(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 November 2013 (28.11.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/175246 A2

(51) International Patent Classification: Not classified

(21) International Application Number: PCT/GE2013/000002

(22) International Filing Date: 18 April 2013 (18.04.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
AP 2012 12719 22 May 2012 (22.05.2012) GE

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

WO 2013/175246 A2

(54) Title: CONDUCTIVITY METHOD TO DEFINE CEMENT ACTIVITY, AMOUNT OF CEMENT AND WATER IN CONCRETE MIXTURE AND CONCRETE STRENGTH

(57) Abstract: Cement activity, specific consumption of cement and water and concrete strength are defined by conductivity method taking into consideration type and share content of mineral additives in cement and specific conductivity and temperature of tested solution.

Method description

Conductivity Method to Define Cement Activity, Amount of Cement and Water in Concrete Mixture and Concrete Strength

The given invention is referred to building materials production and can be used to define the activity of Portland cements and their variations as well as strength of any heavy concretes manufactured on the basis of this cement.

Conductivity method to define cement activity (1) is known in literature and it implies producing cement-water mixture of definite concentration in order to define its temperature and conductivity and measuring cement activity according to the following formula:

$$R=\frac{a}{K}\left\{\frac{\lambda_T}{(1+\alpha(T-T_0))}+b\frac{\lambda_T}{(1+\alpha(T-T_0))^2}\right\}(1-CD)$$

Formula 1

Where:

α – Coefficient depend on water – cement mixture preparation time
R – Cement activity in standard age MPa
K – Water-cement mixture concentration g/l
λ_T - Specific conductivity - SC - Cm/m
α - Temperature coefficient of conductance (resistance) degree $^{-1}$
T – Temperature of water-cement mixture
T_0 –Temperature of adjustment, usually 20 degrees Celsius
b – Coefficient regarding non-linear dependence between mixture concentration and S.C.
C – Coefficient regarding dependence of additive events on cement strength
D – Fraction of total mass in cement %

The above given formula does not give the opportunity to determine the amount of cement and water in concrete mixture and to predict concrete strength.
Besides, at the temperature of 20 degrees Celsius S.C. of water-cement mixture λ>0..027 Cm/m the formula shows large difference between the values received by formula 1 and standard method (theoretical values are exagerated).

Table 1 gives activity parameters for purely clinker Portland cements received by formula 1 at different temperatures

Table 1

№	λ_T	T	α	λ	a	b	R_F	Rs	D	C	Δ%
1	2	3	4	5	6	7	8	9	10	11	12
1	0,15	15	0,03	0,1765	140,0	2,2	34,3	35,6	0	0,005	3,65
2	0,20	17	0,03	0,2198	140,0	2,2	45,7	44,5	0	0,005	-2,70
3	0,25	19	0,03	0,2577	140,0	2,2	46,5	55,5	0	0,005	-1,80
4	0,30	22	0,03	0,2830	140,0	2,2	64,3	56,7	0	0,005	-13,4
5	0,35	24	0,03	0,3125	140,0	2,2	73,8	57,7	0	0,005	-27,9
6	0,40	25	0,03	0,3478	140,0	2,2	85,9	58,5	0	0,005	-46,8

The results are received for purely clinker Portland cements (that is D=0) for K=1. As it proceeds from the table in examples 4.5 and 6 the difference between activity received by formula1 and standard method is rather high which is undesirable.

The technical result of the invention is in reducing time for defining cement activity, higher accuracy of the received results for water and cement amount in concrete mixture.

The given method enables within a short period of time to define with maximum accuracy cement activity, cement and water amount in concrete mixture.

The method is performed in the following way: one takes Portland cement of any type, produced by simultaneous grinding clinker and gypsum (together with mineral additives or without them), prepares water-cement mixture of definite concentration by stirring it for 30-60 seconds, then he lowers the conductivity meter and measures S.C. and temperature in a special device constructed for defining cement activity and concrete strength and equipped with a special program where other characteristics of cement and concrete mixture are introduced, resulting in defining cement activity, cement and water amount in concrete mixture and predicted concrete strength.

Activity of cement of any age, any water-cement ration at any hardening temperature is calculated in accordance with the formula:

$$R^{BEND} = A\rho\lambda^2 \ell n(1.77\mathrm{T}+1)(1-(\frac{D}{100})^{v})e^{-\mu\sqrt[8]{PH}\,\lambda - 0.0327\sqrt[4]{T}\,e^{0.0327t} + 0.0002t^2 - 0.91\sqrt[8]{T} - 3.52Z}$$

Formula 2

Where:

A- Coefficient depending upon mineralogical content of cement clinker

ρ – Cement density g/cm^3
λ- S.C. of water-cement mixture at 20° C
T – Hardening period per day
D – Fraction of total mass of the additive in cement %
ν – Coefficient regarding the influence additive type upon cement activity
μ – Coefficient regarding the influence of free alkali upon S.C.
P– Fineness of cement grinding by sieve analyses %
H – Normal thickness of cement dough %
t - Cement hardening temperature °C
e – Base of natural logarithms (Neper value) 2.72

If cement is tested in the absence of distilled water, then any water with primary S.C. - $\lambda<0.05$ Cm/m is taken.

If water temperature exceeds 19-21 degrees, the following formula is used:

$$\lambda_{20}=\frac{\lambda t}{1+\alpha(t-20)}$$

Formula 3

Where:
λt – S.C. value at temperature t
α - Temperature coefficient of conductance (resistance), in this case a = 0.03. The value of λ_{20} is calculated by formula (2).
Formula (2) gives the value of cement activity in bending. Strength value in compression, where the member -91√T is absent in formula (2), is calculated as follows:

$$R^{COM}=A\rho\lambda^2 \ell n(1.77\mathrm{T}+1)\left(1-\left(\frac{D}{100}\right)^{\nu}\right)e^{-\mu\sqrt[8]{PH}\lambda-0.0327\sqrt[4]{T}e^{0.0327t}+0.0002t^2-3.52Z}$$

Formula 4

If ordinary values of Euro Standard E-196 are introduced into formulas (2) and (4) when t=28, Z=0.5 and t=20° C, then formulas (2) and (4) acquire an evident solution and for A=0.16 we can have:

$$R=0.02546\rho\lambda^2 2e^{-\mu\sqrt[8]{PH}\lambda}\left(1-\left(\frac{D}{100}\right)^{\nu}\right)$$

Formula 5 — in bending

$$R=0.1\rho\lambda^2 e^{-\mu\sqrt[8]{PH}\,\lambda}\left(1-\left(\frac{D}{100}\right)^{v}\right)$$

Formula 6 — in compression

Determination of specific consumption of cement in concrete mixture takes place in accordance with the following formula:

$$Q=C(\lambda_c-b)$$

Formula 7

Where coefficients C and b depend upon alkali content in clinker and are defined separately for each lot,
λc – Specific conductivity of water-concrete solution of definite concentration.

To define coefficient C one can take concrete mixture produced on the basis of that cement lot for which C is determined by previously known specific consumption.

This mixture is used to prepare water-concrete solution of definite concentration (0.1 – 10.0) in % and S.C. of the solution is further defined in accordance with the formula:

$$C=\frac{Q}{(\lambda_6-b)}$$

And it is then calculated.

We may suppose, that if we have water-concrete solution with the prior known cement consumption 400kg/m3 S.C. L=0.075 then we receive C=6667. This coefficient remains unchanged for the device until cement lot is changed and specific consumption of cement for the other mixtures basing on this cement will be defined according to the formula:

$$Q=6667(\lambda-0.015)$$

If for another concrete mixture of the same cement S.C. of water-concrete solution of the same concentration appeared to be λ=0,095, then cement consumption for this mixture is Q=6667(0,095 – 0,015) = 533.4 kg. It is implied in the example that the water temperature for the experiment is within (19 – 21) °C

Total water amount in one cubic meter of concrete mixture is calculated according to the formula:

$$W=\left\{460e^{-0,7(\sqrt[8]{d}+0.1M-0.65x)}\sqrt{\ell n(0.047e^{0.913\sqrt[8]{d}}L+e)}+N+2(H-25)+0.1(Q-400)\right\}(1-q)$$

Formula 8

Where:
d – Maximal diameter of coarse filler in mm
M – Grain size module of the applied sand
x – Fraction of total mass in the total filler amount
L – Characteristics of concrete mixture mobility – settlement of standard cone of concrete mixture in cm
N – Coefficient accounting for coarse filler type (for gravel – N=0, for crushed rock N=10)
H – Normal thickness of cement dough NGCT which is the basis for manufacturing of the given mixture (at H < 25 this member is absent)
Q – Specific cement consumption in concrete mixture (at Q < 400 this member vanishes from the calculation)
q – Coefficient considering plasticizer influence. It shows the share of decreased water due to using this plasticizer without changing its mobility (that is without changing cone settlement) q = 0.00 – 0.30.

The notion of negative meaning of cone settlement (theoretically) was introduced for tough concrete mixtures and for mixtures with zero settlement L value is calculated in accordance with toughness parameter in seconds. In this case L value is defined in accordance with the formula:

$$L=-0,17\,\ell n^2(\tau+1)$$

Formula 9

The example for concrete mixture with characteristics d=20mm; M=2.0; x=0.5; is coarse filler type – crushed rock (that is N=10), cone settlement L=18.0; cm H=28.5%; q=0; (mixture without plasticizer) Q=450kg/m^3; then formula (8) gives W=263.8 l/m^3.

It is extremely high water consumption caused by using relatively thin sand and its high share in total filler amount and the desired result may be achieved by using plasticizer with the efficiency of 25% and we can get 263.8 (1 – 0.25) = 197.9 l.

This arrangement without change in cement consumption can considerably increase concrete strength and if there is no need in it in order to maintain strength it is possible to decrease cement consumption up to 338kg or nearly by 25%.

If in formula (8) all the parameters are left without changing (except for cone settlement which is equal to null for tough mixtures) and concrete mixture with toughness t=100sec is tested as an example, then in the formula we take not the true value of cone settlement L=0, but its negative value calculated in accordance with formula (9)

$$L=-0.17\ell n^2(\tau+1)=-0.17\,\ell n^2(100+1)=-3.62$$

By putting this value in formula (8) we receive W = 181.4.0.8553 + 10 + 7 + 5 = 177.1 l. That means that by using concrete mixture with toughness 100sec in comparison with movable mixture the water amount decreases from 263.8 l to 177.1 l or nearly by 33%. This arrangement increases the strength of concrete stone nearly by 67% (proceeding from initial strength) and if there is no need in it, in this case one can theoretically decrease cement consumption from 450 kg. to 305kg. Or 33% (proceeding from initial consumption).

Predicted strength of concrete stone from this mixture is calculated according to the formula

$$R^{CON} = \eta R^{CEM} \sin^2(0.45 \frac{Q}{W})$$

Formula 10

Where:
η – Coefficient which takes into account the quality of used materials and applied technology. For high quality materials and advanced technology which increases concrete strength twice as much, η= 3, for materials of average quality η = 1.5, for low quality materials and outdated technology η = 1.0
Rc – Cement activity in MPa calculated by the device according to formulas (2); (3); (4) and (5).
Q – Specific consumption of cement determined by the device according to formula (7)
W – True amount of water in one cubic meter of concrete mixture. It is calculated by the device in accordance with formula (8).

It is desirable for every concrete user to know the exact parameter of n coefficient for his production conditions by laboratory method. For this purpose one must prepare mixture basing upon known parameters Rc, Q and W and standard concrete samples, test them within standard period and define average standard concrete strength.
Then, from formula (10)

$$\eta = \frac{R^{CON}}{R^{CEN}} \sin^2(0.45 \frac{Q}{W})$$

And this n value is used till the quality of the materials is used.

We can assume as an example that cement activity is tested by the device R = 36.5 MPa (it is taken as an assumption that cement sample is available and has been tested) and we assume that according to formula (7) specific consumption of cement is Q = 420kg and specific consumption of water is W = 225 l. Then in accordance with formula (10) we get:

$$R^{CON} = 1.5\mathrm{R}^{CEM} \sin^2(0.45 \frac{420}{225}) = 30.4\ \textit{МПА}$$

Classical formula by Bolomei gives approximately the same result.

$$R = AR^{CEM}\left(\frac{Q}{W} - 0.5\right) = 0{,}6\,36{,}5\left(\frac{420}{225} - 0.5\right) = 29.9\,M\Pi A$$

The difference between the received results does not exceed 1.6% which is negligible while assessing concrete strength.

Defining concrete strength by the suggested method presents difficulty when nothing is known about cement activity, its amount in the mixture and a cement sample is absent.

The calculation in this case is made in a "roundabout" way. It is necessary to determine S.C. L of water-concrete solution of the needed concentration, according to formula (7) C = 7000 for the vast majority of cements and then specific cement consumption Q is defined. After defining cone settlement (or toughness) and volumetric mass of concrete mixture Y and basing on these data one can determine concrete mass, which contains the necessary amount of cement mass m to identify its activity. Such mixture mass is calculated in accordance with the formula:

$$M = \frac{\gamma m}{Q}$$

This mixture is dissolved in water in order to receive solution of the needed concentration (as well as in identifying cement activity) and determine with the help of the device MELANI-01 cement activity by entering average cement characteristics into the device. Then according to formula (10) concrete strength is approximately determined. This procedure does not exclude increased relative error up to 15%.

As distinct from the known methods the given formulas embrace the factors of influence upon cement activity fully (or near to it) resulting in a small relative error of 5-7%.

INVENTION CLAIMS

Conductivity method to define cement activity and specific consumption of cement and water in concrete mixture and predicted concrete strength, which envisages producing water-cement solution, measuring its conductivity characteristics and determining activity is distinguished by the fact that conductivity meter is lowered into prepared water-cement solution to measure S.C. and temperature.. The device for measuring cement activity and concrete strength is equipped with special program where cement characteristics are entered. After that the activity of cement of any age, any water-cement ratio under any hardening conditions is defined according to the formulas:

$$R^{BEND}=A\rho\lambda^2 \ell n(1.77\mathrm{T}+1)(1-(\frac{D}{100})^{\nu})e^{-\mu\sqrt[8]{PH}\lambda-0.0327\sqrt[4]{T}e^{0.0327t}+0.0002t^2-0.91\sqrt[8]{T}-3.52Z}$$

Formula 2

$$R^{COM}=A\rho\lambda^2 \ell n(1.77\mathrm{T}+1)(1-(\frac{D}{100})^{\nu})e^{-\mu\sqrt[8]{PH}\lambda-0.0327\sqrt[4]{T}e^{0.0327t}+0.0002t^2-3.52Z}$$

Formula 4

Where:
R comp. – Cement activity in compression and R bend – cement activity in bending
A – Coefficient depending upon mineralogical content of clinker
ρ – Cement density g/cm^3
λ - S.C. of water-cement solution of definite concentration at temperature 20 degrees C defined by formula:

$$\lambda=\frac{\lambda t}{(1+a(T-20))}$$

Formula 3

T – Hardening period per day
D – Number of additives in cement %
ν – Coefficient considering the influence of additive type upon cement activity
μ – Coefficient considering the influence of free alkali in clinker upon S.C. of L
P – Cement grinding fineness by sieve analyses %
H – Normal thickness of cement dough %
t – Hardening temperature of cement sample ° C
Z – Indicator of water-cement ratio
e – Basis of natural logarithms; (Neper value) e = 2.72
Q – Cement consumption in concrete mixture is calculated according to the formula kg/m^3

$$Q=C(\lambda_{CON}-b)$$

Where coefficients C and b depend upon cement type and mineralogical content and they are defined separately for each lot
λco. – S.C. of water-concrete solution at t=20 ° C
W – Specific water consumption in concrete mixture in l/m3 and is calculated by formula:

$$W=\left\{460e^{-0,7(\sqrt[8]{d}+0.1M-0.65x)}\sqrt{\ell n(0.047e^{0.913\sqrt[8]{d}}L+e)}+N+2(H-25)+0.1(Q-400)\right\}(1-q)$$
Formula 8

Where:
d – Maximal size of coarse filler in mm
M – Module of sand coarseness by sieve analyses
X – Sand share in total amount of filler
L – Settlement of standard cone of concrete mixture. When L=0 (for tough mixtures) cone settlement acquires negative value (conditional) and is calculated according to the formula:

$$L=-0.17\ell n^2(\tau+1)$$

Where:
r – Mixture toughness in seconds
N – Coefficient which takes into account coarse filler type; for gravel N=0, for crushed rock N=10.
H – Normal thickness of cement dough %
Q – Specific cement consumption in concrete mixture kg/m3
q – Coefficient considering the influence of plasticizer upon concrete mixture mobility.

Concrete strength is calculated according to the formula:

$$R^{CON}=\eta R^{CEM}\sin^2(0.45\frac{Q}{W})$$

Where:
η - Coefficient to consider material quality
Rc – Cement activity in compression MPA
Q – Specific consumption of cement in mixture kg/m3
W – Total amount of water in concrete mixture, l/m3