World Academy of Science, Engineering and Technology
International Journal of Structural and Construction Engineering
Vol:15, No:6, 2021

The Impact of Alumina Cement on Properties of Portland Cement Slurries and Mortars

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***Abstract*—**The addition of a small amount of alumina cement to Portland cement results in immediate setting, a rapid increase in the compressive strength and a clear increase of the adhesion to concrete substrate. This phenomenon is used, among others, for the production of liquid floor self-levelling compounds. Alumina cement is several times more expensive than Portland cement and is a component having a significant impact on prices of products manufactured with its use. For the production of liquid floor self-levelling compounds, low-alumina cement containing approximately 40% Al_2O_3 is normally used. The aim of the study was to determine the impact of Portland cement with the addition of alumina cement on the basic physical and mechanical properties of cement slurries and mortars. CEM I 42.5R and three types of alumina cement containing 40%, 50% and 70% of Al_2O_3 were used for the tests. Mixes containing 4%, 6%, 8%, 10% and 12% of different varieties of alumina cement were prepared; for which, the time of initial and final setting, compressive and flexural strength and adhesion to concrete substrate were determined. The analysis of the obtained test results showed that a similar immediate setting effect and clearly better adhesion strength can be obtained using the addition of 6% of high-alumina cement than 12% of low-alumina cement. As the prices of these cements are similar, this can give significant financial savings in the production of liquid floor self-levelling compounds.

***Keywords*—**Alumina cement, immediate setting, compression strength, adhesion to substrate.

I. Introduction

ALUMINA cement has a turbulent history of over a century. After a good reception by the market in the 1880s, at the turn of the 19th and 20th centuries it gained bad reputation for causing a series of construction disasters in Great Britain and Spain. For some time, its use was even banned in civil construction. In an improved version, during the First World War it was used for rapid construction of fortifications and the technology of its production was a military secret. The renaissance of interest in alumina cement took place in the 1990s. In the "low aluminum" version, it began to be used as an ingredient in many products of the so-called construction chemicals, among other things as an addition to self-levelling flooring compounds.

The production of alumina cement is very energy consuming, which is why its price is several times higher than that of Portland cement. Materials used for the production of alumina cement (mainly limestone and bauxite) get completely melted in the production process. Hence the French name, often adopted (also in English): fused cement (ciment fondu). In recent years, the name "aluminum-calcium cement" has also been used more and more often [1], [9].

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II. Alumina Cement

Alumina cement is a hydraulic fast-hardening binder obtained by melting an alumina-rich component (usually bauxite) with limestone. During the process of alumina cement hydration, a significant amount of heat is released (38 J/g). This enables concrete works to be carried out without additional protection, even at temperatures as low as -10 °C [3]. Alumina cements are produced in low and high aluminum varieties. The low-aluminum variety contains 40-50% Al_2O_3 and is intended mainly for the production of many loose products of construction chemicals (glues, self-levelling compounds). The high-aluminum variety contains up to 70% Al_2O_3 and is intended for the production of concrete and mortar resistant to high temperatures (even up to 1700 °C).

The basic setting components for alumina cements are low alkaline calcium aluminates (CA and $C_{12}A_7$). C_2S content does not exceed a few percent, therefore in the hydrated alumina cement there is practically no calcium hydroxide ($Ca(OH)_2$), due to which this cement is characterized by high resistance to many acid and salt corrosive factors [1], [2].

Concretes made with the use of alumina cement are characterized with a rapid increase in compressive strength over time. After 24 hours they reach about 80% of the final strength (about 50 N/mm^2).

The addition of a certain amount of alumina cement to Portland cement results in the phenomenon of immediate binding [4]. It is often used in the production of, for instance, self-levelling flooring compounds [5]. With a relatively small amount of alumina cement (up to approximately a dozen percent), the gypsum contained in the Portland cement is used in reactions with hydrated calcium aluminates, and as a result, immediate setting occurs in the Portland cement devoid of retardant.

Alumina cements are mainly used for the production of refractory concretes exposed to chloride and sulphate aggression as well as for ad hoc repair work carried out in sub-zero temperatures. Alumina cement is also an important component of many loose products of the construction chemicals. It is used in combination with Portland cement in order to increase the adhesion to the substrate and to accelerate setting and hardening time.

III. Methodology of the Study

The aim of the study was to determine the impact of the use of Portland cement with the addition of alumina cement on selected physical and mechanical properties of slurries and mortars. CEM I 42.5R [8] and three varieties of alumina cement containing 40%, 50% and 70% of Al_2O_3 were used for the tests. The alumina cements are respectively referred to as "40", "50" and "70" in the following part of the paper [10].

In preliminary tests, Portland cement mixtures containing 4%, 6%, 8%, 10% and 12% (by weight) of alumina cement were prepared for the "40" variety and 4%, 6% and 8% for the "50" and "70" alumina cement varieties. The time of initial and final setting was determined for them [7]. Based on the results of the preliminary tests, the optimum proportion of Portland cement and each of the alumina cement varieties was determined, resulting in a significant shortening of setting time. For this proportion, compressive and flexural strength tests of mortars were performed after 1 day, 2 days, 7 days and 28 days of curing and their adhesion to the concrete substrate was determined.

The setting time was measured using a Vicat apparatus. Compressive and flexural strength tests [6] were carried out using 4 × 4 × 16 cm samples. Throughout the whole period of care, the samples were stored in laboratory conditions at temperature of 18 ± 2 ^{o}C and relative humidity of air > 90%. The adhesion of the mortars to the substrate was measured using a pull-off device.

IV. Test Results and Their Analysis

A. Testing the Setting Time

In the preliminary tests, measurements of the time of the initial and final setting were carried out for the mixtures of Portland cement (CEM I 42.5R) and alumina cements. The aim of the study was to determine the effectiveness of the alumina cement admixture in reducing the setting time. Mixes containing the addition of 4%, 6% and 8% of alumina cements "50" and "70" were prepared. Due to the lower Al_2O_3 content than in the case of high-alumina cements, and thus probably lower efficiency in shortening the setting time, additional mixes containing 10% and 12% of alumina cement "40" were prepared.

The results of the initial setting obtained in the study, being the arithmetic mean of three measurements, are shown in Fig. 1 and the results of the final setting are presented in Fig. 2. The initial setting time for "pure" CEM I 42.5R is 150 minutes. The addition of up to 6% of alumina cement "40" practically has no impact on accelerating the setting time. It was only when 12% of alumina cement "40" was added that the setting time significantly accelerated (40 minutes).

For alumina cements "50" and "70", the addition of as little as 4% of alumina cement to Portland cement already significantly accelerates the setting. With further increase in the amount of alumina cement (both for "50" and "70"), further significant acceleration of the initial setting occurs. For 8% of alumina cement "50" it is 30 minutes and for cement "70" it is only 20 minutes.

The time of the end of setting for "pure" CEM I 42.5R is 210 minutes. Similar to the initial setting, the addition of a small amount of alumina cement "40" (up to 6%) has practically no effect on accelerating the final setting. However, with the amounts above 6%, the acceleration of the final setting occurs quite intensively, proportionately to the amount of cement "40". For the addition of 12% of cement "40" it is 60 minutes. For cements "50" and "70", the acceleration of the final setting is intensive in the entire content range (0-8%), proportionately to the amount of alumina cement added. For 8% of cement "50", the time of the final setting is 60 minutes and for cement "70" it is 50 minutes.

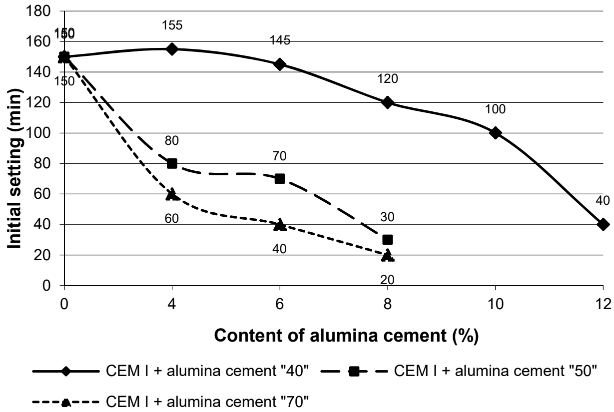

Fig. 1 Relationship between the time of initial setting of cement and the content of alumina cement by weight in Portland cement mix

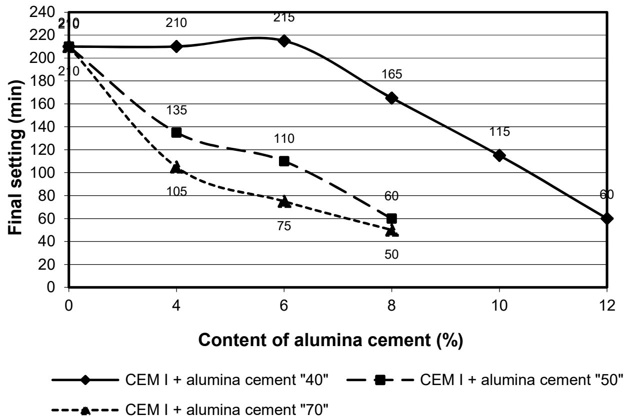

Fig. 2 Relationship between the time of final setting of cement and the content of alumina cement by weight in Portland cement mix

B. Compressive Strength and Flexural Strength Tests

Analyzing the obtained test results (see Section IV *A*), it can be stated that the impact of the addition of 12% of alumina cement "40" on both the initial and final setting of CEM I 42.5R is similar to the addition of 8% of cement "50" or 6% of cement "70". Therefore, for further tests (of compressive strength, flexural strength and adhesion to concrete), the following proportions of CEM I 42.5R mixes with alumina cements were selected

- CEM I 42.5R + 12% of alumina cement "40"
- CEM I 42.5R + 8% of alumina cement "50"

- CEM I 42.5R + 6% of alumina cement "70"

The values of the compressive strength obtained for mortars with different alumina cement content in the mix with Portland cement are presented in Table I and Fig. 3. The results presented are the arithmetic mean of four measurements. The mortars were made using sand with standard grain size, in accordance with [6].

Analyzing the presented test results shows that the compressive strength values for both CEM I 42.5R and CEM I 42.5R with the addition of 12% of cement "40" are similar at the start and after 28 days of curing and they total, respectively, 41.13 N/mm^2 and 39.55 N/mm^2. It is similar for CEM I 42.5R with 8% addition of cement "50" and for CEM I 42.5R with 6% addition of cement "70". After 28 days of curing, significantly higher strength values were obtained (respectively, 47.48 N/mm^2 and 45.39 N/mm^2). The obtained strength values are about 15% higher than for CEM I 42.5R with 12% content of cement "40".

TABLE I
OBTAINED VALUES OF COMPRESSIVE STRENGTH FOR MORTARS WITH DIFFERENT CONTENT OF ALUMINA CEMENT IN PORTLAND CEMENT MIXES

Testing mixes of Portland cement with alumina cement	Compression strength (N/mm^2)			
	1 day	2 days	7 days	28 days
CEM I	2.53	14.46	34.64	41.13
CEM I + alumina cement "40" (12%)	2.88	17.06	33.21	39.55
CEM I + alumina cement "50" (8%)	2.91	20.29	40.55	47.48
CEM I + alumina cement "70" (6%)	3.11	21.24	37.97	45.39

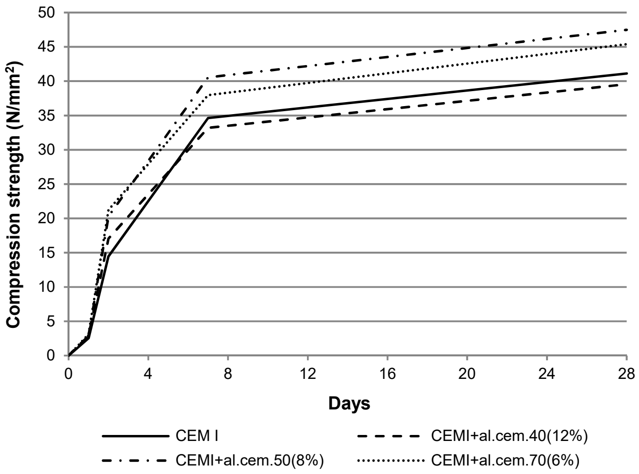

Fig. 3 Relationship between compressive strength and curing time of mortars with various alumina cement content in Portland cement mixes

The obtained values of flexural strength for mortars with different content of alumina cement in the mixes with Portland cement are presented in Table II and Fig. 4. The presented results are the arithmetic mean of four measurements. After the first day of curing, the flexural strength values are similar for all tested samples (approximately 1 MPa on average).

After 2 days and 7 days of curing, the highest flexural strength value is achieved by the CEM I 42.5R sample with 6% addition of cement "70" and the lowest (which is obvious), is the sample made using the "pure" CEM I 42.5R. After 28 days of curing, the highest value of flexural strength was achieved for the sample made of "pure" CEM I 42.5R (7.92 N/mm^2). The other samples made of mortars with different content of alumina cement in the Portland cement mixes achieved flexural strength of approximately 7 N/mm^2, which is around 10% lower value than for the sample made of "pure" CEM I 42.5R

TABLE II
OBTAINED VALUES OF FLEXURAL STRENGTH FOR MORTARS WITH DIFFERENT CONTENT OF ALUMINA CEMENT IN PORTLAND CEMENT MIXES

Testing mixes of Portland cement with alumina cement	Flexural strength (N/mm^2)			
	1 day	2 days	7 days	28 days
CEM I	0.82	3.37	5.44	7.92
CEM i + alumina cement "40" (12%)	1.01	4.53	6.05	7.10
CEM i + alumina cement "50" (8%)	1.10	4.96	5.88	6.72
CEM i + alumina cement "70" (6%)	1.03	5.07	6.55	7.25

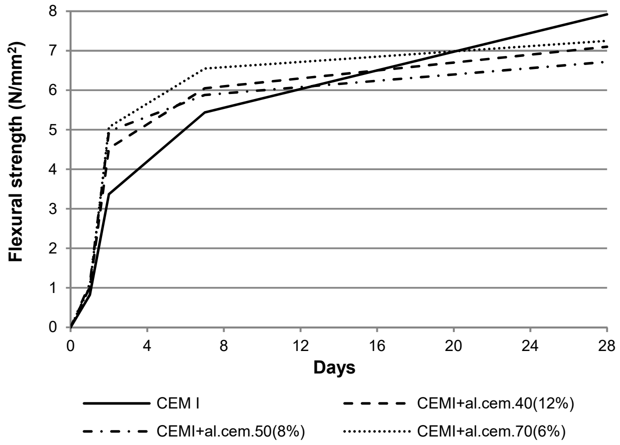

Fig. 4 Relationship between flexural strength and time of mortar curing for mortars with various alumina cement content in mixes with Portland cement

C. Testing Adhesion to Concrete Substrate

A very important characteristic of all self-levelling compounds and repair compounds is strong adhesion to the substrate to which they are applied. For all tested mixes of Portland cement with "40", "50" and "70" alumina cements, the adhesion of mortars to concrete substrate was measured.

The obtained results, being the arithmetic mean of five measurements, are presented in Fig. 5. The adhesive strength for mortar made of CEM I 42.5R is 3.19 N/mm^2. The addition of 12% of cement "40" increases the adhesion by approximately 18% to 3.77 N/mm^2. On the other hand, the addition of 6% content of cement "70" results in an increase in adhesion of as much as around 35% (up to 4.31 N/mm^2). As it can be observed, the 6% addition of cement "70" is about 15% more effective than 12% addition of cement “40”.

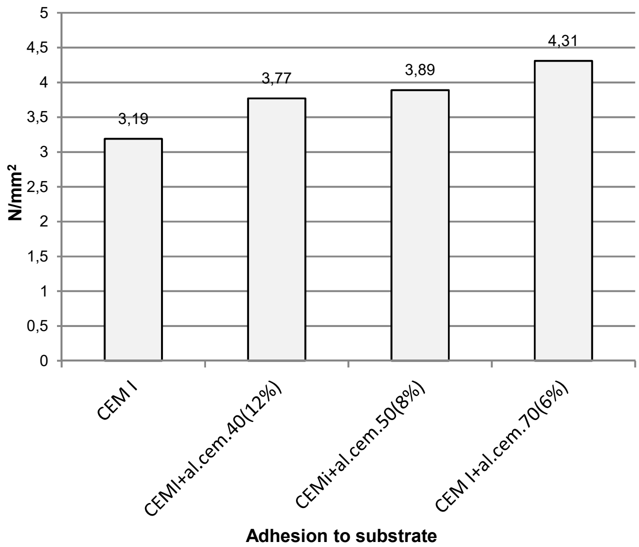

Fig. 5 Relationship between the strength of adhesion to concrete substrate for mortars of Portland cement mixes with various content of alumina

V. Conclusion

As a result of the analysis of test results it can be stated that the impact of adding to Portland cement different varieties of alumina cement, containing various amounts of Al_2O_3, results in a significant change in a number of physical and mechanical characteristics of slurries and mortars.

Proportionately to the increasing amount of Al_2O_3 in a mix with CEM I 42.5R:

- the initial and final setting process accelerates (immediate setting is initiated),
- the adhesion of mortars to concrete substrate increases,
- the compressive strength of the mortar increases both in the early stage and after 28 days of curing.

The analysis of test results obtained also demonstrated that the impact of the addition of 12% of cement "40" on both the initial and final setting of CEM I 42.5R is similar to that of the addition of 8% of cement "50" or 6% of cement "70". The use of 6% content of cement "70" in the mix with Portland cement increases the adhesion to the concrete substrate much more than the addition of 12% content of cement "40". High adhesion to substrate is a very important characteristic for various repair and self-levelling compounds. The short time of setting is also essential.

The prices of various varieties of alumina cements differ slightly (usually the differences do not exceed a dozen percent). Thus, replacing relatively inefficient cement "40" with "70" can give the manufacturer significant financial savings and ultimately can reduce the market price of the product.

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