DESCRIPTION OF THE INVENTION

A procedure for a simultaneous reliable prediction of the mechanical strength, the durability against environmental actions, and the service lifetime of structures from concrete, with technical and financial optimization capability.

This invention concerns the under design or the existing structures from concrete, i.e., houses, buildings, bridges, roads, tunnels, and any kind constructions from concrete (the material formed by mixing cement, aggregates and water, with or without the incorporation of admixtures and additions, which develops its properties by hydration of the cement).

In all concrete constructions besides the common strength problems, in presence or not of seismic activity, serious problems from environmental attack may be presented which decrease significantly their durability and service lifetime. In the literature there is a vast majority of papers dealing with the degradation mechanisms, attempting either to study them experimentally or to simulate them using fundamental or empirical models. The lots of experimental results and the complicated mathematical models on the other hand, make difficult their wide use from the concrete engineers. It is time all this information to be included in friendly procedure, where the user by giving the minimum required data will be receiving reliably the concrete mix design, ensuring the specified strength level and service lifetime, at the minimum cost.

Such a procedure, with the characteristic title EUCON, it was developed by the present inventors (a composite word from the Greek prefix ευ: good, correct, right, and the Latin prefix of concrete and construction, con). Using the procedure EUCON an optimum concrete design can be achieved by estimating reliably the concrete strength, durability and production cost. In order the procedure EUCON to become easier during its application, it is offered as a software package, especially user-friendly, based on an extended theoretical background [1-5]. After the definition of mix design and structure characteristics, as well as an assumption regarding the environmental conditions where the structure will be found or it is found, the concrete service life can be reliably predicted using fundamental mathematical models that simulate the deterioration mechanisms and rate. The prediction is focused on the basic deterioration phenomena of the reinforced concrete, such as carbonation and chloride penetration, and on various chemical attacks. The procedure reliability is strengthened by appropriate experimental results. Aspects on concrete compressive strength and production cost are also considered. This procedure enable mixture proportions to be accurately specified and concrete performance reliably predicted. The procedure structure is in full compliance with the new European Standards, for cement: EN 197 [6] and for concrete: EN 206 [7].

In Figure 1, the logical flowchart followed in the procedure EUCON is presented. First, the essential parameters that characterize a concrete composition (mix design) are selected or calculated, and this is the main source, which all other concrete characteristics depend on. Afterwards, the main physical and chemical characteristics of concrete are calculated (chemical composition of hydrated cementitious materials, porosity and related characteristics) and this is also another source to receive more information.

Based on the selected mix design (cement type and strength class, cement content, water/cement ratio, air content, aggregates type, type and activity of additions, etc.), a first approximation of the compressive strength class of concrete is estimated.

For each significant deterioration mechanism, according to the specific environment where the structure would be found, an appropriate proven predictive model is used. Concrete carbonation and chloride penetration are the most common causes for reinforcement corrosion and further concrete deterioration. The service life of the structure found in these environments that cause either carbonation or chloride attack is calculated. The degree of deterioration from a possible chemical attack is also estimated. Finally, cost and environmental aspects regarding concrete composition are full analysed. Now, for the initially selected concrete composition the most essential properties have been predicted, such as strength, service life and cost. The designer can then modify accordingly the concrete composition to improve further every required property.

The computer program that based on the procedure EUCON, for faster estimations, is divided into several tabs, each of them destined to perform specific calculations. These tabs have to be used in a successive way, as follows.

In the cover-1st tab, the general information for the project under examination may be introduced (optional tab). This includes the identification of the project, the serial number of the trial concrete mix, the present date, and the names of the designer and the company that undertake the design study.

The 2nd tab concerns data and calculation for the concrete mix design, and together with the 3rd tab that calculates the chemical and volumetric composition of the concrete, are basic tasks that all other calculations are depend on (mandatory tabs that have to be used initially in a successive way: first the tab for mix design and then the tab for chemical and volumetric composition).

All other remaining tabs, i.e., the 4th tab for strength approximation, the 5th tab for estimation of service life regarding concrete carbonation, the 6th tab for estimation of service life regarding chloride penetration, and the 7th tab for cost estimations, are based on the previous two tabs and they can be used independently in order to estimate each specific characteristic they deal with.

All tabs contain:

- a field that the user introduces the data (default values that can change from the user: the "white boxes", dependent variables that cannot change: the "yellow boxes"),
- a calculation button, and
- a field of the results ("orange boxes" with results in blue bold colour that cannot change).

In the following, typical results are presented concerning various exposure classes and compositional parameters.

Example 1. Reinforcement Corrosion Induced by Carbonation

In order to investigate the EN 206 recommendations for limiting composition values [7] or to propose other for specific properties and service lifetime, the above procedure EUCON is used. As an example, a common cement type in Greece is considered, CEM II/B-M 32.5N, for concrete production, using common crushed aggregates of maximum nominal upper size of 31.5 mm, a cement content of 300 kg/m^3, a water/ cement ratio of 0.5 and addition of common quantities of retarder and plasticizer. We suppose a non-protected concrete surface, exposed to urban environment (CO_2-content: 0.08%). Through the procedure EUCON, the precise concrete composition is estimated, the main physical and chemical characteristics that given in Figure 1, and the strength class of concrete, C25/30. In the case of the exposure class XC3 (external concrete surfaces sheltered from rain and internal concrete with higher than normal relative humidity, moderate humidity: 70%), the period for corrosion initiation, for a concrete cover to reinforcement equal to 25 mm, is estimated as 36 years. In the case of application of a typical cement-lime mortar as protecting coating, 20 mm width, and rich in lime, a prolongation of 30 years is estimated for the corrosion initiation period. The purchase cost of the constituent materials for concrete composition is estimated as 31.53 €/m^3, whereas the total production cost of concrete as 39,78 €/m^3.

Example 2. Reinforcement Corrosion Induced by Chlorides

In order to investigate the EN 206 recommendations for limiting composition values [7] or to propose other for an intended, perhaps higher, service lifetime of a concrete structure exposed in these conditions, the above procedure EUCON is used. As an example, a common cement type in Greece is considered, CEM II/B-M 32.5N, for concrete production, using common crushed aggregates of maximum nominal upper size of 31.5 mm, a cement content of 320 kg/m^3, a water/ cement ratio of 0.45 and addition of common quantities of retarder and plasticizer. We suppose a non-coated, non-protected concrete (without concrete or reinforcement coating, corrosion inhibitors, cathodic protection, etc.), exposed to a Mediterranean marine environment (concentration of Cl^- in the sea water: 20 kg/m^3). Through the procedure EUCON, the precise concrete composition is estimated, the main physical and chemical characteristics that given in Figure 1, and the strength class of concrete, C30/37. In the case of the exposure class XS2 (parts of marine structure permanently submerged in the water), the period for corrosion initiation, for a concrete cover to reinforcement equal to 40 mm, is estimated as 67 years. The purchase cost of the constituent materials for concrete composition is estimated as 32.88 €/m^3, whereas the total production cost of concrete as 41,43 €/m^3.

LITERATURE CITED

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4. Papadakis, V.G., M.N. Fardis, C.G. Vayenas, "Physicochemical Processes and Mathematical Modeling of Concrete Chlorination", Chem.Eng.Sci., 51, 505(1996).
5. Papadakis, V.G., "Effect of Supplementary Cementing Materials on Concrete Resistance Against Carbonation and Chloride Ingress", Cement and Concrete Research, 30(2), 291-299 (2000).
6. European Standard EN 197-1, “Cement – Part 1: Composition, Specifications and Conformity Criteria for Common Cements”, CEN, Brussels (2000).
7. European Standard EN 206-1, “Concrete – Part 1: Specification, Performance, Production and Conformity”, CEN, Brussels (2000).

CLAIMS

1. A procedure for a simultaneous reliable prediction of the mechanical strengrh, the durability against environmental actions, and the service lifetime of structures from concrete, with technical and financial optimization capability. This procedure is characterized from the fact that the user by giving the minimum required data will be receiving reliably the concrete mix design, ensuring the specified strength level and service lifetime, at the minimum cost.

After the definition of mix design and structure characteristics, as well as an assumption regarding the environmental conditions where the structure will be found or it is found, the concrete service life can be reliably predicted using fundamental mathematical models that simulate the deterioration mechanisms and rate. The prediction is focused on the basic deterioration phenomena of the reinforced concrete, such as carbonation and chloride penetration, and on various chemical attacks. The procedure reliability is strengthened by appropriate experimental results. Aspects on concrete compressive strength and production cost are also considered. This procedure enable mixture proportions to be accurately specified and concrete performance reliably predicted.

2. Procedures as in claim 1 that exclude from calculation the prediction of the mechanical strength and/ or the prediction of cost and/ or the capability of technical and financial optimization.

3. Procedures, methods, or products that contain a procedure as in claims 1 or 2 for calculations, including the computer programs.

A B S T R A C T

A procedure for a simultaneous reliable prediction of the mechanical strengrh, the durability against environmental actions, and the service lifetime of structures from concrete, with technical and financial optimization capability.

By using the present procedure, with the characteristic title EUCON, an optimum concrete design is achieved for any kind of technical constructions and structures, and the concrete strength, durability, and cost are reliably and simultaneously estimated.

In order the procedure EUCON to become easier during its application, it is offered as a software package, especially user-friendly, based on an extended theoretical background. After the definition of mix design and structure characteristics, as well as an assumption regarding the environmental conditions where the structure will be found or it is found, the concrete service life can be reliably predicted using fundamental mathematical models that simulate the deterioration mechanisms and rate. The prediction is focused on the basic deterioration phenomena of the reinforced concrete, such as carbonation and chloride penetration, and on various chemical attacks. The procedure reliability is strengthened by appropriate experimental results. Aspects on concrete compressive strength and production cost are also considered.

This procedure enable mixture proportions to be accurately specified and concrete performance reliably predicted. The procedure structure is in full compliance with the new European Standards, for cement: EN 197 and for concrete: EN 206.

CONCRETE MIX DESIGN

INPUT
Cement: Cement type according to EN 197, standard strength class, early strength class. Composition of cement in clinker, other main constituents, minor additional constituents, and calcium sulphate. Cement density and cement content.
Additions: Additions type I: filler aggregate and/or pigments, density and content. Additions type II: siliceous or calcareous fly ash and/or silica fume, fly ash density and content, silica fume density and content.
Admixtures: Admixture type: retarder, accelerator, air-entraining, plasticizer, superplasticizer, other. Density, solid content, dosage. Total admixture content.
Water: Water added, water from admixtures and aggregates, water density, effective water content.
Aggregates: Aggregate type, aggregate density, maximum nominal upper aggregate size.
Air: Entrapped-air content, entrained-air content, total air content.
CALCULATION: Aggregate content, water/cement ratio, aggregate/cement ratio, fresh concrete density.

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CHEMICAL AND VOLUMETRIC CHARACTERISTICS OF CONCRETE

INPUT
Cement composition and oxide analysis: Oxide analysis of portland clinker, oxide analysis and activity of other main constituents of cement.
Oxide analysis and activity of additions: Oxide analysis and activity of silica fume and fly ash used.
CALCULATION: Reaction degree of other main constituents of cement and of concrete additions. Calcium hydroxide content, calcium-silicate-hydrate content, chemically-bound water content, concrete porosity.

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CONCRETE STRENGTH	CONCRETE LIFE REGARDING CARBONATION	CONCRETE LIFE REGARDING CHLORIDE PENETRATION	CONCRETE LIFE REGARDING CHEMICAL ATTACK	COST AND ENVIRON-MENTAL ASPECTS
CALCULATION Mean compressive strength, strength class, strength ratio 2/28 days, strength development.	**INPUT** **Environ. conditions** Exposure class, relative humidity, CO_2-content in air. **CALCULATION** For specific cover and protection: corrosion-initiation period, corrosion-propagation period, total service life.	**INPUT** **Environ. conditions** Exposure class, relative humidity, Cl^- concentration. **Initial-boundary conditions.** **Threshold for corrosion.** **CALCULATION** For specific cover and protection: corrosion-initiation period, corrosion-propagation period, total service life.	**INPUT** **Envir. conditions** Exposure class, relative humidity, type of deteriorating agent and concentration. **CALCULATION** For specific agent and protection measures: total service life.	**INPUT** **Financial input** Purchase cost of constituents, mixing, transport. and delivery cost. **Environ. input** Environmental impact from constituents production. **CALCULATION** Concrete production cost. Environmental cost.

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TECHNICAL AND ECONOMICAL OPTIMIZATION

Mix design optimization
to achieve the specified mechanical and durability characteristics at the lowest cost.

Figure 1 Logical diagram of the procedure EUCON for concrete mix design for specified strength class, service life and cost.