to the experiences in real projects and in laboratory research work, criteria are provided. An example of short-term accelerated tests against the desired intensifying agent is the abrasion or ASTM C1293 test. An example of a short-term non-accelerated test in non-intensified conditions is the freezing and thawing test.

Keywords; concrete durability, concrete quality, related tests

Introduction

Realizing the durability of concrete in different conditions requires being in these conditions and spending considerable time and usually it is not possible to conduct research in real conditions (Dorontsev AV, et. al., 2022; Florina MG, et. al., 2022). In order to determine whether a concrete works properly and optimally in such conditions, there is a need to conduct short-term tests (Blahun S, et. al., 2022; ElgendyTyaaa., 2022). In these tests, the aggressive factors are intensified (accelerated) or the test is not accelerated and is performed under normal conditions; in the second case, the standard of comparison changes. Sometimes some short-term tests related to durability and exposed to an agent other than the intended agent are used and according to the experiences in real projects and in laboratory research work, criteria are presented (Sadovnikova N, et. al., 2022; Nabavi SS, et. al., 2022).

An example of a short-term accelerated test against the desired intensifying agent is the erosion or ASTM C1293 test. An example of a short-term non-accelerated test in non-intensified conditions is the freezing and thawing test. Among the short-term tests related to durability that have not been exposed to the main factor, we can mention the water absorption or capillary attraction test. Shrinkage tests may also be related to durability (Bhardwaj M, et. al., 2022). This research is based on library and laboratory studies.

Background

In their article, Talajuran and Dehnavi (2021) identified and evaluated factors affecting concrete qualities. Concrete strength is one of the most important characteristics of hardened concrete which depends on several factors, and this characteristic is used as a criterion to confirm the quality of concrete. Concrete and various types of concrete structures are widely used in buildings and urban infrastructures. In order to produce concrete with appropriate quality in all types of concrete production plants, especially in ready-mix concrete production plants, there is a need to provide seven main factors, including: efficient equipment for concrete production, skilled manpower, material quality management, quality control, expert people, calibration, accuracy and appropriate tools, and most importantly, compliance with important standards in the construction phase.

Mohsen Binandeh et al. (2016) investigated the strength and durability parameters of unreinforced

concrete parts made with sand dredged from the Persian Gulf. The preparation of aggregate used in concrete, which constitutes about three quarters of the volume of concrete, has become a challenging issue for sustainable development due to environmental issues. One of the most appropriate solutions, especially in the coastal areas of the seas and oceans, is the use of dredged marine sand (DMS) to make concrete.

Evaluation of concrete quality in terms of durability and its criteria

Durability assessment is done by performing tests on hardened concrete at a young age and sometimes at an existing age. For this, criteria and standards are needed. Below are some concrete evaluation tests and their criteria:

Freeze-thaw testing

These tests exist in two ways in the standards:

Continual freezing and thawing in saturated state in water or air and controlling weight loss, strength reduction, volume increase and dynamic elastic modulus reduction ASTM (2003);

Continual freezing and thawing in the vicinity of salt water or de-icing salts and controlling the scaling of the concrete surface and reducing its weight ASTM (2005).

However, these tests are mainly performed on concrete in the laboratory at a young age of 28 to 90 days, and it takes a long time. Today, the dynamic modulus reduction parameter is used in saturated freezing tests such as ASTM C666. After a certain number of freezing cycles, the percentage of the initial dynamic modulus of elasticity is obtained. The minimum acceptable percentage of the initial dynamic modulus of elasticity is considered a criterion or rule. For example, concrete is considered to be durable if it has at least 60 or 80% dynamic modulus of elasticity after 300 cycles of repeated freezing and thawing.

In some cases, the number of frost cycles that bring the dynamic modulus of elasticity to 60% of the initial value is determined. Obviously in this case, the minimum number of freezing cycles should be declared as a criterion (Mahta, 2013).

In successive freezing and thawing tests exposed to deicing materials, the weight percentage of flaked concrete is usually obtained after a certain number of freezing cycles. By limiting the amount of flaked material, a criterion is provided. For example, in ASTM C1372, after 100 specific freezing cycles, in the ASTM C1262 test, it should not exceed 1% of the initial weight.

Although in this experiment, the number of freezing cycles to achieve a certain percentage of flaking can be chosen as a criterion, but this is not a precedent. In ASTM C1262, which is used for prefabricated concrete parts and some masonry parts, and 3% water or salt water (depending on the need) is poured near the lower part of the part, according to the specific criterion of weight loss against a certain number of freezing cycles, the durable quality of the part is controlled.

Crystallization test of salts

No specific test has been planned to investigate the effect of salt crystallization on the durability of concrete, although it is considered an important factor in the destruction of the surface of concrete in semi-arid and dry areas.

Durability test against sulfates

To check the durability of concrete against sulfates, there is no specific standard test in ASTM and EN. It is also clear that there is no specific criterion either. After many years that have passed since the diagnosis of concrete failure due to the attack of sulfates, there is no specific test and durability criterion of concrete against sulfate attack or specific sulfate. It is tried to increase the durability of concrete by using the right cement, limiting the ratio of water to cement or the grade of cement, or using concrete additives such as pozzolans and slags, or bubble generators and waterproofing materials, but how to detect this increase in durability is not clear. It has been tried to conduct tests on cement or mortar in sulfate solution and measure their expansion and determine the quality of cement in terms of dealing with the attack of sulfates by determining criteria. Tests for sulfate penetration and diffusion in concrete are planned but not yet standardized. However, sulfate penetration in concrete cannot accurately represent the durability of concrete against sulfates (Xu,

A., Shayan, 199).

Carbonation test

Until recently, the simple and common test to determine the depth of carbonation was performed only based on RILEM CPC18 instructions. EN has also recently provided a standard guideline similar to RILEM. In this test, the depth of carbonated concrete is measured with phenolphthalein solution as a reagent. Usually, this test is measured on hardened concrete under real environmental conditions, under which the penetration of CO2 can be accelerated (RILEM Committee CPC18 1988). However, a specific criterion for the ability to deal with carbonation and the depth of its penetration has not yet been provided, although it is possible to measure the permeability of CO2 gas in concrete. By measuring the pH of concrete powder, you can draw the pH profile against the depth and determine the carbonation depth. (Building and Housing Research Center, 1378)

Expansion test caused by the reaction of alkalis with concrete aggregates

Usually, most of the tests in this field are performed on mortar, or they have special conditions such as intensifying the prevailing conditions or increasing alkalinity in the mortar or the storage environment. According to the ASTM C1293 standard and a number of Canadian standards, the expansion of concrete in conditions close to reality, but at a temperature of 38 or 60 degrees with 100% humidity, is obtained in a time longer than 6 months or a year or more. Criteria such as 0.04% expansion after three months at 60 degrees Celsius or after one year at 38 degrees Celsius are provided. However, in this test, the potential expansion of concrete is obtained. For carbonate aggregate, ASTM C1105 is used and criteria are provided for it.

Rapid Alkali Content Tester

Abrasion Tests

In the ASTM standard for concrete, four abrasion tests are presented and these tests or other tests are also used for some concrete parts:

ASTM C944 for Abrasion of Concrete or Mortar (Rotary Sanding Method);

ASTM C418 for Abrasion of Concrete (Sand Blasting Method);

ASTM C779 for Abrasion of Horizontal Concrete Surfaces (three methods of rotating abrasive disc, toothed cylindrical wheel, rotating bearing);

ASTM C1138 for Abrasion of Concrete (Underwater Method).

It seems that much care has been taken in the abrasion tests to be closer to the existing reality In different cases, for each type of part or surface in each project or specific application, a criterion is provided that indicates the durability of concrete against abrasion. In some other standards, wide

wheel abrasion test and Bohme abrasion test are provided. For example, in the concrete table standard (EN 1340), these two tests are foreseen and a specific criterion is provided in each case.

Penetration tests

Concrete permeability tests are performed against water and various gases and even some other special fluids.

Water permeability tests

Concrete water permeability tests have been carried out since the distant past based on Darcy's relation. The US Army and USBR have developed tests to determine the water permeability of concrete, which is very difficult. In the US Army method (CRD-C48), a pressure of about 14 atmospheres is used, and in the USBR 4913 method, a pressure of 28.5 atmospheres is used. (US Amy, 1992) In these tests, the value of k is obtained with the L/T dimension. In each project, the maximum value of k is determined and it is necessary for the desired concrete to meet this demand. The concretes that are currently made for water projects have low permeability, and it is practically impossible to perform this test and determine k directly. For this reason, by measuring the depth of water penetration in this test and using a series of experimental relationships based on different assumptions, it has been tried to obtain the value of k from the depth of penetration, the results of which are not reliable.

Gas permeability tests

Gas permeability tests, especially oxygen, have different methods, the most famous of which is related to the CemBureau (European Cement Association) method, which is also included in RILEM and the Italian standard (UNI). In this method, a concrete tablet sample is placed under pressure in a chamber with a bypass tube, and at different pressures, the gas flow rate is obtained, and the permeability coefficient is calculated with Darcy's modified relation for compressible fluid. The result of this test method is highly dependent on the moisture content of the concrete sample. For this reason, in the proposed method of this test, two regimes of completely dry samples with specific moisture percentages are suggested.

In the Persian Gulf region, according to the concrete reliability regulations, excellent quality is recommended for conditions D, E and F, very good for B and C, and medium quality for condition A; however, it is possible that by using such concretes in practice, a very good result was not achieved.

Permeability tests against chloride ion (chloride ion diffusion tests)

This method is the most complete way to determine the chloride ion diffusion coefficient in concrete, according to the new ASTM1556 method, which is similar to the NTBuild 443 method. In this method, the hardened concrete is placed in a sodium salt solution with a certain concentration, and at the desired age, after drying, the chloride ion diffusion coefficient is obtained by determining the chloride ion at different depths, according to Fick's law. For the concrete of each project, a specific diffusion coefficient can be considered. In this sense, concretes are divided in the conditions of confrontation with chloride ions.

One of the unique parameters that can be used to predict the concentration of chloride ions at any age is the diffusion coefficient of chlorine ions. Usually, because it is difficult to determine this parameter, it is tried to determine other parameters and replace it; while they practically cannot take its place.

One of the common tests is AASHTO T259, where the concrete surface is exposed to a chloride solution. In this test, the amount of chloride ion is measured at certain ages and at certain depths, and the penetration depth of chloride ion is obtained, with the help of which the quality of concrete can be evaluated in comparison with each other. Anyway, the result of this test is not of permeability, but it shows permeability (AASHTO T259 (2002)).

The device for determining the resistance to chlorine penetration by RCPT electrical conductivity method

Water penetration depth tests

Since water permeability tests are accompanied by many challenges, in some European countries such as Germany, another test was conducted in which, under water pressure, at a certain time, the depth of water penetration in concrete was obtained. Then in EN 12390-8 with brief changes, this test was presented more easily, in which the concrete sample is subjected to a pressure of 0.5 MPa (5 bar) from the bottom surface for three days. Then the maximum depth of water penetration is obtained, which is a parameter to evaluate water penetration in concrete. In various sources, the classification of concretes in the DIN 1048 test is given, but it has not yet been presented for testing based on the EN method. The dispersion of the results of different tests of one type of concrete in this test is high and is not very reliable (Concrete Society, 2008).

Pressure water penetration depth device

Water absorption tests

Water absorption tests exist in different forms, the most important of which are:
Half-hour short-term water absorption (Early Water Absorption);
Final water absorption (long-term) of 2 days or more in normal or boiled conditions (Final Water Absorption);
ISAT (Initial Surface Water Absorption Test);
(Capillary Water Absorption and Water Sorptivity.
Each of these tests shows a specific feature of concrete and it is necessary to use each test when it resembles the existing reality (Building and Housing Research Center, 2017).

Short-term water absorption test

This test is mainly performed for precast concrete parts after core removal with a diameter of 75 mm, which must have a certain length. In this test, the completely dried sample is submerged in the oven and the percentage of water absorption is obtained in half an hour. This test gives the desired concrete surface quality. In England, the quality of concrete tables and some prefabricated parts is controlled by this test. For example, half-hour water absorption of a table should not be more than 2% . In short-term water absorption tests, there is sensitivity about the shape and size of the sample, and the surface-to-volume ratio becomes important. In the BS 1881 standard, special correction coefficients are provided so that if the diameter and length of the sample change compared to the diameter and length of the standard, the corrected results can be calculated. In the recommendations of CIRIA for the Arab regions on the Persian Gulf and the Red Sea, etc., the maximum short-term water absorption according to BS 1881 is 2% Walker, M., (2002).

Final water absorption test

Although in the old and new BS 1881 short-term water absorption test, the final water absorption can be obtained by continuing the test until a constant weight is reached, and even more final water absorption can be obtained by boiling it in water, but in this order, such no predictions have been made. In ASTM C642, the final water absorption value is obtained, and density and porosity can also be obtained. This test is mainly used for prefabricated parts.
In the EN 1340 standard, the final water absorption of prefabricated parts such as concrete tables is seen, which is proposed at least for the volume or mass of the sample. In standards such as ASTM C497, the amount of water absorption of concrete pipes is obtained, which has two methods A and B, according to the method of drying and the time of boiling the sample in water. For example, in some standards of prefabricated parts in ASTM C76, such as reinforced concrete pipes for water and sewage, the maximum final water absorption according to ASTM C497 is 9% for method A and 8.5% for method B. From this point of view, it is possible to provide criteria and classification for the durable quality of concrete, especially if the concrete piece is flooded and water is always present in its vicinity. Such specifications are used in Iran's water and sewage concrete pipe standard No. 8906. In standard EN 1340, a maximum final water absorption of 6% is given for precast concrete tables in cases where there are no acute freezing and thawing conditions against deicing salts.
It seems that for durable concrete, the maximum final water absorption of concrete should be limited to 6% and for boiled state to 5.5%. For the areas along the Persian Gulf, the desired concretes in the environmental conditions classified in the proposed concrete reliability regulations, the following final water absorption value is suggested by me.

Initial surface water absorption test

This test is mainly provided in BS 1881 part208. In this test, it is tried to obtain the absorption amount of water poured on the horizontal surface of the concrete sample or part of the prefabricated parts while the height of the water is not high enough to exert pressure and it is limited to 200 mm. In this test, the amount of absorbed water is reported in grams or milliliters per surface unit (m2) at different time intervals (Iranian National Standard 8904, 2015).
The qualitative classification of concretes in this test can be presented as follows. In England, the

results of this test are used, but it has not been adopted in Iran's concrete reliability regulations in the Persian Gulf or in the standards of prefabricated parts such as tables. However, this test can be used successfully for materials that cause surface sealing and show the surface quality (Building Research and Housing Center, 2007).

Capillary water absorption

A mechanism of water absorption is the upward movement of water in the form of capillary moisture, which requires a special test to be performed in coordination with this mechanism. In these tests, the amount of water absorbed per surface unit, the height of capillary moisture and the rate of capillary water absorption are usually determined and reported, which are not the same in all orders and some of these parameters are addressed in each order.

The RILEM CPC11.2 test command is one of the oldest test commands in this field, which has been used for many years (RILEM Committee CPC11.2 (1982)). Recently, the ASTM C1585 standard order has been presented, which specifies the test conditions and the shape of the specimen more accurately. In this test, a concrete tablet with a diameter of 100 mm and a height of 50 mm is used, the lower part of which is placed in water by 1 to 3 mm, and the humidity around the sample is also controlled. Finally, the capillary water absorption rate is obtained in different time intervals.

Specific electrical resistance test

The ease or difficulty of electric current passing through saturated concrete can be a sign of its permeability to water and especially ion diffusion and migration (especially chloride ion), especially if it is saturated with salt water. This test is very famous and common among researchers, but no specific standard order has been developed for it.

This test uses two copper or brass plates that stick to the water-saturated concrete test surface with the help of fresh cement paste, and the electrical resistance is obtained by applying an alternating current with a certain frequency. It is possible to obtain specific electrical resistance by having the concrete surface and the distance between two metal plates. It is also possible to obtain electrical resistance and specific resistance with four electrodes (Wener's method) and embedding it on the surface of concrete or in a special hole and establishing electrical connection and contact. This method can also be used for existing concrete parts, while the previous method is only used for cubic, cylindrical or prismatic laboratory tests and rectangular cubes. If we don't want to get the specific electrical resistance, two electrodes are used that sink into the concrete to a certain depth and a certain distance from each other, and the electrical resistance of the concrete between the two electrodes can be obtained comparatively.

It is necessary to formulate a single standard order by limiting the possible changes and compare and classify the concretes in this regard. Apparently, a committee in ASTM is working on developing such guidelines (Shekarchi, 2015).

Concrete volume and structure change tests

It should be noted that there are tests on shrinkage and expansion of concrete that are related to durability. Some forms of durability do not have a valid standard test. In the standard test (ASTM (2001), the initial volumetric changes of fresh concrete are investigated. Also, in recent years, two tests ASTM C1579 and ASTM C1581 have been proposed by ASTM (2006) in relation to determining the cracking time of concrete bound paste that is exposed to specific evaporation. In the case of hardened concrete, only ASTM C490 test can be seen which can show the shrinkage of hardened concrete. Also, some tests such as petrography of concrete ASTMC856, examine the problems in concrete and its durability, which does not have a specific quantitative aspect. In addition, nowadays experiments using electron microscopy are performed in connection with qualitative research, which is mainly based on the scanning method. Recently, a standard guideline for SEM testing of hardened concrete has been provided in ASTM C1723.

The Half-Cell testing method

This test does not directly represent the quality of concrete in terms of durability but in the laboratory, by making samples with different concretes and keeping the concrete in similar conditions, the corrosion potential of the rebars can be obtained, which can somehow represent the

quality of the concrete used in each of the samples in a comparative way. Standard instructions for determining the corrosion potential of rebars in concrete parts of structures are provided in the workshop (on site), with the condition that the concrete rebar does not have a special coating such as epoxy or zinc. However, this test can also be done in the laboratory with some changes. For this purpose, a voltmeter and an electrode are used, and the positive pole of the circuit is connected to the electrode and the negative pole is connected to the rebar, and the voltage (potential difference) between the rebar and the concrete surface is determined. Usually, the place of contact between the electrode and the concrete surface is well moistened with moisturizing materials to establish a connection. In this test, according to the standard instructions, copper-copper sulfate electrode is used, but it is also possible to use a saturated calomel electrode or a silver-silver chloride electrode and convert the obtained results according to the ASTM standard (ASTM, 2009).

In the workshop, by creating a grid at intervals of 0.5 to one meter on the concrete surface, measurements are made and equipotential lines are drawn. The result of the test shows the presence of corrosion activities of the rebars during the test. It should be noted that by performing this test, it is not possible to directly determine the severity of rebar corrosion or its corrosion rate.

Based on the result of the corrosion potential test, it is not possible to comment easily in the workshop about the quality of concretes in terms of permeability against chloride ion or CO2. In the laboratory, rebar is usually placed in the concrete in such a way that the thickness of the concrete on it is exactly defined and uniform. If the rebar is completely buried in concrete, a wire should be connected to it and transferred outside. If the rebar head is outside the concrete, the outer part and a part of the inner part (more than the cover) should be covered with epoxy. Usually, prepared cylindrical samples are placed in salt water up to two-thirds of the height and the potential difference is read at different times. It has not yet determined the standard recipe for the concentration of salt water, how to prepare samples, the age of exposure to salt water, etc., and researchers use the same method for different concretes. If the rebar of the concrete sample is completely buried, it can be completely submerged in salt water (Tadayyon, 1381).

Corrosion severity of rebars test

Corrosion severity of rebars is usually expressed as mA/cm2 or mm/year. Corrosion severity of rebars actually shows the rate of corrosion of rebars at the time of the test and under the prevailing conditions. Each 1 mA/cm2 is actually equivalent to 11.6 micrometers of corrosion on the surface of the rebar every year, which is based on the existing experiences of this conversion. Today, this test is performed in the laboratory as well as in the workshop, where the ASTM G5 standard is used in the laboratory, but there is no standard instruction for the workshop. Measuring the intensity of corrosion of rebars is done by potentiostatic or potentiodynamic method, which potentiostatic method is more useful in case of corrosion of concrete rebars.

In this test, a rectangular cube is made, which has one rebar at the top and two rebars at the bottom. On top of the sample, a basin is installed in which salt water solution with a certain concentration is poured and a resistance is installed between the lower and upper rebars. The salt water solution is emptied and refilled in certain periods, and by measuring the voltage difference, the amount of electric current intensity is obtained In a period of time, the total passing current is obtained; the higher it is, the higher the corrosion intensity of the rebars. Of course, the amount of current intensity per unit area of rebar is also determined (Building and Housing Research Center, 2013).

Conclusion

In the assessment and criteria of durability of concrete, the importance of durability and the gradual process of evaluating the durability issue have been addressed and while pointing to the examination of durability from different points of view, the need to perform durability tests has been raised. It has also been tried to classify these tests for direct or indirect examination of concrete durability, and the problems of durability tests and its relationship with reality have been proposed. According to the definition of ACI 201, the durability of concrete containing Portland cement is its ability to resist weathering, chemical attack, abrasion, or any process that leads to damage. Therefore, a durable concrete is a concrete that maintains its original shape, quality and serviceability to a large extent in the prevailing environmental conditions. Now, it is accepted that the durable specifications of the

materials used in the structures should be included in the same way as the mechanical specifications, which also includes the cost. The increasing cost of repairing and rebuilding damaged structures due to the destruction of consumables accounts for a significant part of the cost of building structures.

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