# CONSIDERAŢII TEORETICE ŞI DETERMINĂRI DE LABORATOR REFERITOARE LA CONTRACŢIA BETONULUI
# THEORETICAL CONSIDERATIONS AND LAB DETERMINATIONS REGARDING CONCRETE SHRINKAGE

**LIANA IUREŞ [1*] , CORNELIU BOB[1], REMUS CHENDES[1], CĂTĂLIN BADEA[1], RADU POPA [1]**
[1]*Facultatea de Construcţii, Universitatea „Politehnica" Timişoara, România,*

***The concrete it is delivered on the construction site having two main characteristics: it will harden and it will present drying cracks. The cracks due to hardening of the concrete will lead to complains of the beneficiary and to shortening of the durability of the concrete structure. The drying shrinkage sensibly influences the resistance structures' integrity. It was noticed that for the elements that have the free shrinkage constrained, it is possible to appear cracks. The present paper propose the introduction of two new coefficients: $\Omega$ - characteristic shrinkage and $\gamma$ - cracking indices, that are for a facile characterisation of the efficiency of an admixture used in concrete, on the reduction of the shrinkage effects and cracking tendency.***

***Betonul este livrat pe şantier având două caracteristici principale: se va întări şi va prezenta fisuri de uscare. Crăpăturile datorate întăririi betonului vor duce la reclamaţii din partea beneficiarului şi la reducerea durabilităţii structurii de beton. Contracţia datorată uscării influenţează sensibil integritatea structurilor de rezistenţă. S-a constatat că pentru elementele care au contracţii împiedicate, este posibil să apară fisuri.***

***Lucrarea de faţă propune introducerea a doi noi coeficienţi: $\Omega$ - contracţie caracteristică şi $\gamma$ - indice de fisurare, utili pentru o caracterizare facilă a eficienţei unui amestec utilizat în beton, asupra reducerii efectelor contracţiei şi a tendinţei de crăpare.***

***Keywords:*** *concrete, durability, shrinkage, admixtures.*

## 1. Theoretical considerations upon drying shrinkage of concrete

A negative characteristic of using concrete as building material it is due to its volumic instability during time passing; by other words, it is the concrete property to shrink and crack during its drying process.

It is well known that the water release from fresh concrete into the environment leads to drying shrinkage. The main factors that influence the size of this process are:

- The aggregates used in the concrete have the principal influence upon drying shrinkage; they are capable to reduce the real size of the shrinkage.
- The water content influences the shrinkage by reducing the prelevance of aggregate volume – which restrain the shrinkage effect. By water volume increasing into concrete composition, the shrinkage will increase proportionally.
- The cement characteristics have a little influence upon concrete shrinkage; a bigger shrinkage of a hardened cement paste dose not necessary leads to a big shrinkage of the concrete made with that cement type. It is known that the milling finess and the content of $C_3A$ and also the dosage have an influence upon the concrete shrinkage.
- The shrinkage process takes place during a long time, but, practically, it can be considered that it takes place in a great speed in the first days – weeks after concrete casting, being of negligible values after 1 – 5 years.
- The shrinkage value reduces proportionally with humidity, being zero at 100% humidity.
- The shrinkage it is influenced by building elements dimensions: when the ratio element volume/element surface increase, the shrinkage linearly decrease in function of other parameters.

Drying shrinkage it is measured staring at 24 hours since the concrete was made and cast, more exactly since forwork it is removed. According to the international standards ASTM C157 and RILEM CPC9, the shrinkage of the concrete should be measured on prisms having standard dimensions, by measuring the length variations in time. The phenomena of drying shrinkage developing depends on the element dimensions and forms, because these two geometrical characteristics directly influence the amount of the humidity that it is lost into the air from the concrete element. According to the previous sentence, it was proven in other international researches that bigger elements will present drying shrinkage over a longer time period, but the final value of this shrinkage could finally be smaller than the value presented by concrete elements having a small ratio of volume/surface. This long period of shrinkage development in the concrete elements having a big volume/surface ratio, it can be computed (according to CEB-FIB, 1990) by use of

* Autor corespondent/*Corresponding author*,
E-mail: liana.iures@upt.ro

the following relationship

$$\varepsilon_s(t,t_0)=\varepsilon_{s0}[\beta_s(t)-\beta_s(t_0)] \tag{1.1}$$

where:

$\varepsilon_{s0} = \varepsilon_1 \times \varepsilon_2$ - initial shrinkage coefficient;

$\varepsilon_1$ - factor which depends on the environment;

$\varepsilon_2$ - factor which depends on $h_0$;

$h_0$ - thickness coefficient , depends on the elements dimension and environmental humidity;

$\beta_s$ - factor of shrinkage time evolution, depends on $h_0$;

t - concretes age;

$t_0$ - the age at which the concretes drying started.

The hydrated cement paste shrinkage begins on the concrete elements surface and then, depending on the capilar sizes existing in the cement paste structure, as well as the relative humidity of the surrounding environment and the cement type, it is propagated, slower or quickly, into internal structure of the concrete. This it can be an accurate approach of big interconnected capilars that are present into internal structure of usual concrete, this fact leading to a faster shrinkage. For high-performance concretes [1 - 4], the drying shrinkage is slowered down due to the presence of small and very small capilars which are quickly disconnected by means of the hydratation products.

Capilar tensions appear when the relative air humidity it is between 45 and 95%, due to meniscus forming into the water pores existing in the cement paste. The meniscus is under hydrostatic tension, forming a curved surface. The water makes compression over the solid skeleton, thus, it results a decreasing of pores sizes. Capilary effort ($P_{cap}$) it is defined as depending on pores radius (r), water superficial tension ($\gamma$) and relative humidity (RH) and it can be written:

$$P_{cap}=\frac{2\gamma}{r}=\frac{ln(RH)}{K} \tag{1.2}$$

where K it is a constant.

The separation pressure represents the pressure caused by absorbed water which exists into the capilars pores. By loosing absorbed water, the separation pressure decreases, this leads the cement particles to come closer one to the other, so shrinkage is produced.

## 2. Used shrinkage admixtures

The use of shrinkage admixtures in concrete compositions started in 1980 in Japan and USA [5,6]. After the year of 1989, these admixtures appeared on romanian concrete products, too. By publishing of the „Practical Code For Concrete, Reinforced Concrete and Prestressed Concrete Works - (NE 012 /1999)", it was introduced the obligativity of using admixtures into concretes' compositions [7,[8].

The researches for establishing some shrinkage reduced concretes' compositions were made as a research project type Grant CNCSIS Type AT, no. 32940, Theme no. 5 Code CNCSIS 203, over a period of 2 years, named "Shrinkage reduced concretes obtained with use of special admixtures"[9 - 11].

The experimental tests were based on establishing the optimum utilisation percentage of three different additives for shrinkage reducing of the hardened concrete [12]; also the optimisation of the compositions and manufacturing technology for these types of concretes, by using the products and materials typically for our country.

The effects of the admixtures upon fresh and hardened properties of the concrete were into the field of the research interest. The use of such shrinkage reducing admixtures into the concretes compositions leads to the followings benefits:

- reduction of autogenous and drying shrinkage of the concrete;
- reduction of the possibility of reinforcements corrosion and concrete degradation by an efficient limitation of humidity and chlorine ions penetration through micro or macro cracks, the durability it is increased;
- the final concrete surfaces are smoother;
- the maintenance cost of the concrete structures made by shrinkage reduced concretes it is lower.

The price of shrinkage reduced admixtures it can be considered by some high, but their usage can reduce or eliminate the need of using air entrainment or water reducing admixtures into concretes' compositions [13]. The secondary effects that the use of such admixtures into concrete would be the main subjects for further researches.

***The tested admixtures were:***

- **SR - 2** it is an superior alcohol base admixture, used for concretes and mortars for obtaining a superior durability, impermeability and preventing drying shrinkage. The effect produced by SR – 2: cohesion growing. The recommended dosage it is (0,5 – 3,0) % solution from the cement mass.
- **ECLIPSE** it is a liquid admixture used for cracks formed due to hydraulic contraction, reduction into concretes and mortars. The recommended dosage it is (1,0–2,5) % solution from the cement mass (2,5–10 l/m$^3$).
- **FM 40** it is a superplasticizer based on polycarboxylic esters used for high resistance concretes and mortars. It is also characterised by imposing a setting time delayed to the concretes. The recommended dosage it is (0,2 – 2,5) % solution from the cement mass.

**Table 1**

Tested concrete compositions / *Compoziţia betoanelor testate*

| Concrete | Cement type and dosage | Aggregate | W/C ratio | |
|---|---|---|---|---|
| Control sample C20/25 | II/A-S32,5R 407 kg/m$^3$ | River aggregate $\phi_{max}$=16mm | 0,5 | |
| Concrete with Eclipse C20/25 | II/A-S32,5R 407 kg/m$^3$ | River aggregate $\phi_{max}$=16mm | 1.5% ad | 0.39 |
| | | | 2% ad | 0.36 |
| | | | 2.3% ad | 0.34 |
| Concrete with FM 40 C20/25 | II/A-S32,5R 407 kg/m$^3$ | River aggregate $\phi_{max}$=16mm | 1.5% ad | 0.39 |
| | | | 2% ad | 0.36 |
| | | | 2.3% ad | 0.34 |
| Concrete with SR2 C20/25 | II/A-S32,5R 407 kg/m$^3$ | River aggregate $\phi_{max}$=16mm | 1.5% ad | 0.39 |
| | | | 2% ad | 0.36 |
| | | | 2.3% ad | 0.34 |

**Table 2**

Properties of hardened concrete made with ECLIPSE/ *Proprietăţi ale betoanelor întărite realizate cu ECLIPSE*

| Concrete class | Type of concrete | Characteristics of hardened concrete at 28 days | | | |
|---|---|---|---|---|---|
| | | Compression strength | | Bending tensile strength | |
| | | $f_c$ N/mm$^2$ | $\pm\Delta f_c$ % | $f_{ct}$ N/mm$^2$ | $\pm\Delta f_{ct}$ % |
| C20/25 | Control concrete sample | 31.00 | - | 2.43 | - |
| | Concrete with Eclipse 1.5% | 32.6 | +5.16 | 2.22 | -8.64 |
| | Concrete with Eclipse 2.0% | 33.1 | +6.77 | 2.46 | +1.23 |
| | Concrete with Eclipse 2.3% | 33.9 | +9.35 | 2.59 | +1.45 |

**Table 3**

*Properties of hardened concrete made with FM 40 / Proprietăţi ale betoanelor întărite realizate cu aditivul FM 40*

| Concrete class | Type of concrete | Characteristics of hardened concrete at 28 days | | | |
|---|---|---|---|---|---|
| | | Compression strength | | Bending tensile strength | |
| | | $f_c$ N/mm$^2$ | $\pm\Delta f_c$ % | $f_{ct}$ N/mm$^2$ | $\pm\Delta f_{ct}$ % |
| C20/25 | Control concrete sample | 31.16 | - | 2.38 | - |
| | Concrete with FM 40 1.5% | 36.02 | +15.59 | 2.57 | +7.98 |
| | Concrete with FM 40 2.0% | 37.24 | +19.51 | 2.54 | +6.72 |
| | Concrete with FM 40 2.3% | 38.39 | +23.2 | 2.57 | +7.98 |

**Table 4**

Properties of hardened concrete made with SR – 2 */ Proprietăţi ale betoanelor întărite realizate cu aditivul SR – 2*

| Concrete class | Type of concrete | Characteristics of hardened concrete at 28 days | | | |
|---|---|---|---|---|---|
| | | Compression strength | | Bending tensile strength | |
| | | $f_c$ N/mm$^2$ | $\pm\Delta f_c$ % | $f_{ct}$ N/mm$^2$ | $\pm\Delta f_{ct}$ % |
| C20/25 | Control concrete sample | 27.3 | - | 2.95 | - |
| | Concrete with SR - 2 1.5% | 23.98 | -10.05 | 1.88 | -36.27 |
| | Concrete with SR - 2 2.0% | 24.5 | -8.10 | 2.09 | -29.15 |
| | Concrete with SR - 2 2.3% | 21.5 | -19.35 | 1.61 | -45.42 |

## 3. Characteristic shrinkage and cracking index

The experimental laboratory research was done by taking into consideration the upon presented additives: Eclipse, SR2 and FM 40, their effect on shrinkage of the tested mortars or concretes compositions. The experimental tests took into account three different percentages for each additive, the physical – mechanical characteristics of the concretes were determined, as well as the measuring of the drying shrinkage over a time period of 90 days was done. The studied compositions are presented in the Table 1.

**Table 5**

Characteristic Shrinkage / *Contracţia caracteristică*

| Sample | | Characteristic shrinkage Ω ,($m^2$/N) |
|---|---|---|
| Control sample | | 1,19x10$^{-5}$ |
| **Eclipse** | 1.5% | **0.85x10$^{-5}$** |
| | 2.0% | **0.66x10$^{-5}$** |
| | 2.3% | **0.47x10$^{-5}$** |
| FM 40 | 1.5% | 0.88x10$^{-5}$ |
| | 2.0% | 0.75x10$^{-5}$ |
| | 2.3% | 0.64x10$^{-5}$ |
| SR 2 | 1.5% | 1.16x10$^{-5}$ |
| | 2.0% | 1.13x10$^{-5}$ |
| | 2.3% | 1.14x10$^{-5}$ |

**Table 6**

Cracking Index / *Indice de fisurare*

| Sample | | Cracking Index γ |
|---|---|---|
| Control sample | | 4,96 |
| **Eclipse** | 1.5% | 4.18 |
| | 2.0% | 2.92 |
| | **2.3%** | **2.05** |
| FM 40 | 1.5% | 3.85 |
| | 2.0% | 3.18 |
| | 2.3% | 2.20 |
| SR 2 | 1.5% | 4.96 |
| | 2.0% | 4.02 |
| | 2.3% | 4.00 |

The authors propose the introduction of two new coefficients denoted **Ω** and **γ,** for a facile characterisation of the efficiency of an admixture, used in mortars and concretes, on the shrinkage and cracking reducing effects.

***1.) Ω - Characteristic shrinkage***, equals to the ratio between the shrinkage presented by the concrete element and its compression strength determined on cubic samples with l=15 cm, at 28 days (Tables 2, 3 and 4).

The concretes shrinkage deformation, in hardened state, was measured by means of microcomparators having the scale 1/1000 mm. The temperature and humidity of the environment was also taken into consideration. The samples of hardened concrete were made of prismatic shape with the following dimensions 100x100x550 mm. As control zero sample, the shrinkage was compared with the measured values on a glass sample.

For building elements, when Ω has the smallest values, the admixtures efficiency it should be considered higher.

Defining $\Omega = \frac{\varepsilon_c}{f_c}\left(\frac{m^2}{N}\right)$ as **characteristic shrinkage**, from the Table 5 results that the Eclipse admixture, regardless it dose not have any important increases when one reffers to the compression strength, compared to FM 40, it presents a more important characteristic shrinkage, as it can be observed in Figure 1:

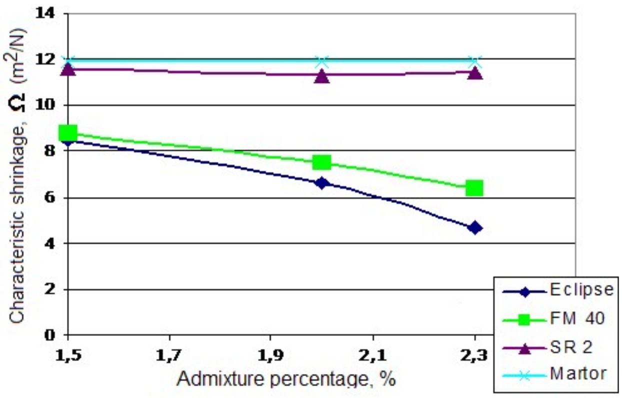


Fig. 1 - Characteristic shrinkage – admixture percentage / *Contracţia caracteristică – procentul de aditivi.*

**2.) γ – Cracking index** equals to the ratio between the effort which is present into concrete element and its bending tensile strength determined on standard prisms at 28 days (Table 6).

$$\gamma = \frac{\sigma}{f_{ct}} \Rightarrow \gamma = \frac{E \cdot \varepsilon_c}{f_{ct}}$$

**It will be considered that the concrete element will crack if γ ≥ 1.**

For reduced values of γ , the admixture efficiency in reducing the cracking appearance probability should be considered higher, as it can be observed in Figure 2.

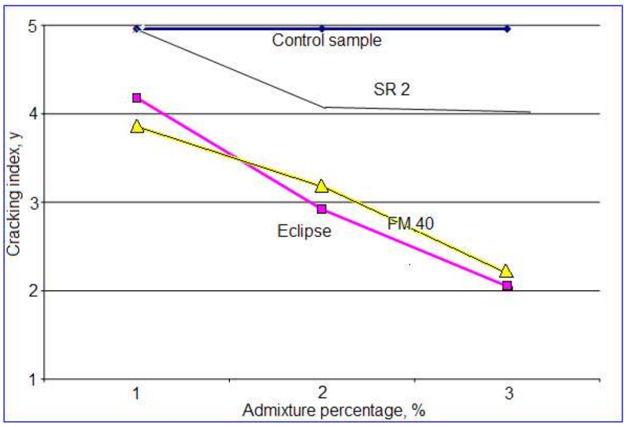


Fig. 2 - Cracking index γ – admixture percentage / *Indice de crăpare γ – procentul de aditivi.*

## 4. Conclusions

1. The cracking tendency decrease by admixture percentage increase, but it should be mentioned that, by using a bigger admixture percentage than the maximum imposed one by the producer, dose not necessary leads to a decrease of the drying shrinkage tendency in that concrete.

2. The presented results by using the upper three admixtures are in accordance with other results obtained into experimental researches from our country and from other countries, as well.

3. Introducing the two new coefficients, Ω - **characteristic shrinkage** and **γ** – **cracking index**, one should can estimate accurately the cracking tendency of a hardened concrete, taking into account its mechanical strengths. This manner is on useful hand when designing concrete structures and also for estimations regarding to the durability of such structures.

By mean of these coefficients, Ω - characteristic shrinkage and **γ** – cracking index, it can also be established the efficiency of an admixture in shrinkage reduction, leading to an optimisation of shrinkage reduced concretes composition.

4. Taking into account these two coefficients, it is proposed, as future work, the writing of provisory instructions for the compositions of shrinkage reduced concretes.

5. As future work, it is proposed, the establishing of the optimum composition by using shrinkage reducing admixtures existing on romanian market, so that the final ratio between final product price/shrinkage reducing effect should be a competitive one. Other future work will take into the consideration experimental and laboratory tests made with different percentages of the studied admixtures into concretes such as: lightweight concretes, self-compacting concretes etc., or replacing into the tested composition some of the cement mass by using of silica powder or slag.

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