IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: Anna Kotwa 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 032017

IOP Conf. Series: Materials Science and Engineering 471 (2019) 032017 doi:10.1088/1757-899X/471/3/032017

Physico-Mechanical Features of Portland Cement Mortars Replaced Partially with Aluminium Cement

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Abstract. The purpose of the research was to recognize the effect of the addition of aluminium cement on the properties of cement mortar made of Portland cement CEM I 42.5R. Alumina cement is a hydraulic binder. It is a finely ground organic material that when mixed with water binds as a result of reactions and hydration processes. After hydration, stable hydrate phases form and, as a consequence, the material strength parameter is obtained. The main constituent is calcium aluminate ($CaO·Al_2O_3$), in smaller amounts there are: calcium aluminate, dicalcium silicate and calcium aluminium silicate or gelenite. Hydraulic hardening of aluminium cement occurs mainly through calcium hydration but other chemicals may also take part in the hardening process. The specific chemical composition of aluminium cement and the fact that calcium hydroxide is not released during hydration allows the leaven to resist many aggressive factors. Therefore, in the literature, we can meet guidelines so that the w / c ratio is not greater than 0.40 for applications to structural elements. The article discusses the results of laboratory tests on the impact of replacing Portland cement with aluminium cement in the amount of 10%, 20%, 50%, 100% on the physical and mechanical properties of mortars. The rheological properties of mortars, i.e. consistency, setting time and parameters of hardened mortars were examined, among others compressive and bending strength, capillary rise and absorbability. Compressive strength and bending strength were tested after 1, 7 and 28 days on samples with dimensions 4 x 4 x 16 cm. Absorption and capillary rupture were tested 28 days after being formed on standard bar beams 4x4x16cm. The mortar was made with a constant coefficient w/c = 0.38.

1. Introduction

Lafarge Company in 1908. patented a new type of cement, which significantly differed in properties from Portland cement. I am talking about a clay cement, which after being made with water has, above all, high compressive strength after just 3 days. On the other hand, the mortar made of Portland cement reaches the final compressive strength in a much longer time, because only after 28 days of maturation. In addition, mortars made of aluminium cement are characterized by considerable resistance to many aggressive factors. Alumina cements are often used for the production of fast-curing concretes and refractory masses. Elements made of this cement are used in places exposed to high ambient temperatures. Alumina cement can also be used in mortars, concrete mixes when working at reduced temperatures even up to minus 10 °C [1].

The current development of technology, as well as requirements in relation to mortars available on the market, forces scientists to look for new mortar ingredients, as well as the possibility of modifying mortar components by adding chemical admixtures and mineral additives. Recently, interest in aluminium has been revived by the use of aluminium cement and its unusual properties when mixed with water. In the construction industry, as a binder in type F adhesive mortars, the most common is a mixture of two aluminous and Portland cements in varying proportions depending on the manufacturer. Literature has been published in the literature [2,3], which indicates the intentional mixing of aluminium and Portland cement in fixed proportions. The author indicates that the best ratio is 1: 5. Alumina or Portland cement in the mortar should be from 20 to 80%, then there is a fairly fast bond. Usually chemical admixtures in the form of methylcellulose and powders are also present in the composition of mortars, which are re-dispersible and result in a longer setting time. Occurrence of mortar in Portland and Portland cement in proportions of 50:50, causes quite long time of setting mortar. Hence the necessity of searching for new chemical admixtures compatible with both cements and shortening the setting time of mortars [2,4,5].

The aim of the laboratory tests was to determine the impact of replacing Portland cement with aluminium cement in variable proportions on rheological properties and parameters of hardened mortars. The research was performed with Górkal 40 aluminium cement, where aluminium oxide is not less than 40% of its mass. The basic phase of aluminium cement is monocalcium aluminate (CA). Portland cement was applied CEM I 42.5R. The chemical admixture ISOLA BV 100 was dosed into all the tested series of mortars.

2. Laboratory tests

The purpose of the laboratory tests was to determine the impact of replacing with aluminium cement Górkal 40 Portland cement CEM I 42.5R in variable proportions of 10%, 20%, 50%, 100% on rheological features and selected parameters of hardened mortars. An attempt was made to estimate the optimum amount of the additive in the form of aluminium cement, allowing to achieve the best parameters of hardened mortars. Quartz sand with a grain size of 0 - 2 mm (PN-EN 13139:2003), [6] and tap water according to PN-EN 1008:2004, [7] was used for laboratory tests. The mortar was made with a constant coefficient w / c = 0.38. For each series of mortars, a plasticizing admixture was added in accordance with PN-EN 934-2:2010, [8] in an amount of 0.5% by weight of Portland and aluminium cement. The admixture was added to the ingredients of the mortar together with the mixing water. The amount of chemical admixture used was constant.

Rheological investigations were performed, ie consistency and setting time as well as measurement of hardened mortar parameters. The compressive and bending strength after 1, 7, 28 days, water absorption and capillary rise after 28 days were estimated. Samples were made in the form of standard bars with dimensions 4 x 4 x 16 cm. Control bars were also made without the addition of aluminium cement. The mortars were prepared in a standard laboratory mixer. Samples were prepared with the composition given in table 1.

Table 1. Mortar composition.

Ingredients, [g]	Series ident. SW	Series ident. 10%	Series ident. 20%	Series ident. 50%	Series ident. SG
Portland cement	500	450	400	250	-----
Alumina cement	-----	50	100	250	500
Sand 0-2mm	1350	1350	1350	1350	1350
Water	190	190	190	190	190
Chemical admixture	2,5	2,5	2,5	2,5	2,5

The chemical and mineralogical composition as well as selected properties of aluminium and Portland cement are presented in Tables 2 and 3.

Table 2. Properties of aluminium cement Górkal 40.

Chemical composition	Special properties	Mineralogical composition
Content - Al_2O_3 min. 40%	Fire retardation usual 128 sP	basic phase:
Content - CaO min. 36%	Specific gravity 3.0 g / cm^3	calcium monogllinate CA
Content - SiO_2 2 - 4%	Bulk density 1.1 g / cm^3	accompanying phases:
Content - Fe_2O_3 14%	Specific surface area according to Blaine	C_4AF brownmillerite
	3100 - 3800 cm^2 / g	$C_{12}A_7$ twelve-calcium
	The grain size in the range 0 - 63 µm min 80%	rootstock
	Temperature at which work can be done -10°C	C_2AS gelenite

Table 3. Properties of Portland cement CEM I 42,5R.

Physico-chemical-mechanical parameters	The values
Specific surface area according to Blaine	3307cm²/g
The beginning of binding time	216 min
End of binding time	291 min
Compressive strength after 2 days, according to PN-EN 196-1	26,7 MPa
Compressive strength after 28 days, according to PN-EN 196-1	55,7MPa
Specific density	3,10 g/cm³
water demand	27,70%
Sulphate content (as SO_3)	3,23%
Chloride content (as Cl-)	0,051%
Alkali content (eq Na_2O)	0,83%

The characteristics of the chemical admixture used are:
1.improvement of workability with the same w/c,
2. increase of early compressive strength,
3. no effect on the delay in cement setting.

3. Results and discussions

The determination of binding times for leavens from a mixture of cements in fixed proportions was carried out in accordance with PN-EN 196-1: 2016-07, [9].

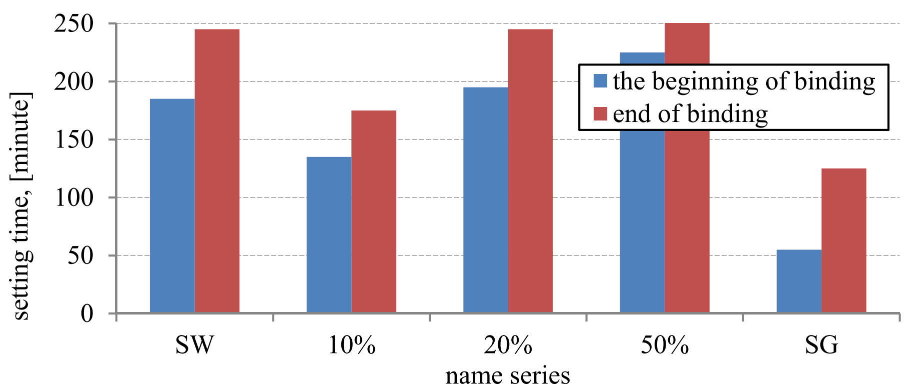

Figure 1. Determination of leaven binding times.

Comparing the beginnings and ends of the bond, one can see a tendency that the more clay cement added to the Portland cement, the longer the beginning and the end of the bond. The longest start and end of the bond is characterized by leaven cement CEM I 42.5 R of 50% aluminium cement, and the shortest by itself aluminium cement. This phenomenon is associated with different chemical and mineralogical compositions. Aluminium cement is a quick binding binder.

Testing the consistency of fresh mortars was carried out in accordance with PN-EN 1015-3:2000, [10]. The measure of the consistency of the mortar is the diameter (cm) of the spilled mortar cake. The result should be the arithmetic mean of both diameters from two measurements.

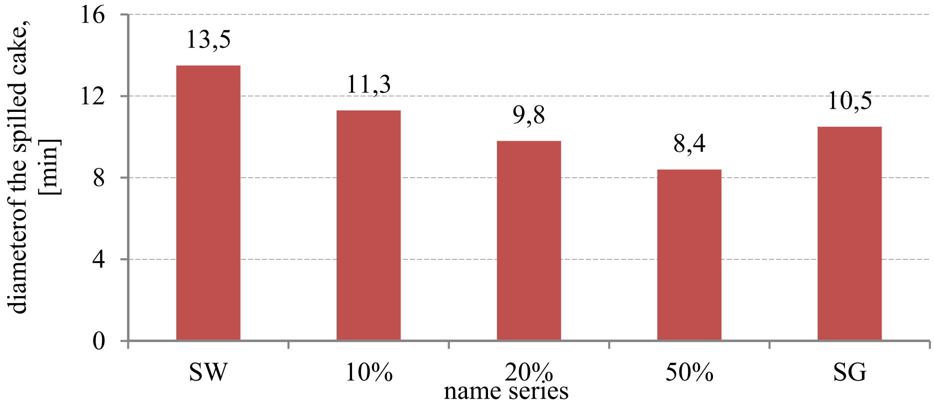

Figure 2. The diameter of a spilled cake for tested mortars.

Measurements of consistency of fresh mortar showed that replacement with Portland cement with Portland cement, despite the chemical admixture used, causes a significant deterioration in consistency with the amount of cement mortar added to the mortar. All mortars were made maintaining the same coefficient w/c = 0.38. The rapid formation of hydrates affected the achievement of such results. Mortar made of aluminium and Portland cement in 50:50 proportions is characterized by the worst workability.

The compressive strength for mortars made of aluminium cement, Portland cement and mixtures of both cements in variable proportions was determined after 1, 7, 28 days after forming. After demoulding, the mortars ripened in water at + 18 °C until testing. The test was carried out in accordance with PN-EN 1015-11, [11].

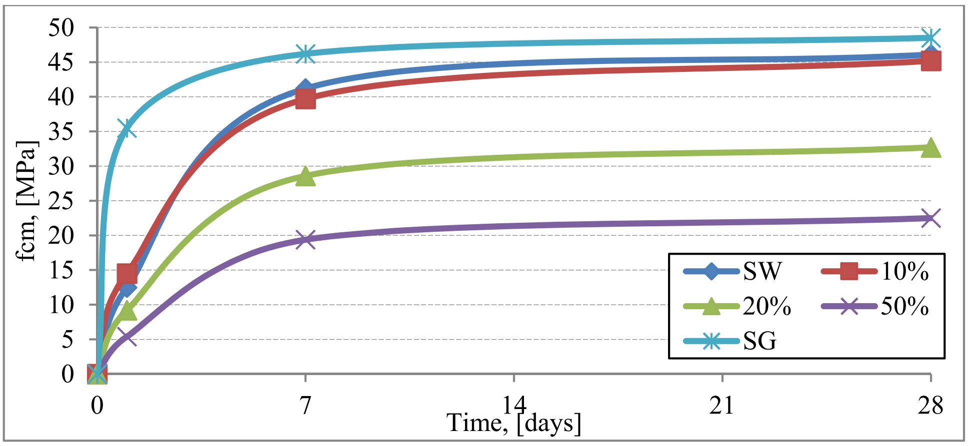

Figure 3. Growth in compressive strength of mortars over time.

Laboratory tests show a tendency that mortars with more aluminium cement are characterized by a lower compressive strength increase over a period of 28 days.

The more clay cement in the mortar, the greater the decrease in compressive strength. The lowest compressive strength obtained mortars made of aluminium and Portland cement in the proportions of 50:50, ie 22.5MPa after 28 days of ripening. The highest compressive strength of 48.5MPa was obtained for mortars made of 100% aluminium cement. Noteworthy is the speed of compression strength increase during the first 7 days. The highest strength is mortar made of aluminium cement alone and after 7 days it is 35.5 MPa. Comparing mortar made of 100% from aluminium or Portland cement alone, mortar made of aluminium cement has a higher compressive strength of 5.2% compared to cement mortar CEM I 42.5R.

Flexural strength was carried out on samples with dimensions 4x4x16cm according to PN-EN 1015-11 [11]. Measurement of the increase in bending strength was carried out after 1, 7, 28 days after forming. Samples after demoulding ripened in water at + 18 °C.

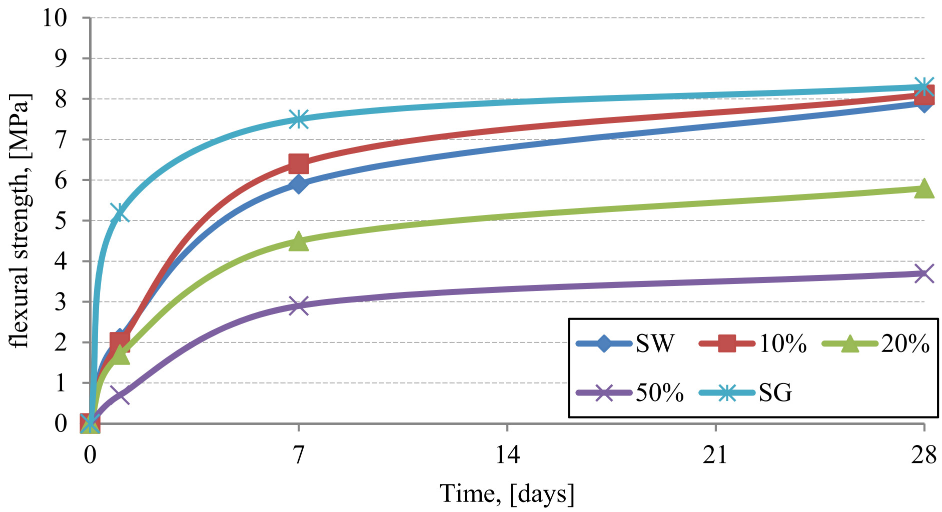

Figure 4. Growth in bending strength, [MPa].

Analysing the obtained measurements of the increase in bending strength, it should be stated that the highest increase in bending strength is characterized by mortars made of aluminium cement alone. After 28 days, the bending strength is 8.3 MPa. Mortars made of Portland cement and Portland cement mortar with 10% aluminium cement have a similar increase in bending strength. The more clay cement in the mortar, the lower the increase in bending strength. The smallest increase in bending strength is characterized by mortar with the addition of 50% of aluminium cement and after 28 days an increase in bending strength of 3.7 MPa was noted.

The capillary rising test for mortars was made on samples with dimensions of 40x40x160mm. Samples for the first 7 days were ripened in water at + 18 °C, another 21 days in an air-dry environment at + 18 ° C. The samples were then dried to constant weight. The samples were placed in a bath tub on plastic washers submerging them 1-3 mm in water. The water deficit was successively supplemented. The mortar was measured every 24 hours until two identical measurements were obtained.

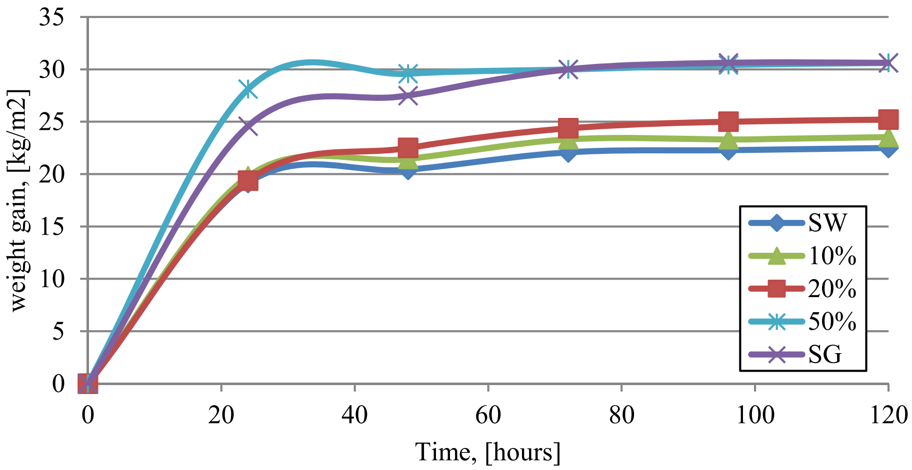

Figure 5. Growth of mortar mass in capillary pull, [kg/m2].

The analysis of figure 5 shows that the largest increase in mass in capillary pull was noted for mortars, where 50% of the Portland cement weight was replaced with aluminium cement. Similar weight gains have mortars made of aluminium cement and Portland cement mortar with 50% aluminium cement. The smallest weight gain is found in mortars from Portland cement alone. Comparable weight gain is obtained from Portland cement mortar and Portland cement mortar with 10% aluminium cement.

The absorbability testing for mortars was performed on samples with dimensions of 40x40x160mm according to PN-88 / B-06250, [12]. Samples for the first 7 days were ripened in water at + 18 °C, another 21 days in an air-dry environment at + 18 ° C. The samples were then dried to constant weight. The samples were placed in a tub, submerging them halfway up in water. After 24 hours the samples were poured up to + 1 cm above the surface of the samples. The mortar was measured every 24 hours until two identical measurements were obtained.

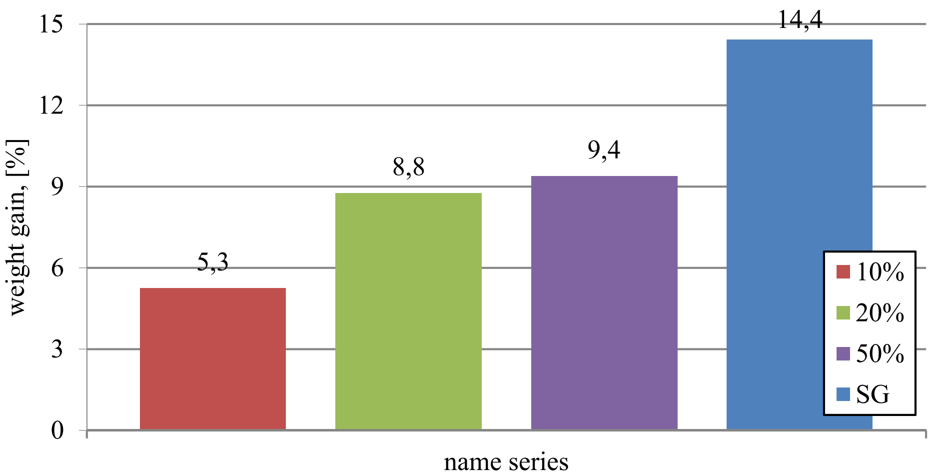

Figure 6. Growth of mortar mass in the absorbability test in relation to the reference mortar from Portland cement alone, [%].

Analysing the obtained results in the water absorption test, the largest increase in mass is characterized by mortar made of aluminium cement itself, the weight gain of which is 14.4% more than for Portland cement mortar. Figure 6 shows the dependence, the more clay cement in the mortar, the greater the weight gain in the absorbability test. Analysing the obtained results, the Portland cement mortar showed the smallest weight gain. These elements cannot be exposed to external factors. Only mortar made of Portland cement with 10% of aluminium cement is at the limit of application to elements subjected to periodic exposure to external factors, [13].

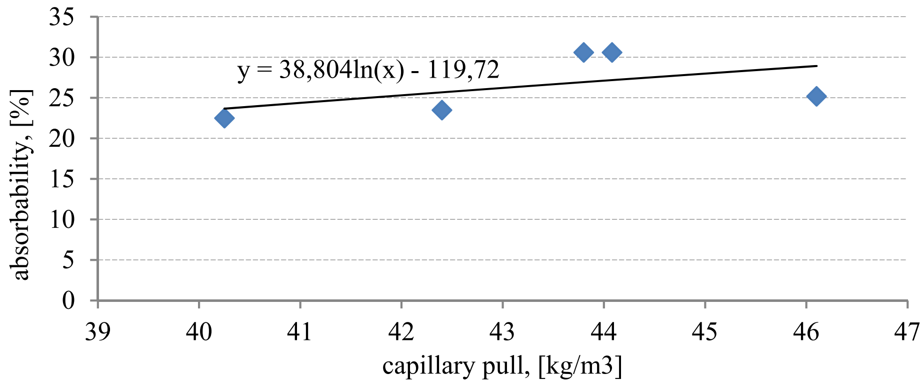

Figure 7. Logarithmic dependence of the weight gain in capillary pull on absorbability for the tested mortar series.

Based on the logarithmic dependence developed, having an estimated weight gain for one laboratory test, the second parameter can be estimated without performing a time-consuming test procedure.

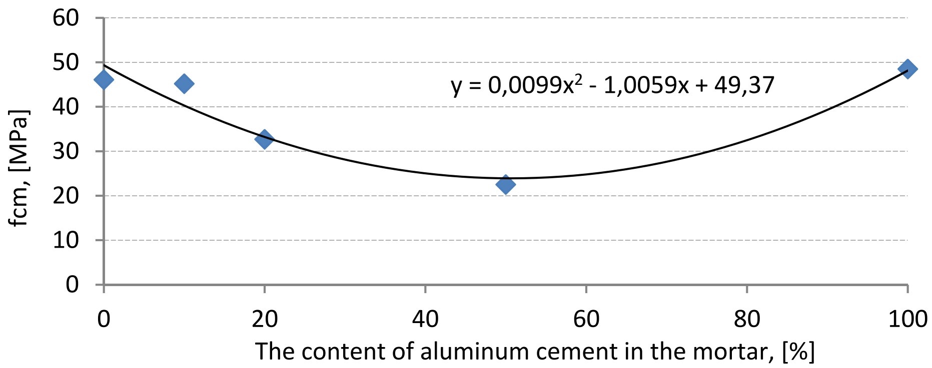

Figure 8. Polynomial dependence of the mortar compression strength increase after 28 days of ripening, in which Portland cement was replaced with aluminium cement in the amount from 0 to 100%.

The presented dependence in figures8 allows estimating the compression strength increase after 28 days of mortar maturation depending on how much Portland cement will be replaced with aluminium cement. This dependence will allow estimating the compressive strength of mortars from a mixture of two aluminium and Portland cements in varying proportions.

4. Conclusions

The laboratory tests carried out allow to draw the following conclusions:

- aluminium cement, depending on its amount in fresh mortar, shortens the beginning and end of the leaven binding. Alumina cement can replace Portland cement up to 20%. The use of a 50:50 ratio causes a significant shift during the start and end of the setting of such mortar.

- replacement of Portland cement with aluminium cement causes deterioration of the consistency of fresh mortar. The more clay cement in the mortar, the worse the workability of the mortar.
- the highest compressive strength obtained from mortars made of aluminium cement alone. The lowest compressive strength was achieved by mortars in which Portland cement was replaced with 50% aluminium cement. A similar increase in compressive strength is characteristic for mortar made of Portland cement and mortar, in which Portland cement was replaced with 10% aluminium cement.
- comparable bending strengths for mortars made of Portland cement alone, as well as for the aluminous cement and mortar made of a mixture of Portland cement and 10% of aluminium cement. The smallest value was noted for the mortar in which Portland cement was replaced with 50% aluminium cement.
- in the capillary lift test the smallest mass increase was recorded for Portland cement mortar and mortar, in which Portland cement was replaced with 10% clay cement. The largest increase in mass is characterized by mortars made of aluminium cement and mortar from mixtures of Portland and clay cements in the ratio 50:50.
- the smallest absorbability is characterized by mortars from Portland cement alone. The most absorbable is mortar made of aluminium cement.

Summing up the results of laboratory tests, it can be concluded that the Portland cement mortar in which Portland cement was replaced with 10% aluminium cement shows the best rheological properties and parameters of hardened mortars.

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