DIGITAL QUANTIFICATION OF EFFECTS OF ADMIXTURES ON EARLY SHRINKAGE CRACKING

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Abstract: The study of the effect of early shrinkage is important to prevent aesthetic defects and, especially, to avoid the reduction of durability of concrete elements due to surface cracking. This paper presents the application of a new digital imaging methodology to quantify the effects of polypropylene macrofibres, microfibres and glycolether shrinkage reducing admixture (SRA) on early shrinkage cracking. This way, the effectiveness of different admixtures incorporated into the common base mix design of concrete can be compared impartially through the total cracking area, maximum crack width, total crack length, among other parameters that this methodology provides. The results demonstrate the great capacity of the methodology to isolate and determine the characteristics of an entire cracking pattern, and the similarity of behaviour between admixtures. Nevertheless, the presence of 1 kg/m^3 of microfibres leads to the delay and the decrease of early shrinkage cracking pattern.

1 INTRODUCTION

Early age deterioration of concrete is a persistent problem that arises from rapid complex volume changes when strength is relatively low. The induced stresses often promote cracking affecting durability, and long-term service life of concrete structures.

Most of this type of failures is caused by concrete shrinkage, especially in restrained members with strict environmental conditions as the strain is usually limited and curing is not enough to prevent cracking. Therefore, other solutions have been introduced in concrete to reduce and control the shrinkage effects. Among others, it can be mentioned the incorporation of fibres, and/or SRA. While fibres distribute uniformly the separate efforts stopping the growth and evolution of cracks, SRA modifies the properties of water in the paste, reducing the capillary tension developed inside the pores.

Nowadays, the lack of a simple impartial standardized methodology complicates, on the one hand, the determination of the effectiveness of the different products added to concrete to decrease early shrinkage cracking and, on the other hand, the comparison between them. For this reason, a new comparative methodology [1] is used in this work for calculating the cracking parameters and comparing, with them and the visual results also provided, the different options proposed here to reduce as much as possible the effects caused by early shrinkage in any type of concrete subjected to any environmental conditions.

2 EXPERIMENTAL PROGRAM

2.1 Materials

Seven types of concrete of 30 MPa, commonly used in pavement applications, were tested: one plain conventional concrete (CC), five with different types and contents of polymeric fibres (FRC1, FRC2, FRC3, FRC4 and FRC5) and another with a glycolether SRA (SC). Such concrete were produced using CEM 32.5R II, crushed siliceous aggregates and superplasticizer based on second-generation polycarboxylate ethers. Thus, the use of the same aggregate, admixture, water and cement types and contents (Table 1) allowed a more homogeneous comparison, reflecting the results only the influence of these admixtures in the behaviour of concrete.

There are some recommendations for minimizing shrinkage effects, such as several curing methods, revibration and refinishing of fresh concrete, the use of expansive cements or admixtures or the addition of fibres or SRA [2-8]. Some of the mentioned actions could not eliminate early age shrinkage due to the limitation of time of the test. For this reason, fibres, SRA and combinations between them were chosen as they were incorporated directly into the mixture and, therefore, permitting to act from the beginning of the test.

Table 1: Mix design.

	CC	FRC					SC
[kg/m^3]		1	2	3	4	5	
Cement	350	350	350	350	350	350	350
Sand	920	920	920	920	920	920	920
Grave	970	970	970	970	970	970	970
Water	200	200	200	200	200	200	200
Suplerplas-ticizer [l/m^3]	2.7	2.7	2.7	2.7	2.7	2.7	2.3
SRA [%]	--	--	--	--	--	--	1.0
Macrofibre	--	4.5	--	2.0	--	--	--
Microfibre	--	--	2.0	1.0	1.0	0.5	--

2.2 Test method

The test design was basically based on Yokoyama et al. [9] and Mora tests [10] and the standard test method described in ASTM C1579-06 [11]. It consisted of highly-restrained square concrete slabs of 800 mm of side and 100 mm of thickness, whose four edges and bottom surface were restrained by means of bolts and a wooden panel, respectively. Thus, each slab only had one free surface, which was exposed to controlled environmental conditions: 75% of relative humidity, 2 m/s of wind velocity and over 45ºC of temperature, provided with common tools during approximately 20 hours (Figure 1). Both restraints speeded up the dehydration process and, therefore, increased the cracking pattern.

3 DIGITAL QUANTIFICATION

In order to quantify early shrinkage cracking and serve as impartial analysis procedure to compare cracking patterns and their respective characteristic parameters, the digital imaging methodology developed by Ruiz-Ripoll et al. [1] was applied as it is a technique which minimizes the effort of estimation of shrinkage effects, providing accurate measurements in an easy and comfortable way.

Figure 1: Environmental tunnel.

Basically, the application of the methodology consisted of taking pictures of the entire cracking pattern. Afterwards, the pictures were unified and treated by common software applications. The image obtained in the previous step was filtered to correct the lens defects, arrange the contrast between lights and shadows, and finally cracks were individualized and highlighted (Figure 2). As a result, parameters such as total cracking area, maximum crack width, total crack length, average crack width and crack reduction ratio (CRR) were easily calculated. This last parameter was very useful to evaluate the effects of admixtures from the point of view of durability and sustainability of concrete as it represented the efficacy of the product added to the mixture for reducing the average crack width caused by shrinkage.

3 ANALYSIS OF RESULTS

As expected, from the point of view of early shrinkage cracking, the worst mixture is the plain conventional concrete. It undergoes the highest cracked area, which is distributed in many width cracks. Nevertheless, the crack length registered in the SC concrete, which contains SRA, is longer than the CC one. It is due to the fact that SC cracking pattern is composed by finer and longer cracks, as proved its average crack width in Table 2, being lower the concrete damage.

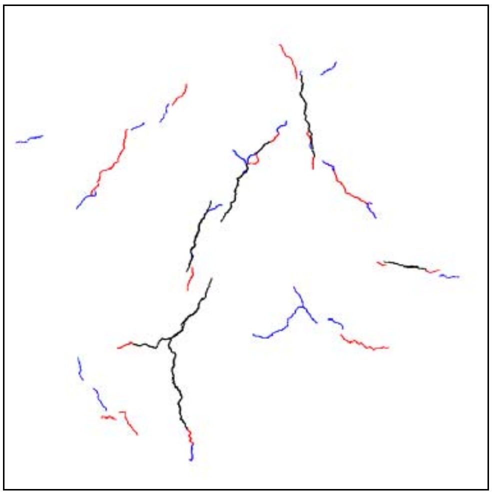

Figure 2: Early shrinkage cracking pattern.

Table 2: Cracking parameters.

	CC	FRC					SC
		1	2	3	4	5	
Area [cm^2]	10	1	2	4	2	8	9
Length [cm]	208	43	55	101	71	202	248
Maxi-mum width [mm]	1.69	0.80	0.64	0.80	0.68	1.45	1.04
Avera-ge width [mm]	0.65	0.48	0.40	0.44	0.30	0.51	0.47
CRR [%]	--	26.9	39.2	32.3	53.8	21.5	28.5

Focusing on the crack width, the parameter that affects the durability and structural integrity more adversely, it can be seen how all shrinkage reducing concrete have a similar average crack width around 0.40 mm (±0.10 mm). However, they differ in their maximum crack widths, specially the FRC5 and SC mixtures. These unfavourable cases are caused by the insufficient fibres and excessive water content, respectively.

As the CRR indicates, concrete with enough microfibres content, FRC2 and FRC4, are the ones that present the best performance in all this terms because they are dispersed easily within all the paste and do not form balls, leading to a completely homogeneous three-dimensional network, which is reflected in their parameters. In spite of the fact that a high account induces a reduction of the maximum crack width, the values of the cracked area and crack length of FRC2 and FRC4 are approximately equal here. Nevertheless, the average crack width is much higher when 2 kg/m^3 of microfibres (FRC2) are incorporated. Such fact indicates that FRC4 suffers a lower strain, caused by evaporation, than FRC2. Therefore, the highest cracking reduction is reached with the addition of 1 kg/m^3 of microfibres.

The results confirm that the utilization of a common base mix design permits to know directly the effectiveness of distinct admixtures to reduce shrinkage cracking and their implications in the workability of concrete. In fact, in the case of SC it is recommended that the base mix proportions in its design contain less water and superplasticizer, that is to say, less paste volume, because the SRA provides the necessary fluidity. This way, the performance of this admixture would be optimized as its average crack width indicates.

4 CONCLUSIONS

Early shrinkage cracking can be measured in an uncomplicated and fast way: a realistic cracking pattern can be obtained and quantified without the need of any special apparatus. This is absolutely essential because not only does this method provide an estimation of this phenomenon, but does it also expand the horizons of applicability due to its flexibility (common tools and environmental tunnel could be modified according to the needs). Furthermore, it can be easily adapted to tests on site.

Furthermore, the digital imaging methodology applied is a very useful, impartial and comparable way to determine the cracking pattern of distinct concrete, through numerical and graphic results, which allows getting a global and precise vision of the geometry and distribution of early shrinkage cracking in slabs. In this paper, the effects of fibres and SRA have been analyzed. In general, the use of fibres can decrease early shrinkage cracking although their effectiveness depends on their dimensions and proportions basically. The effect of SRA is similar from the point of view of the CRR. The considerable differences found with regard to the cracked area, crack length and maximum crack width are due to the excessive water content which has the base mix design for this material.

All this leads to conclude that the best option to reduce early shrinkage cracking in concrete of 30 MPa is the addition of 1 kg/m^3 of microfibres. This fact proves that higher addition content does not always involve better results but it can be optimized to enhance the workability and, thus, decrease the costs.

Finally, it must be taken into account that a lower value of shrinkage cracking does not guarantee that cracking in concrete is avoided because other several factors affect it. Only the size and propagation of cracks can be reduced but it is impossible to eliminate them. Besides the numerous aspects that influence shrinkage, some others like creep, modulus of elasticity, and tensile strength of concrete also have an effect on the potential risk of cracking. Despite of the difficulty to control all those factors, if these mixtures with additions get a crack width inferior to 0.40 mm, range in which the results presented are found, they may be clogged due to accumulation of dirt, calcium deposits, etc.

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