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Chloride Transport in Ultra High Performance Concrete

R. Pernicová

Abstract**—**Chloride resistance in Ultra High Performance Concrete (UHPC) is determined in this paper. This work deals with the one dimension chloride transport, which can be potentially dangerous particularly for the durability of concrete structures. Risk of reinforcement corrosion due to exposure to the concrete surface to direct the action of chloride ions (mainly in the form de-icing salts or groundwater) is dangerously increases. The measured data are investigated depending on the depth of penetration of chloride ions into the concrete structure. Comparative measurements with normal strength concrete are done as well. The experimental results showed that UHCP have improved resistance of chlorides penetration than NSC and also chloride diffusion depth is significantly lower in UHCP.

Keywords**—**Chloride, One dimensional diffusion, Transport, Salinity, UHPC.

I. Introduction

CONCRETES with very high strength have been developed since the 80 years 20th century, but bigger boom showed in the last decade with the advent of nanotechnology. With regard to novelty of the issues designers do not have enough information and without a systematic solution to the current situation does not change. Also we do not know with certainty how the material will behave during its lifetime, when diverse external influences will act on it. Therefore it is important to know behavior UHPC during the time, especially transport of corrosive media (chloride, water, CO_2, O_2) in material and the corrosion processes of reinforcement. With these information is possible to eliminate these effects, and prolong the time between the implementation of repairs and service life of the whole structure.

Designing recipe of the Ultra High Performance Concrete with dispersed reinforcement (denote as UHPC) is a complex problem. The UHPC is a new cementitious composite material which is used for reducing of structure weight and eliminated, partly or entirely, conventional steel reinforcement bars and reinforcing cage [1]. From the normal type of concrete differ mainly in grain size and amount of aggregate, in the kind of ingredients used in the processing technology. Generally is UHPC defined as concretes attaining compressive strengths exceeding 150 MPa in practice, however in laboratory even 400-800 MPa, and the direct tensile strength systematically higher than 15 MPa. Their very high strength is achieved due to extremely low porosity. UHPC concretes exhibits increased mechanical properties and superior durability to NSC (Normal Strength Concrete 60 MPa) [2].

R. Pernicova is with the Czech Technical University in Prague, Klokner Institute, Šolínova 7, 166 08 Prague 6, Czech Republic (phone: +420-22435-3513; e-mail: radka.pernicova@ klok.cvut.cz).

The deterioration of building materials is caused in many cases by water-soluble salts [3]. The most common salts are on chloride, sulfate and nitrate origin. They can come into building structures from several sources. The largest amounts of chloride come from using of de-icing salts on roads and pavements during winter period. Typical source of salts in building structures is also intrusion of salty water from the grounds of buildings or capillary action of ground moisture. Salts can be even present in original building material, or they can be formed there by chemical reactions.

Due to novelty of UHPC, this material should be tested in difficult stressful environments to determine samples resistant due to external conditions and resistance of aggressive environment. Chlorides are potentially very dangerous for most porous building materials. Chloride capacity belongs to the most important parameters which can indicate the extent of this danger [4]. Steel reinforced concrete structures exposed to the ingress of chloride, need to be durable for at least the intended working life. The possibility of reinforcement corrosion is significantly increased as the chloride level at the embedded reinforcement increases. The biggest influence on the chloride transport properties has concrete composition, so it is important to consider influence not only the individual basic materials but also additives and admixtures [5].For this reason, the chloride diffusivity or penetrability of the concrete is important properties, which show the potential chloride resistance properties of a concrete mix. Therefore, in this paper the main attention is paid to the chloride transport as an instrument for estimating durability of UHPC [6].

II. Materials and Samples

Basic tested material was ultra high performance denoted as UHPC. For the comparative measurement was used normal strength concrete, denote as NSC.

Both concrete were prepared in mass of ingredients: a binder (cement, micro silica, including additives) and standardized sand. Composition is given in Table I. For this mixture was used Portland cement. Samples were mixed in a mixer according to ČSN EN 196-1. Specimens (150x150x150 mm in dimension) were cut from bigger concrete element, which were removed from the moulds after 24 hours and then were cured 7 days at temperature 20 ± 1°C.

The composition of mixtures for sample preparation is presented in Table I.

TABLE I
THE COMPOSITION OF MIXTURES FOR SAMPLE PREPARATION

Type of mixture [kg]	UHPC	NSC
cement+ micro silica+ fly ash	880	-
cement+ micro silica	-	495
0-2mm	1200	760
4-16mm	-	935
water	160	160
plastificator	40	5.7
v/c	0.23	0.33

In designing of UHPC recipe as dispersed reinforcement was used the fibers, with high tensile strength, made of high carbon steel coated brass. Their shape and size allows the use of large amounts of fibers in m3, without compromising the ability of mixing concrete. Due to the high tensile strength and possibility of applications in large quantities, fibers can effectively bridge the cracks and help with cracked concrete structure to withstand greater loads and ensure that the design will have elastic properties. The fibers provide a non-corrosive solution that is thinner and lighter than traditional approaches and is less demanding on equipment, thereby reducing the cost of labor and materials.

Fig. 1 Fibers (carbon steel coated brass) used in the experiment

The technical parameters of used fibers are given in Table II.

TABLE II
THE TECHNICAL PARAMETERS OF USED FIBERS

Material	carbon steel coated brass
diameter	0.2 mm
length	13 mm
tensile strength	more than 2200 MPa
water absorption	low
Alkali resistance	high

III. MEASUREMENT METHOD AND RESULTS

At first, basic material properties of tested concrete were determined. As fundamental physical material characteristics, bulk density ρb [kg m-3] and compressive strengths fc [MPa] were determined. Bulk density was measured using gravimetric method, compressive strengths was done at 28 days of hardening period. Basic properties of all materials are summarized in Table III.

TABLE III
BASIC PROPERTIES OF ALL MATERIALS

Type of mixture	f_c [MPa]	ρ_{bulk} [kg/m^3]
UHPC	150	2325
NSC	57	2260

Investigation of chloride resistance parameters was carried out according to the norm [cen/ts 12390-11]. It is a method for determining the unidirectional non-steady state chloride penetration parameters. The test method enables the determination of the chloride penetration at a specified age, e.g. for ranking of concrete quality by comparative testing. Since resistance to chloride penetration depends on the ageing, including the effects of continual hydration, then the ranking may also change with age.

A specimen is cast and cured in accordance with EN 12390-2, with curing period of 28 days. The specimen is divided into two sub-specimens, a "profile specimen" that is used to determine the chloride profile after exposure to unidirectional chloride ingress, and an initial chloride sub-specimen that is used to determine the initial chloride level, Ci. This initial figure is taken as the chloride level of the cast concrete. The initial chloride content is determined by grinding approximately a 1 mm thin layer of the sample from the sawn surface of the initial chloride content specimen and discarded.

Fig. 2 Samples immersed in the 3% NaCl

The steady-state chloride diffusion coefficient is measured on water saturated samples. The profile specimen is for 24 hours vacuum saturated with distilled water first and then coated on all sides but one and then the uncoated face is exposed to a chloride exposure solution. After sealing the surfaces, the specimens were placed in saturated calcium hydroxide solution for at least 18 h. After storage in saturated calcium hydroxide solution, the specimens were transferred directly to exposure without surface drying.

The reference solution is a 3 % by mass sodium chloride (NaCI) solution, for a period of 90 days. Chloride solution was not less than 12.5 milliliters per square centimeter of exposed surface. After 90 days of exposure, eight parallel layers of the chloride exposed surface were ground of the profile specimen. First six layers were approximately one millimetre thin, next three 2mm.

Each layer gives a sample of at least 10 g of dry concrete. Amount of chloride ions was determined by capillary electrophoresis system. Method is based on leaching grinding samples in distilled water in mass ratio 1:10 (sample: water). This mixture was shaking 24 hours to proper leach salt ion to the water. After one day ions were determined in a form chloride peak in the spectrum of measurement sample. Amount of chloride ion were calculated as content area under curve of chloride peak. Figs. 3 and 4 show chloride peak in different depth. The tests were performed according to EN ISO 10304-1.

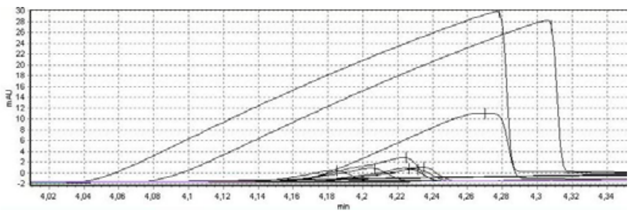

Fig. 3 Chloride peaks of UHPC

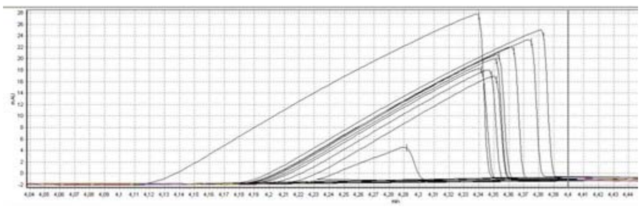

Fig. 4 Chloride peaks of NSC

Chloride content of UHPC is after third layer rapidly lower. That means the most susceptible to degradation are first three mm from the surface. On the other side value of NSC are very high even in depth one centimeter from surface. It can be risky even to the regular steel reinforcement.

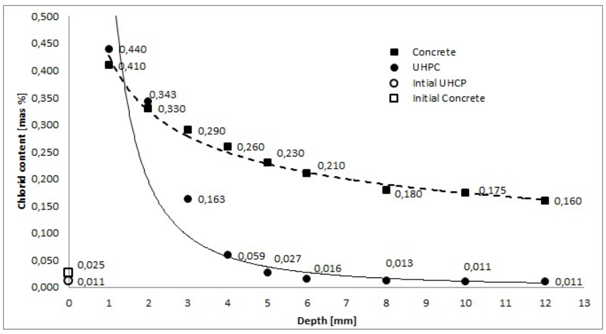

Fig. 5 Chloride content depending on the depth of sample

Important is the depth, where the chloride content first reaches a value between C1 and C1 + 0,015 %. This is the last point used in the regression analysis and it is called the "zero point". Zero Point of UHPC is in depth 8mm. NSC has no zero point in measurement depth. In depth of zeropoint UHPC has NSC more than fifteen times higher amount of chloride ions than in UHPC and seven times higher value than its initial content.

TABLE IV
THE CLASSIFICATION OF SALINITY ACCORDING TO ČSN P 73 0610

Degree of salinization	Chloride [% mass]
I Low	< 0.075
II Increased	0.075-0.2
III High	0.2-0.5
IV Very high	> 0.5

Table IV shows the degree of salinity structure and potential danger of reinforcement corrosion. As can be seen, both initial content of chloride belong to the low degree, so there is minimal risk of corrosion. But in the moment, when the structure is in direct impact of chloride, values dangerously rise almost to the group IV. Therefore, the most important is the depth, when the chloride content belongs to low category again.

IV. CONCLUSION

Chloride resistance of Ultra High Performance Concrete and as comparative normal strength concrete was determined in this paper. Main attention was devoted to the determination of penetration of the chloride ions to the structure of materials. Results obtained by capillary electrophoresis method shown, that UHPC has better resistance against chloride penetration than NSC and chloride diffusion depth is significantly lower in UHPC. Chloride content in the first two layers is very similar in both concrete. Values vary within several percent. However, from the 3 mm depth huge difference beginning to appears in the decline of chloride curves. UHPC curve reaches point "Zero", same value as initial chloride content, between s 9-10 mm from the surface. On the other hand, in last surveyed layer has NSC still more than seven times higher value than its initial content.

In the future, it is necessary to focus on long-term (years) chloride treatment and on dislocation of the zero point.

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