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Influence of the water and aggregate contents on the concrete mixing evolution

J. Moreno-Juez [a,b,*], B. Cazacliu [a], R. Artoni [a]

[a] IFSTTAR, Aggregates and Material Processing Laboratory, Route de Bouaye – CS4, 44344 Bouguenais Cedex, Nantes, France
[b] Tecnalia, Materials Business Unit, Sustainable Construction Division, Geldo, Edificio 700, Parque Tecnológico de Bizkaia, 48160 Derio, Spain

HIGHLIGHTS

- Monitoring tools employed for analysing concretes and mortars mixing evolution.
- The influence of water and coarse aggregate on the mixing evolution was analysed.
- Difference between mixtures due to the wall effect exerted by coarse aggregates.
- New mixture parameter defined: the "effective water-to-powder ratio in the mortar".
- Better estimation of the real effective water and of the fresh properties.

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ABSTRACT

A new image analysis technique coupled with the power consumption were employed in this paper and proved to be a relevant method to detect the different characteristic times of the mixing evolution, i.e. the cohesion time, the fluidity time and the half-life time of the mixture evolution after fluidity. It was shown that the "effective water-to-powder ratio in the mortar" which excludes from the effective water the quantity of water needed to fill the less compact packing in the vicinity of the coarse aggregates, governed the mixing behaviour before fluidity and the interval of water content where the concrete mixture behaves as a homogenous and fluid granular suspension. It was also shown that the mixing behaviour was adversely affected by the amount of water into the mixture. The fluidity and cohesive times were faster to be obtained when the water proportion was increased. At opposite, it was more difficult to obtain the final consistency for a more fluid mixture, at given super-plasticizer proportioning. As a general remark, the behaviour seemed controlled by the mixture composition before the fluidity point and by the mixture consistency after the fluidity point. To end, the image analysis technique coupled with the mixing power technique can be employed at the end of the mixing to complete the information obtained with the other methods of analysis in order to monitor the consistency of the mixture. But, the use of the cohesion and fluidity times, easy to detect with the texture analysis, could be more efficient monitoring tools from an industrial point of view.

1. Introduction

New varieties of concrete have been developed during the last years and this trend seems to be far from over. These concretes present, in most cases, advanced formulations more difficult to be controlled in manufacturing than standard ones. This is the case of technical concretes such as self-compacting concretes (SCC) which need a thorough control of the fresh properties, constituents and mixing process [1–7]. Another example is the recycled aggregate concretes (RAC) with less controlled constituents. In this case, an important control of the water dosage is imposed due to high aggregates absorption [8–13]. For this concrete, an optimized mixing process and mixing time during production is mandatory to ensure a good homogenization of the material and at the same time to avoid the degradation of the components [14–16].

These new concretes require a better control of the properties during the manufacturing phase, which we are not able to provide satisfactory today. The monitoring of concrete evolution during mixing allows us to:

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[*] Corresponding author at: IFSTTAR, Aggregates and Material Processing Laboratory, Route de Bouaye – CS4, 44344 Bouguenais Cedex, Nantes, France.
E-mail address: jaimemorenojuez@hotmail.com (J. Moreno-Juez).

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- better know the actual composition in the mixer,
- determine the optimal mixing time for the actual composition present in the mixer.

Indeed, an evolution model, defining the characteristic points of a concrete mixing process, was developed by Cazacliu and Roquet [17,18]. Based on the power consumption during mixing, they defined the cohesion and the fluidity time as being the two main transition times in the mixing of cementitious materials. The cohesion time is the transition from the wet granular state to a state where granules not yet dissolved are already connected by liquid bridges ("raspberry shape structure"). The fluidity time is the instant of transition from a raspberry shape structure to a granular suspension state in all the mixed volume. At the fluidity time, the mixture has already a fresh concrete appearance but small size agglomerates of fine particles are still present in the mixture. These agglomerates continue to be dispersed under the combined effect of shear and superplasticizers (breaking the agglomeration and releasing entrapped water by chemical action [19]) [1,20]. After the fluidity point, the mixing power suffers a hyperbolic evolution defined by a half-life time t^*. This half-life time indicates how fast the mixture is progressing toward the asymptotic limit once the transition obtained. The evolution of the mixing power reflects the evolution with mixing time of fresh concrete properties for the batch under investigation (i.e. the rheology) [21]. It also gives information of the evolution with mixing time of some hardened concrete properties, as the compressive strength [20].

In this context, it is necessary to better understand the relation between the characteristic points and the formulation or the rheology of concretes manufactured, notably for estimating the amount of real effective water present in the actual batch, the consistency and fresh properties of the concrete produced and the actual progress of the mixing process.

For this purpose, a novel detection method for characteristic points based on image analysis technique was employed. This technique, developed by Moreno-Juez et al. [22], has been used because of its high precision with respect to other methods. On the other hand, its simplicity and availability in laboratories with small quantities, makes possible to multiply the tests for a complete study of the influence of several parameters. The ability of the image analysis technique to characterize the mixture evolution during mixing by comparison with the mixing power consumption evolution was investigated in this previous work [22]. By this method the transition points are more repeatable and easier to define than by using the power curves.

During this study, the image analysis technique and the mixing power technique, have been employed together to detect the main transition times characterizing the mixing evolution and the structuration process. Three different characteristic times are detected and evaluated in this work: the cohesion time t_c and the fluidity time t_f as defined by Cazacliu et al. [18] and the half-life time t_* of the mixing evolution after fluidity [21]. These times were detected and analysed in different batches with different concrete and mortar recipes.

2. Experimental method

2.1. Materials and equipment

2.1.1. Materials employed and mixtures formulation

The materials employed were a common cement CEMI 52.5, modified polycarboxylates superplasticizer (HRWR), calcium carbonate filler, natural 0/4 silico-calcareous sand (granularity in Table 1) and natural 4/10 siliceous crushed aggregate (Table 2).

In total, 9 different formulations were produced, 4 mortars and 5 concretes. The only difference between the 4 mortars and between the 5 concretes respectively was the water proportioning, with the aim of studying its influence on the mixing evolution. The materials employed and their proportions are given in Table 3. Aggregates are employed completely dry. The effective water W in Table 3 is calculated taking into account the water absorption of aggregates after 5 mins (WA 5 min) instead 24 h (WA24h) as generally used. This amount of water absorbed seems more relevant for the water absorbed during the mixing process.

Table 1
Properties of the 0/4 sand.

	Cumulative passing material (%)								Density 24 h (kg/m^3)	WA 5 min (%)	WA 24 h (%)
	0.63 mm	0.125 mm	0.25 mm	0.5 mm	1 mm	2 mm	4 mm	5.6 mm			
Average	0.9	3	13	40	71	87	97	100	2640	0.30 ± 0.01	0.32 ± 0.01

Table 2
Properties of the 4/10 coarse aggregates.

	Cumulative passing material (%)						Density 24 h (kg/m^3)	WA 5 min (%)	WA 24 h (%)
	2 mm	4 mm	6.3 mm	8 mm	9 mm	10 mm			
Average	1.6	9.1	21.3	36.9	63.8	100	2470	1.58 ± 0.1	2.0 ± 0.1

Table 3
Formulation of the 9 mixtures studied.

Mixture Type*	W/P Ratio**	N° of tests	Coarse aggregate 4/10 kg/m^3	Sand kg/m^3	Cement kg/m^3	Filler kg/m^3	HRWR kg/m^3	Effective Water*** W kg/m^3
Mortar	0.261	2		1269	533	254	16.5	205.7
Mortar	0.269	2		1261	530	252	16.4	210.6
Mortar	0.277	2		1253	526	251	16.3	215.5
Mortar	0.285	2		1245	523	249	16.2	220.4
Concrete	0.259	1	422	1054	443	211	13.7	169.4
Concrete	0.263	1	421	1052	442	210	13.7	171.2
Concrete	0.267	3	419	1049	440	210	13.6	173.7
Concrete	0.275	2	417	1043	438	209	13.6	178.0
Concrete	0.283	2	415	1037	436	208	13.5	182.3

[*] The proportions of the mortar components were the same in the mortar and in the concrete mixtures for a same W/P ratio.
[**] W/P is the effective water-to-powder (cement + filler) mass ratio, employing the effective water determined with WA 5 min.
[***] The effective water W is calculated taking into account the water absorption of aggregates after 5 min (WA 5 min).