APLICAREA METODELOR BAZATE PE PERFORMANȚĂ A DURABILITĂȚII ȘI STABILIREA DOMENIILOR DE UTILIZARE A BETOANELOR PREPARATE CU MATERIALE COMPONENTE DIN REPUBLICA MOLDOVA

APPLICATION OF THE METHODS BASED ON THE PERFORMANCE OF DURABILITY FOR ESTABLISHING THE DOMAINS OF USING THE CONCRETES PRODUCED WITH COMPONENT MATERIALS FROM REPUBLIC OF MOLDOVA

DAN GEORGESCU[1]*, ADELINA APOSTU[1], GHEORGHE CROITORU[2]
[1]Technical University of Civil Engineering Bucharest
[)]Ministry of Regional Development and Construction of Republic of Moldova

This article presents the results of some experimental researches carried out in order to establish the level of performance of the concretes prepared with different types of cements and aggregates that are used in the Republic of Moldova, with a view to develop the National Annex to the EN 206-2013 standard.

Establishing the characteristics of resistance and durability was done by applying some European and national standards and had as its main objectives to establish the domains of using the concretes and the analysis of the conditions of applying the methods based on the performance of durability. In the National Annex were presented (by means linked to practical applying of the document), "deemed to satisfy" rules regarding the types and quality of materials, the composition of concrete and minimal classes of resistance at compression, depending on a certain use of the concrete.

Articolul prezintă rezultatele unor cercetări experimentale efectuate pentru stabilirea nivelurilor de performanță a betoanelor preparate cu diferite tipuri de cimenturi și agregate care se utilizează pe teritoriul Republicii Moldova în vederea elaborării Anexei Naționale la standardul EN 206-2013. Determinarea caracteristicilor de rezistență și durabilitate s-a efectuat prin aplicarea unor standarde europene și naționale și a avut drept obiective principale stabilirea domeniilor de utilizare a betoanelor și analiza condițiilor de aplicare a metodelor bazate pe performanță a durabilității. În Anexa Națională s-au prezentat, din rațiuni legate de aplicarea practică a documentului, reguli de tip „deemed to satisfy" în ceea ce privește tipurile și calitatea materialelor, compoziția betonului și clasele minime de rezistență la compresiune, în funcție de o anumită utilizare a betonului.

Keywords: *cement, concrete, performance, durability.*

1. Introduction

This article shows the results of some experimental researches carried out with a view to drawing up of the national document for applying the European EN 206 [1] standard in R. of Moldova. An important part of this document consists in defining the domains of use of the concretes prepared with component materials produced in R. of Moldova.

Annex F of the standard [1] defines the limits of compositional components of the concrete on each of the exposure classes, specifying that these are valid for cements with use established by applying of national rules/methods. Thus the necessity of establishing the domains of using the cements produced in R. of Moldova came up. In order to achieve this goal, an experimental program was elaborated. This program also contains the types of methods that are to be applied, some based on the performances increasingly recommended also at European level. As a matter of fact, at European level, they are building a system of standards that are to be the base of applying some methods of performance CEN TS 12390-9 [2], CEN TS 12390-10 [3], CEN TS 12390-11 [4]. Already, there are documents detailing the application of the concept of equivalent durability as per CEN TR 16563 [5]. The most advanced method still in a faze of European recognition and application - obviously representing the future of approaching the durability of concrete - is the method of classifying the concrete in resistance classes to various actions of the environment, probabilistic approach, similar to the one used in case of the compression resistance classes of concrete.

* Autor corespondent/*Corresponding author*,
E-mail: danpaulgeorgescu@yahoo.com

A recent analysis regarding the application of the methods based on performance of concrete durability, carried out at a national regulation level of some European states, revealed that only in a single country, Switzerland, there is a regulation where durability is specified by CEN 104/SC1/WG1 N55 [6] performance. On the other hand, even if the criteria for evaluation are not explicitly presented in national regulations, all states have methods of testing the concrete against various actions of the environment, and obviously these methods had been applied before the specification of using certain cements in completion of Annex F of EN 206 standard.

In this article we present the application and the analysis of application of three methods of determining of concrete's resistance to various kinds of attacks due to the environment: freeze/thaw, chemical attack of sulphates and of chlorides. Also, among the cements on which the tests were carried out, three types of cement have been selected, bearing in mind their priori different behavior, CEM I 42,5N, CEM II/B-S 32,5N and CEM II/B-LL 32,5R.

2. Experimentation. Methods and materials

2.1 Application of the methods for determining the behavior of concretes in freeze/thaw

In order to study the behavior of concretes submitted to freeze/thaw we applied trial methods in accordance with European standard CEN/TS 12390-9[2], for determining the quantity of scaled material.

The concrete compositions evaluated for scaling are:

- 300 kg/m^3 dosage A/C rate = 0.6 for XF1, XF3 classes of exposure
- 320 kg/m^3 cement dosage and A/C rate = 0.5, concretes with air entrained, for XF2, XF4 classes of exposure

2.1.1 Cube test

Criteria for evaluation of scaling:

XF1 class of exposure (300 kg/m^3 dosage and A/C rate = 0.6)

The quantity of scaled material must determine a reduction lower than 5% of the mass of concrete test piece after applying 56 cycles, and lower than 10% after 100 de cycles.

XF3 class of exposure (300 kg/m^3 dosage and A/C rate = 0.6)

The quantity of scaled material must determine a reduction lower than 3% of the mass of concrete test piece after applying of 56 cycles, and lower than 5% after 100 de cycles.

Figures 1 and 2 present the results recorded for concretes prepared with the three types of cement.

2.1.2 Slab test

Criteria for evaluating the scaling:

- *for XF2 class of exposure (*320 kg/m^3 cement dosage and A/C rate = 0.5, with entrained air*)*

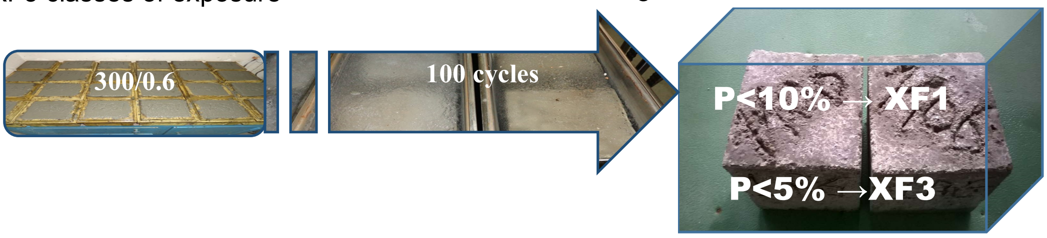
The quantity of scaled material must be less than 1.3 Kg/m^2 after 56 freeze/thaw cycles .

- *for XF4 class of exposure (*320 kg/m^3 cement dosage and A/C rate = 0.5, with entrained air*)*

The quantity of scaled material must be less than 1Kg/m^2 after 56 freeze/thaw cycles.

The quantity of scaled material was determined for concrete blocks of 50x150x150 mm, for a 320 kg/m^3 cement dosage and an A/C rate=0.5.

The results obtained using "slab test" method regarding concrete scaling are prezentate in Figure 3.



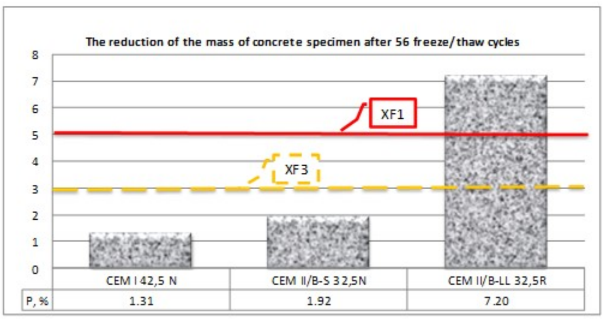


Fig. 1 – The reduction of the mass of concrete specimen after 56 freeze/thaw cycles/ *Reducerea masei probei de beton după 56 cicluri de înghet-dezgheț.*

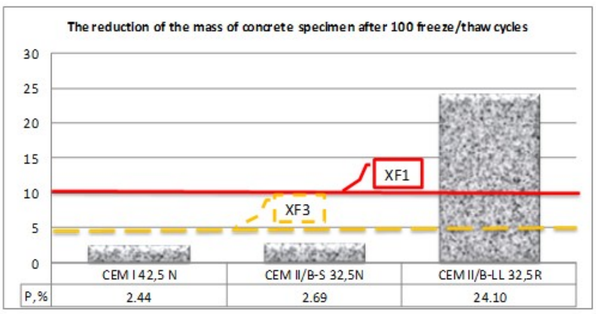
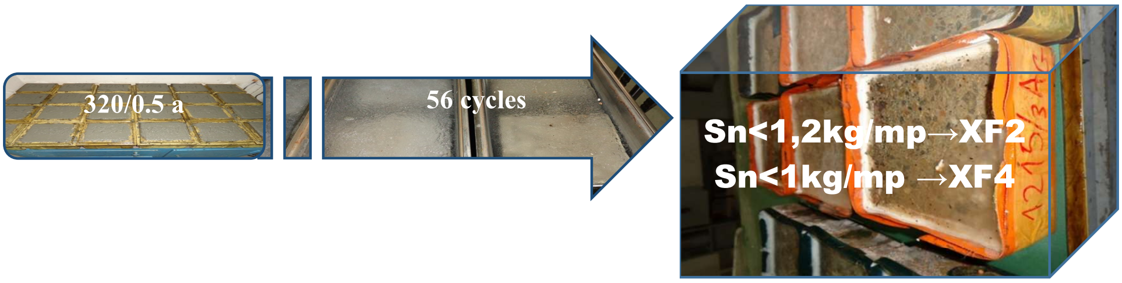


Fig. 2 – The reduction of the mass of concrete specimen after 100 freeze/thaw cycles/ *Reducerea masei probei de beton după 100 cicluri de înghet-dezgheț.*



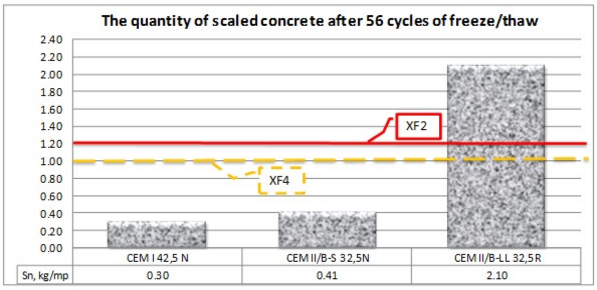


Fig. 3 – The quantity of scaled concrete after 56 cycles of freeze/thaw, with thawing agents, 50x150x150 mm concrete blocks/ *Cantitatea de beton exfoliat după n cicluri de îngheț-dezgheț cu agenți de dezghețare, fâșii de beton de 50x150x150 mm.*

Applying this method for different types of cements, taking into account the undertaken composition parameters, leads to obtaining of some concretes with different levels of resistance to compression, and implicitly different behavior under freeze/thaw action, even with the same values of A/C ratio. This, in a more general approach, justifies the fact that in Table F of the Annex, it has been mentioned as a mandatory rule - to consider a minimal concrete's resistence to compression, even if the EN 206 standard this provision is only informative.

Table 1 presents the classification of the tested cements into the exposure classes on basis of the experimental results obtained:

Table 1

Classification in exposure classes
Încadrarea în clasele de expunere

Exposure	XF1	XF2	XF3	XF4
Method	Cube test	Slab test	Cube test	Slab test
CEM I 42.5N	X	X	X	X
CEM II/B-S 32.5N	X	X	X	X
CEM II/B-LL 32.5R	o	o	o	o

X = fulfilled criterion
o = unfulfilled criterion

2.2. Applying the method of determining the behavior of concretes to sulphatic attack

The program of experimental research consisted in determining the resistance to sulphates of the concretes prepared with CEM I 42.5N, CEMII/B-S 32.5N and CEMII/B-LL 32.5R. In this way, we determined the values of expansion at 28, 60 and 90 days on test pieces of mortar maintained in a medium sulphated environment (2.37% Na_2SO_4 solution) and an aggressive one (4.4% Na_2SO_4 solution). In order to determine the expansion, we prepared and tested prisms of mortar as per EN 196-1 [7] and pr.ENV 196-X [8].

The evaluation of expansion in chemically aggressive environments is performed after each immersion period and it represents the difference between the mean of the lengths of the three test pieces immersed in moderate/aggressive sulphatic environment and the mean of the lengths of the three corresponding test pieces immersed in water at 28 days, related to the mean of the lengths of the respective three test pieces immersed in water at 28 days.

2.2.1 The results obtained on the mortars exposed to a moderate sulphatic environment

The values obtained on the mortars prepared with the three types of cements are presented in Figure 4.

To be observed that the values obtained for expansions at 90 days are under 0.2 mm/m for the mortars prepared with CEM I 42,5N and 0.2 mm/m for the mortars prepared with II/B-S 32.5N respectively.

The value of exposure obtained on concretes prepared with CEM II/B-LL 32.5R is much higher than the values obtained on the other types of cements.

2.2.2. The results obtained on mortars exposed to an aggressive sulphatic environment

The values obtained on mortars prepared with the three types of cements are shown in Figure 5.

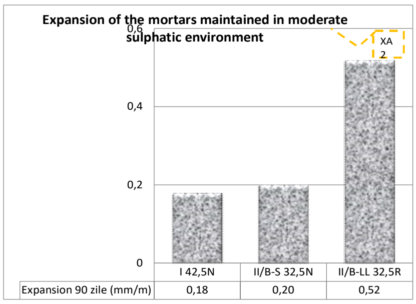


Fig. 4 – The expansion of the mortars maintained in moderate sulphatic environment, XA2 class of exposure/ *Expansiunea mortarelor menținute în mediu sulfatic moderat, clasa de expunere XA2.*

We can notice that the values obtained at 90 days for the expansion of mortars prepared with the four types of cement are under 0.5 mm/m (fig. 5), except the mortars prepared with CEM II/B-LL 32.5R.

To integrate in XA3 class of exposure, the evaluating criterion for concrete's resistence to sulphatic attack is:

The value of expansion of mortar test pieces must not exceed 0.5 mm/m after 90 days of maintaining them in 4.4% Na_2SO_4 solution.

Having in mind the results obtained for exposure in a moderate sulphate environment, we could consider that, in case of XA3 exposure, the behavior of mortars containing CEM I 42.5N and CEMII/B-S 32.5N is adequate.

The mortars prepared with CEM II/B-LL 32.5R present a higher degree of expansion than the one afferent to the criterion.

The sulphatic attack is very distructive for concrete and can take place especially in case of the concrete in the foundations (hidden parts of structures). For that reason, it is forbidden to advise the use of a type of cement not resistant to sulphates for XA2 and XA3 classes. At an European level, there are some suggestions of criteria for establishing the domains of using the cements of XA classes of exposure. One of these suggestions was presented in this article (based on the expansion of concrete at a certain phase of sulphatic attack). We mention that, due to the relatively low number of trials performed and

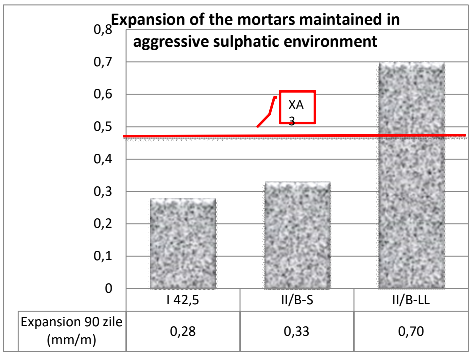


Fig. 5 – Expansion of the mortars maintained in aggressive sulphatic environment, XA3 class of exposure/ *Expansiunea mortarelor menținute în mediu sulfatic agresiv, clasa de expunere XA3.*

having in mind the latest recommendations in European documents, the results can be considered more with regard to quality. Experimental results indicate, for sure in this case, a none adequate behavior of the concretes prepared with the CEM II/B-LL 32.5R, making this type of cement not recommendable for such applications. The other types of cements were recommended to be used in XA1 class of exposure. For XA2 and XA3 classes, cements resistant to sulphates must be used.

2.3. The application of the methods of determining concrete behavior at the attack of chlorides

Estimation of accelerated penetration of chloride ions was done as per SR 13382 [9] «Concretes and cement mortars. Estimating acceleratted penetration of chloride ions». SR 13382 being a standard specific for the method, the estimate regarding accelerated penetration of chloride ions is done by comparrison between the concretes in the same resistance class prepared with the three types of cements.

For this determination, cylindrical test pieces of concrete of C30/37 and C35/45 classes were prepared. The concrete test pieces were vibrated manually.

In this way, we observed the values regarding the composition and the minimal classes of resistence as per EN 206, for XD classes of exposure (XS not appliable in R. of Moldova).

We prepared concretes of C30/37 class with A/C rates under 0.55 and cement dosage higher than 300 kg/m^3, and respectively concretes of C35/45 class with A/C rates under 0.45 and cement dosage higher than 320 kg/m^3.

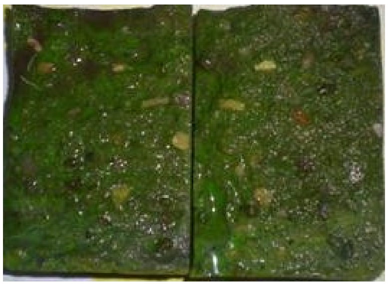
Table 2 presents the compositions we used. The compositions were chosen having in mind the results obtained initially for the resistence at compression.

Table 2

The characteristics of the fresh concretes prepared with a superplastifier admixture
Caracteristicile betoanelor proaspete preparate cu aditiv superplastifiant

C30/37	CEM	Cement dosage (kg/m³)	Water (l)	Admixture (l)	Aggregate (kg)	8%	13%	12%	15%	21%	31%
Recipe						sort 0-0.25mm	sort 0.25-0.5mm	sort 0.5-1mm	sort 1-2mm	sort 2-4mm	sort 4-8mm
RC1	**I 42,5N**	408	211,00	3.47	**1816**	145	236	217	272	381	563
RC2	**B-LL 32,5R**	408	180,00	3.47	**1816**	145	236	217	272	381	563
RC3	**B-S 32,5N**	408	215,00	3.47	**1816**	145	236	217	272	381	563

C35/45	**CEM**	Cement dosage (kg/m³)	Water (l)	Admixture (l)	Aggregate (kg)	8%	13%	12%	15%	21%	31%
Recipe						sort 0-0.25mm	sort 0.25-0.5mm	sort 0.5-1mm	sort 1-2mm	sort 2-4mm	sort 4-8mm
RC4	**I 42,5N**	456	210,00	3.88	1829	146	237	219	274	384	567
RC5	**B-LL 32,5R**	552	206,00	4.70	**1690**	135	219	202	253	354	523
RC6	**B-S 32,5N**	504	224,00	4.29	**1760**	140	228	211	264	369	545



The concrete specimen were maintained in water for 7 days and in air for 21 days, at 20⁰C and 65% humidity. After 28 days, the concrete specimen were maintained for 24 hours in saturated lime water with a content of 3% NaCl.

Measuring the depth of chloride ions penetration is done under the action of electrolysis. The revealing is done by calorimetrical method with fluoresceine and silver nitrate.

After applying the silver nitrate solution, the test pieces were kept in standard conditions for 3 days. During this period, two zones are revealed: first pink-white and the second black-brown. The zone in the specimen that is pink-white is the one with chloride ions, and the black-brown one is not penetrated by the chloride ions.

Figures 6-9 present the values of the chloride ions penetration depths into concretes (measured in central zones of the cylinders) after 28 and 60 days after preparation. The higher values recorded near the cylinder generators are due to solution infiltration between the polyethylene tube and the concrete cylinder.

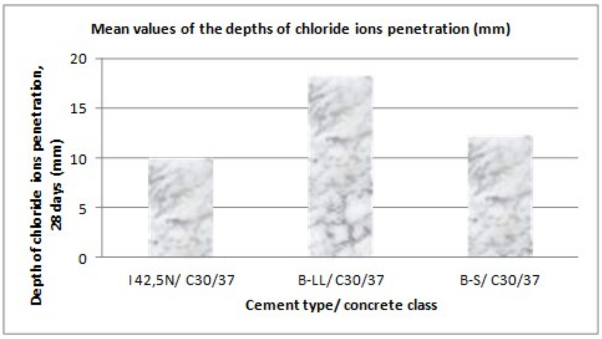


Fig.6 – Mean values of the depths of chloride ions penetration in concretes of C30/37 class at 28 days/*Valorile medii ale adâncimilor de penetrare a ionilor de clor în betoane de clasă C30/37 la vârsta de 28 de zile.*

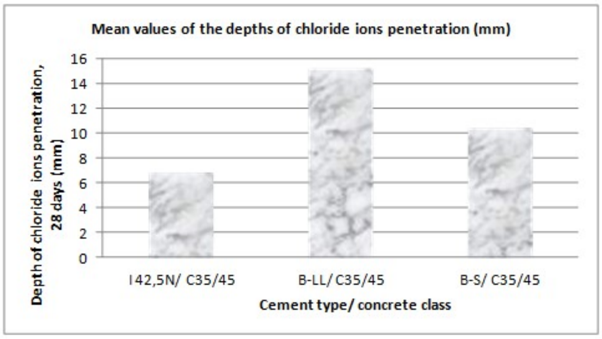


Fig. 7 – Mean values of the depths of chloride ions penetration in concretes of C35/45 class, at 28 days / *Valorile medii (măsurate în zonele centrale ale cilindrilor) ale adâncimilor de penetrare a ionilor de clor în betoane de clasa C35/45 la vârsta de 28 de zile.*

The depth of chloride ions penetration shows a decrease in time between 28 and 60 days.

For compositions corresponding to C35/45 class, the values of chloride ions penetration decrease compared to the values for C30/37 class.

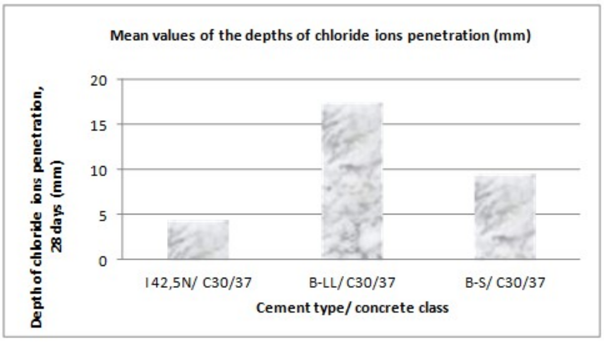


Fig. 8 – Mean values of the depths of chloride ions penetration in concrete of C30/37 class, at 60 days / *Valorile medii ale adâncimilor de penetrare a ionilor de clor în betoane de clasă C30/37 la vârsta de 60 de zile.*

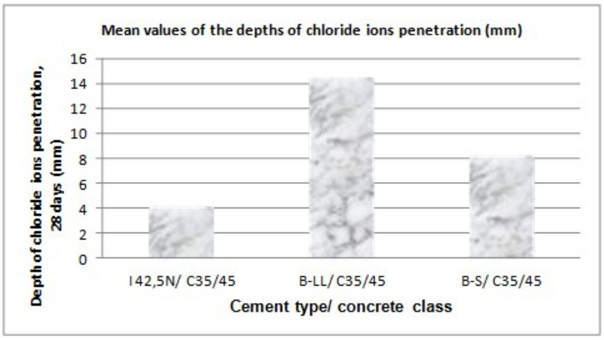
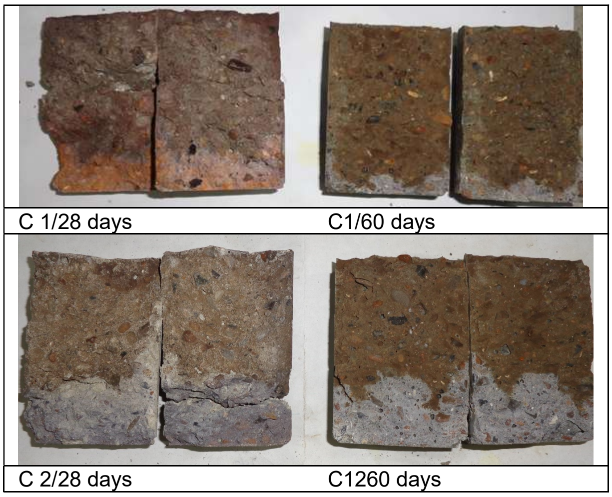


Fig. 9 - Mean values of the depths of chloride ions penetration in concrete of C35/45 class, at 60 days / *Valorile medii ale adâncimilor de penetrare a ionilor de clor în betoane de clasă C35/45 la vârsta de 60 de zile.*



The concretes prepared with CEM I 42,5N have a very good behavior. The highest values were obtained for concretes prepared with CEM II/B-LL.

Experimental measurings were aimed to estimate the domains of use in XD classes of exposure. We must point out that there are no criteria recognised at an European level for determining the domains of use for concretes in this class of exposure. The results obtained in experimental determinations were corroborated with Romanian and European experience. It can be ascertained that the concretes prepared with cements containing limestone and especially II/B type behave less favourably under chlorides' action and therefore they were not adequate to be used for class of exposure XD in Annex F, table F1 of The Code of Practice.

Based on the results shown, annex F at National Annex was completed with the domains corresponding to the use of cement in specific exposure classes.

3. Comments on applying the methods

3.1 Defining the domains of use for cements, with a view to ensuring the same life duration of reinforced concrete structures, is best illustrated in the diagram in Figure 10, (CEB Durable Concrete Structures. Design Guide. Bulletin d'Information, Nr.183,1992 [10]). Few European norms, except United Kingdom contain such a complex approach. Generally, they prefer more "covering and wrapping" provisions regarding the composition of concrete, including the use of certain types of cements. On the other hand, adopting of certain compositions in order to ensure some equivalent performances cannot be done other than by applying some experimental methods.
3.2 Applying some accelerated methods of determining the performances of the concrete submitted to various actions of the environment is essential in order to ensure the durability of the concrete prepared with different types of cement. These methods, corroborated with international "experience" and "the test of time" represent some basic elements in defining the domains of use for cements.
3.3 In European countries various testing methods are used, including accelerated testing for concrete's durability, and there is a tendency to apply some common methods, acknowledged at a European level.
3.4 In this article we presented three methods for testing concrete resistance to freeze/thaw, to the action of sulphates and chlorides and we can distinguish some peculiarities in their application, as follows:

- The method of testing the resistance to freeze/thaw, generally accepted and developed at a European level, is completed with suggestions of criteria of integration, depending on the results obtained, in different XF exposure classes, this being an example of performance approach. This method mirrors much of the behavior (in real time) of the concretes submitted to freeze/thaw process. This method serves in a great extent the selection of suitable component materials (including cements) that can be used in concrete's composition. This method can also help applying the concept of equivalent durability (by obtaining some close values of the scaled concrete when, by

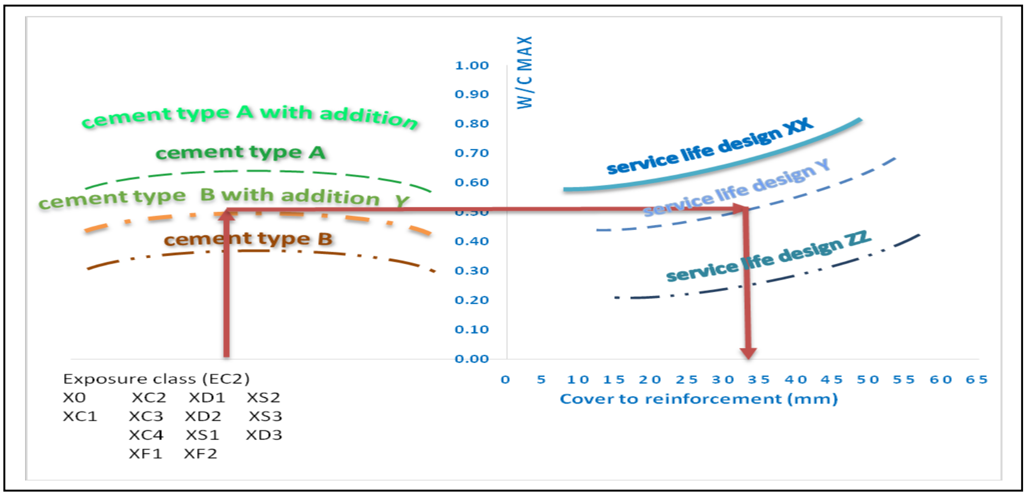


Fig. 10 – The diagram for the relation between the types of cement, A/C rate, classes of exposure and the thickness of the concrete layer covering the reinforcing to ensure a certain life duration of the structures/ *Schema relației între tipurile de ciment, raportul A/C, clasele de expunere și grosimea stratului de acoperire cu beton a armăturilor pentru asigurarea unei anumite durate de viață a structurilor.*

using different component materials, the cement dosage or cement/water ratio are modified).

- The application of the method regarding the evaluation of the resistance to sulphatic attack (based on concrete's expansion due to this phenomenon) is also completed with a performance criterion. Applying this criterion sometimes leads to results that must be rendered more in terms of quality (by comparison to other compositions/cements) and prudently of quantity. The complexity of this phenomenon and the important structural implications which it may induce, mostly in many "hidden" works, lead to the necessity to consider a limit in applying this method and especially its performance criterion. Anyway, cements resistant to sulphates as per standards in force must be used for XA2 and XA3 classes.
- The method of diffusion of chlorides used as per Romanian standard [9] is not completed by criteria of evaluation/integration in specific XD exposure classes. Application of this method led to "quality" conclusions and to comparative assessments between the behaviors of concretes prepared with different types of cements.
- The first two applied methods, which are completed with evaluating criteria, have "standard" compositions, so that the only parameter which differs is the cement. For the third method, not accompanied by evaluating criteria, we used the compositions indicated in EN 206 standard corresponding to exposure classes.

4. Conclusions

The domains of using the cements cannot be determined other than by applying of some accelerated methods preferable based on performance, taking into account international experience and the behavior over time and in real environmental conditions of some cements known to have passed well the test of time. The verification of the relations between the performances of the concrete tested with accelerated methods and of the concrete in the structure represents an essential element in developing some accelerated methods based on performance. [6].

In this article we presented three methods for testing concrete resistance to freeze/thaw, to the action of sulphates and chlorides. Regarding the results obtained by applying the mentioned methods, they generally mirror the peculiarities of the concretes containing relatively large quantities of slag CEM II/B-S and limestone CEM II/B-LL, this leading to suggesting of some specific uses depending on the classes of exposure.

As for the results presented in this article, the methods based on performance determined the domains of use for some cements produced in R. of Moldova, by observing the limit values of concrete composition as presented in [1].

REFERENCES

1. EN 206 - Concrete – Part 1: Specification, performance, production and conformity.
2. CEN/TS 12390-9 Testing hardened concrete. Freeze-thaw resistance. Scaling.
3. CEN/TS 12390-10 - Testing Hardened Concrete - Part 10: Determination of the Relative Carbonation Resistance of Concrete
4. CEN/TS 12390-11 - Testing hardened concrete Part 11: Determination of the chloride resistance of concrete, unidirectional diffusion.
5. CEN/TR 16563 - Principles of the equivalent durability procedure
6. CEN 104/SC1/WG1 N55 - European experience with performance testing for durability and the specification of durability by performance
7. EN 196-1 - Methods of testing cement — Part 1: Determination of strength.
8. pr.ENV 196-X - Determination of cements to attack by sulfate solution or sea water.
9. SR 13382 – Concrete and cement motars – Estimation of accelerated penetration of the clorine ions.
10. CEB Durable Concrete Structures. Design Guide. Bulletin d'Information, Nr.183,1992.

****