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Workability Tests on Fresh Concrete Formulated with Eco-friendly Admixture

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Abstract: Extra-cellular compounds, secreted by microorganisms into their surroundings, can be integrated in concrete composition as admixtures. These substances are important in biofilm formation and some of them can be used as corrosion inhibitor of concrete reinforcement. This paper deals with products made with biological surface active compounds/agents allowing the development of more eco-friendly concrete. The influence of this environmentally friendly bio admixture on setting time, workability, bending and compressive strengths of various mortar based materials made of CEM I, CEM III and CEM V was studied. Mechanical tests were carried out to highlight the influence of admixture in workability and hardening of samples containing the biological product with ratio in the range of 0-2.5%. It was demonstrated that the presence of the new bio-compound admixture in mortar decreases their compressive strength after 28 days of standard curing, in spite of remaining higher than standard minimal strength. Furthermore, Vicat needle experiments have shown a tendency of this admixture to decrease the setting time. A discussion was finally proposed in order to correlate the setting times and the decrease of the mortar compressive strength, corresponding in fact to a hardening delay. This setting time delay could be linked to a delay of the admixtured mortar to increase its resistance. The slump results highlight the action of bio-admixture as a plasticizer on mortars because it increases their workability for a same water-cement ratio. This effect seems variable according to the added amount.

Key words: Concrete, mortar, bio admixture, compressive strength, setting time.

1. Introduction

The durability of civil engineering works is an actual issue linked to sustainable development considerations. Besides the issues of CO_2 release associated with the clinker production and the raw materials transport, the environmental impact of the various chemical products used in civil engineering, such as admixtures have to be considered. The fouling of concrete surfaces by biofilms generates important troubles. Many anti-fouling and anti-stain products for concrete can be applied on surfaces. Solutions exist for concrete exposed to light, by implementing the principle of photocatalysis with TiO_2 (titanium dioxide) incorporated in the formulation of concrete, that can degrade organic compounds [1]. In case of buried or submerged structures, TiO_2 is not suitable because of the lack of UV (ultraviolet) radiation. However, TiO_2 is currently the only one anti-fouling and/or anti-stain developed product which can be incorporated into the concrete bulk.

Industrialized anti-fouling substances such as curative or preventive products are generally applied on surfaces. They are composed of algaecide and fungicide (which can cause human health damages), organic systems (latex), fluoropolymers (some are suspected to present carcinogenic risk), mineral systems (silicates) and surfactant systems [2]. Only algaecides or fungicides act against biological fouling, but in a curative action. The other products involve a

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broader anti-fouling action [3]. Thus, the product presented in this paper, i.e., the bio-admixture, appears as the only one which could be incorporated into the concrete bulk and able to prevent the development of biofilms on surfaces immersed in natural water (water conveyance, tanks, etc.) or buried (pipes, tunnels, etc.). Paints with incorporation of active compounds, such as biocides and surface effects, i.e., release coatings, aim to reduce the bioreceptivity of materials or simplify the unhooking of biofilms. Embedded products are silicones, fluoropolymers and EPS (extracellular polymeric substances) [4, 5]. These paintings are especially designed to protect metals from corrosion and biofouling, i.e., increase durability of concrete.

Many studies have been conducted to improve the resistance against biodeterioration of materials, caused by bacteria. However, some of them have the ability to produce substances that have very interesting properties such as inhibition of corrosion of metals [6]. The active principle of this admixture is made of extra-cellular substances, secreted by microorganisms into their surroundings. It contributes to the effort in sustainable development that consists to limit the impact of buildings on environment and human health, with a guarantee of better quality concerning esthetical, durability and resistance criteria, according to the REACH regulation. The action of these organic products was evaluated on its setting time effects on cement as well as the mechanical behavior to the hardened state.

The studied samples were manufactured using three cement bases: a traditional Portland cement (CEM I), as well as a CEM III and a CEM V more eco-friendly because containing industrial by-products, such as GGBS (ground granulated blast-furnace slag) and secondary constituents (in case of CEM III) or siliceous fly ashes (in case of CEM V). GGBS replace the clinker. Cementitious materials are highly used around the world, thus the impact of this study should promote the development of concrete which production generates less greenhouse gas.

2. Materials and Methods

2.1 Bio-admixture Compound

The bio-admixture was produced according to a simple, novel technique based on cultivation of bacteria [7]. It is an eco-friendly product, which was used as BA (bio-admixture) in this study. Bio-admixtures described in the literature can have different possible natures, such as viscosin, viscosinamide and amphisin lipopeptides [8], the rhamnolipid glycolipids [9] or the AP6 protein-like polymer [10]. The BA should complete simultaneously two functions: limit the biocontamination of surface of concrete, as well as inhibit the rebars corrosion of reinforced concrete. This second function was not developed in this paper.

2.2 Sample Preparation

An ordinary Portland cement: CEM I 52.5 N CE CP2 NF (composition: 95% clinker, 5% secondary constituents) and two other composed cements: CEM III/A 42.5 N-LH (composition: 35% clinker, 60% GGBS (ground granulated blast-furnace slag), 5% secondary constituents) and CEM V/A (S-V) 32.5 N CE PM-ES (composition: 51% clinker, 23% GGBS, 26% siliceous fly ashes) were used to manufacture the samples. The three sample types studied were mortars. The mortars batch was composed of 225 g of distilled water, 1,350 g of standard sand and 450 g of cement (water/cement ratio = 0.5) according to the European standard EN 196-1. The manufacturing process was described by the EN 196-1 standard. All samples were submitted to 28 days standard curing (20 ^{o}C ± 2 ^{o}C, HR > 90%). The bio-admixture solution was directly incorporated in the batch. This BA solution was assimilated as water and the unit water of the mortars was modified accordingly. Thus the test results of slump and strengths have a significance. Samples used for mechanical tests were 40 × 40 × 160 mm^3 standard mortars of which BA solution rate were 0, 0.5%, 1%, 1.5%, 2% and 2.5% of the cement mass. The BA rates in the samples dedicated to workability tests were the same.

2.3 Setting Time Evaluation

The ability of cement to make fluid concrete to hardened state is represented by the time of setting. The setting times of mortars were determined using Vicat apparatus, according to the NF EN 193-3 standard. The Vicat penetration test provides only comparative results which depend on the needle normalized geometry [11].

2.4 Workability of Samples

Workability is an important parameter of fresh concrete or mortar which influences the durability and strength. It is well known that a considerable numbers of factors affect workability, such as water content in the mix, aggregate grading and humidity of environment [12]. In this paper, the slump loss method, i.e., loss of workability of concrete with time [13], was used. A conventional slump cone for concrete was used for the workability tests.

2.5 Compressive Strength and Bending Strength Tests

The two mechanical tests performed were compression and bending strength tests. The experimental procedure was described in the EN 196-1 standard. For both mechanical tests, value is an average of three measured data.

3. Results and Discussion

3.1 Setting Time

Setting time may be accelerated or retarded based on the admixture's dosage rate and/or interaction with the cement in the concrete mixture. Table 1 presents setting time results, which were obtained after calculation of times of the beginning and the end of setting times (since the introduction of cement in water).

Concerning the initial set, there is no precise modification for CEM III sample. However, it seems that the presence of admixture have a little influence on initial setting time for CEM I, i.e., a small increase can be observed, thus the BA decrease moderately the hardening process of the cement. Whatever the cement, no trend is observed concerning final set. Finally, it seems necessary to implement other experiments to make a better evaluation of workability of samples.

3.2 Slump Test

Slump values of CEM I and CEM V based mortars are presented in Fig. 1. These values decrease with time. Furthermore, the utilization of BA increases slump values.

A rate of 1.5% of bio-admixture allows to reach a maximum slump value of 43 mm for CEM I and 56 mm for CEM V, i.e., it seems that BA induction improves workability of fresh mortar. After 150 minutes, the BA does not disturb the slump loss of fresh mortar (Table 2). The higher workability of CEM I based mortar is stable from 30 min to 60 min, whatever the BA content. However, for CEM V based mortars, values are stable from 90 min to 120 min.

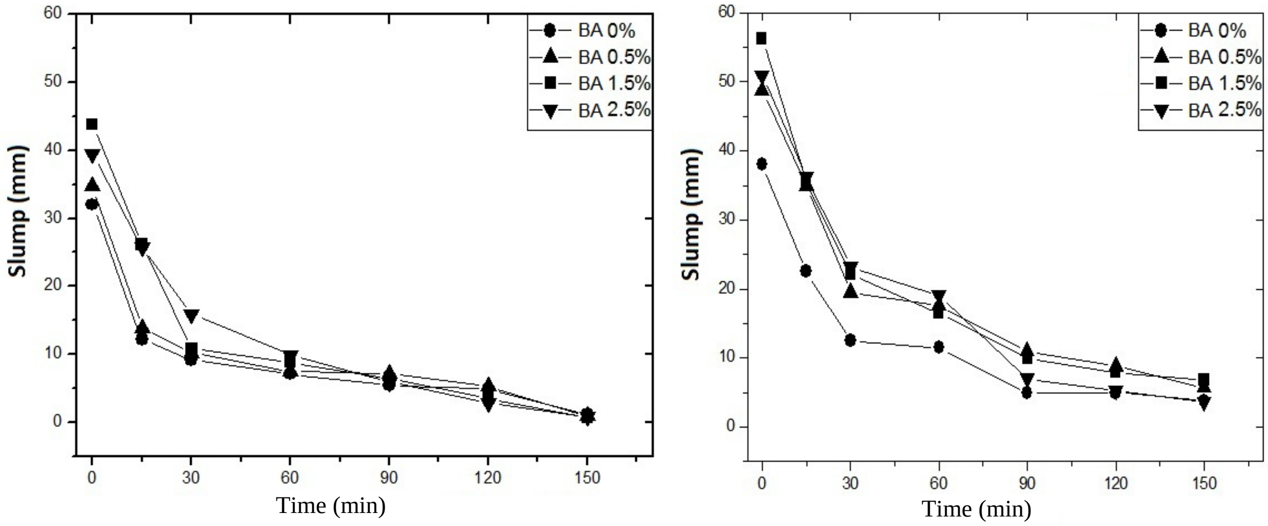
This experimental results allow us to see that the bio-admixture acts as a plasticizer on mortars because it increases their workability for a constant given water-cement ratio. This effect seems variable according to the amount added.

3.3 Mechanical Tests

Compressive and bending strength test values are given in Fig. 2. First, a comparison between CEM I and CEM III will be discussed. Next, comparison between CEM I and CEM V will be presented.

Table 1 Initial and final sets of various samples.

Style	BA (%)	Initial set (min)	Final set (min)
CEM I	0	126	390
	0.5	121	420
	2.5	156	395
CEM III	0	181	462
	0.5	181	463
	2.5	195	445



(a) CEM I (b) CEM V

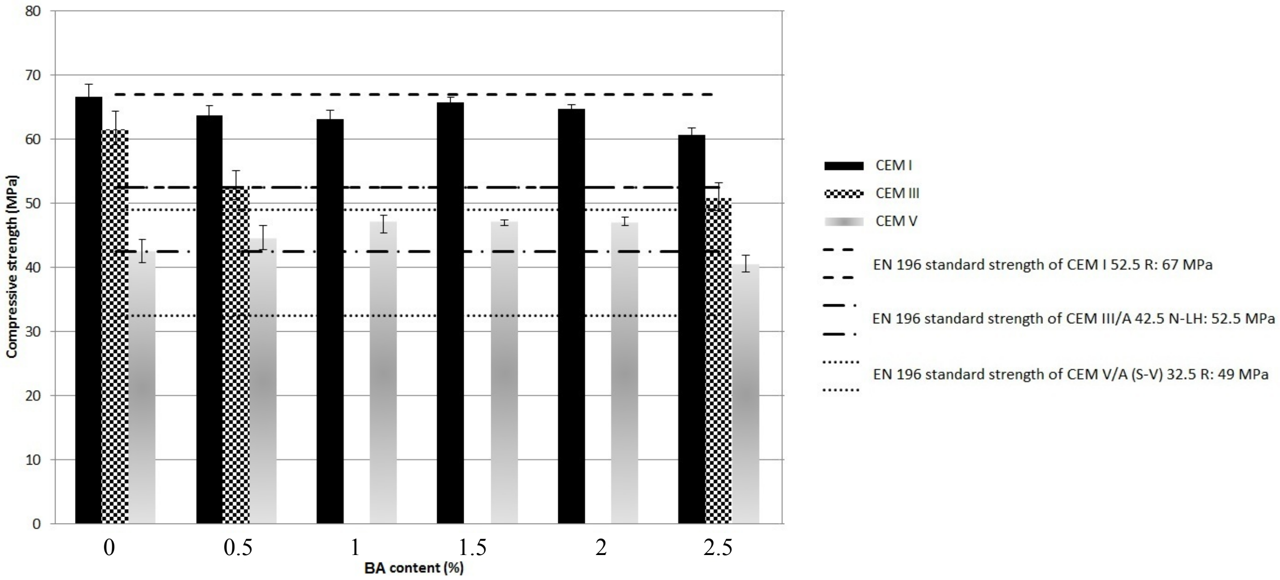
Fig. 1 Evolution of slump of CEM based mortars mixed with bio-admixture according to the time.

Table 2 Slump loss rate evolution of CEM I and CEM V based mortars with time.

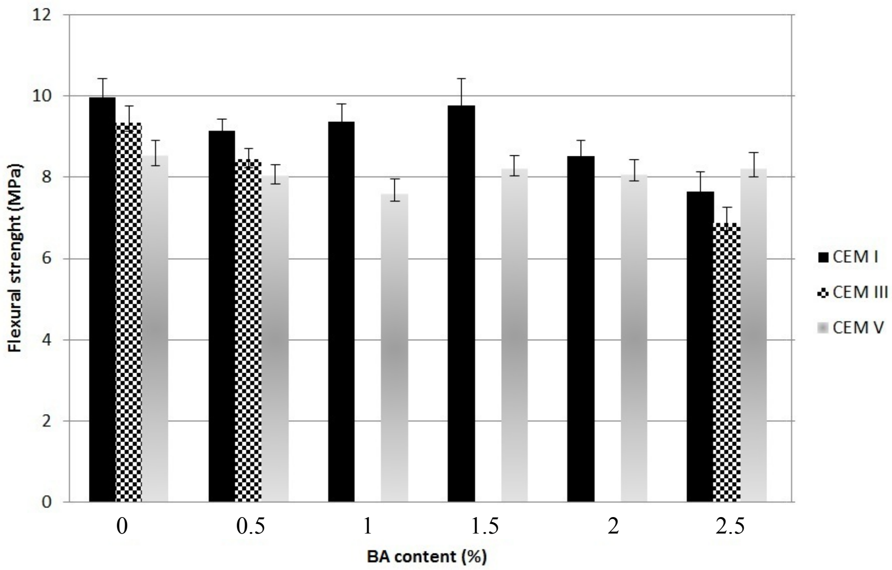
BA concentration (%)	CEM I based mortar		CEM V based mortar	
	0-30 min	0-60 min	0-90 min	0-120 min
0	71%	78%	87%	87%
0.5	70%	78%	77%	82%
1.5	75%	80%	82%	86%
2.5	59%	75%	86%	90%

A small decrease can be observed in Fig. 2, for both compressive and bending strengths, when BA was introduced in the mortar. This decrease occurs both on CEM I and CEM III, according to the BA ratio, but it seems more pronounced for CEM III. Thus resistance could be related to a significant interaction between the admixture and the blast furnace slag. Some research, with other types of admixture, could confirm this observation [14]. It is important to note that the strengths of samples do not decrease obviously. For example, the strengths of CEM V based sample containing 1.5% or 2.5% of BA were almost the same to CEM V without BA. If considering the test error in strengths and the effect of the water included in the BA solution, no precise conclusions could be stated only according to these experimental results. However, compressive strength values remain higher than the minimum data of standard strength, i.e., 52.5 MPa for CEM I and 42.5 MPa for CEM III according to the EN 196-1 standard, and presented in Fig. 2a with colored lines. Thus, the admixture has a reduction effect of resistance at 28 days. This is an important result which lets consider the use of the BA, which is a totally new product, as an admixture. Furthermore, it was earlier demonstrated that a delay of setting time take place with BA addition in mortar, i.e., this setting time delay could be linked to a delay of the admixtured mortar to increase its resistance. Similar statement have been published in Ref. [15].

Furthermore, it can be observed that, logically, compressive and bending strength values are higher for CEM I mortar than CEM V mortar, without admixture (Fig. 2). In both cases, compressive strength values are under the maximum values and above the minimum values of the EN 196-1 standard (see the colored lines in Fig. 2a). Concerning admixtured mortars, both compressive and bending strengths for CEM I and CEM V are the same. Indeed,



(a)



(b)

Fig. 2 Strength test value: (a) compressive strength; (b) bending strength .

according to the standard deviation values for each data and measurement accuracy, no specific distinction can be made. CEM I based mortar shows a high resistance, in the range of 62-66 MPa for compressive strength (values are above the minimal standardized value, i.e., 52.5 MPa) and in the range of 8.6-9.9 MPa for bending strength, for a bio-admixture ratio in the range of 0-2%. For the same BA ratio, the compressive strength values of the CEM V are in the range of 42-47 MPa. Although there is an increasing trend, values can be considered as the same, because of the standard deviation values. Bending strength values of the CEM V based mortar are in the range of 7.8-8.2 MPa.

The workability results have shown that there is an optimum value of 1.5% for CEM I based mortar (see also part 3.2). No similar observation can be made with mechanical tests. However, it is interesting to note that this value enables to virtually have the best result of 9.7 MPa in flexion for CEM I. Only for CEM

I, from 2.5% of bio-admixture content in mortar, both compressive and bending strengths decrease significantly. For CEM V, only compressive strength values decrease. Thus, the behavior of the bio-admixture in the mortar is not always the same, and this result can be attributed to the chemical composition of the mortar, i.e., the interactions of mortar content with admixture, as it was earlier mentioned in the current literature [16].

4. Conclusions

Bacteria products have been used to make an admixture for concrete. The developed products will be used for developing more durable concrete but also for curing and preserving more aged works. First results are encouraging. Indeed, the presence of the bio-admixture in the mortar led to increase the workability in the first 15 min. In addition, admixturization causes a slight decrease of both compressive and bending strengths of the mortars, but values remain higher than the minimum required by the standard.

The results also show that there is an optimal rate of 1.5% of admixture where mechanical resistance after 28 days do not reach the values obtained for mortars without admixture, especially for bending strength of CEM I. The mechanical behavior of admixtured mortars with time must be studied. It is possible that the action of admixture delays the beginning of hardening. The slump results highlight the action of bio-admixture as a plasticizer on mortars because it increases their workability for a same water-cement ratio. This effect seems variable according to the amount added and it will be necessary to implement further analysis in order to determine why the 1.5% rate appears optimal.

Acknowledgments

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