Parameters of Mortars Made of Aluminium and Portland Cement

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Abstract. Alumina cement is included in special cements, which are used primarily for the production of refractory materials. It is significantly different in chemical terms from the Portland cement commonly used in construction. The consequence of this are the different properties of these two hydraulic binders. Portland cement consists mainly of CaO and SiO₂. In turn, the main constituents of aluminium cement are Al₂O₃ and CaO, which form calcium aluminates. However, the main phase constituent of aluminium cement is CA calcium monohydrate. It consists of about 36 ÷ 42% Al₂O₃ containing also a significant amount of gelenite (C₂AS). Strength of Ca₂ after three days of hydration is comparable to the strength of pure hydrated CA. It is also worth mentioning such phases as C₂S and C₄AF. They often occur in Portland cement and in clay cement. The article discusses the results of laboratory tests on the impact of replacing Portland cement with Portland cement on the physical and mechanical properties of mortar. The rheological characteristics of mortars, i.e. the consistency and parameters of hardened mortars, among others compressive strength, capillary rise and absorbability. Replacing aluminium cement with Portland cement in an amount of 10% causes an increase in compressive strength. The increase in compressive strength depends on the amount of Portland cement applied to the mortar. Parameters such as absorbability and capillary rising are improving. Compressive strength was tested after 1, 7, 28 days on samples with dimensions 4 x 4 x 16 cm. Absorption and capillary rising were tested 28 days after being moulded.

1. Introduction
Currently, there is no one recipe and fixed proportions of mortar components, the mixture of which is aluminium cement, Portland cement, water and sand. The main component in such a mortar is aluminium cement in which the essential binding phase is CA. The content of this phase can range from 40% to 70%. Often, in addition to the CA phase, there is a CA₂ phase and other phases in smaller quantities but affecting the leaven such as C₁₂A₇. These phases mainly affect the bonding rate of cement slurries. In mortars with the participation of aluminium cements, the hydration of aluminium cement plays a key role. Due to the complex nature, this process is still not fully recognized. In the literature one can find a basic division of the hydration process, which is divided into three stages: dissolution, nucleation and precipitation. In the first stage, the surface of cement particles is hydroxylated by their dissolution, which leads to the release of Ca⁺ and Al(OH)₄ ions. The remaining Al(OH)₄ ions dissociate into Al⁺ and OH ions. The reaction that occurs all the time with water leads to an increase in Ca⁺ and Al(OH)₄ concentrations. After a certain time, the leaven reaches the saturation point, and we reach the second hydration stage - nucleation. This phase lasts until the first hydrates - crystal nuclei. The effect on the formation of hydrates in the second phase of hydration has:
chemical and mineralogical composition of the cement, w/c ratio, ripening temperature and method and time of mortar care [1]. Many works have been devoted to studies of hydration of aluminium cement, especially in connection with the mortar durability problem, mainly in the aspect of the phase change occurring [2].

The mixing of aluminium and Portland cement according to literature is permissible, but in certain experimentally determined proportions. The phase composition of cements used for making mortars also plays an important role in the selection of cements. Exceeding properly selected proportions of cements may result in deterioration of rheological characteristics and parameters of hardened mortars. This topic is not yet fully recognized by researchers [3]. The use of aluminous cements as the basic component of mortars enables modifying the rheological properties of mortars, influences the beginning and end of bonding, as well as the increase in compressive strength even at reduced temperatures of up to minus 10 °C and reduces the shrinkage of hardened mortars [4].

2. Laboratory tests

The mortar was made with a constant coefficient w/c = 0.4. Laboratory tests applied aluminium cement conforming to PN-EN 14647 [5], Portland CEM I 42.5R cement, tap water and 1-2 mm quartz sand in accordance with PN-EN 13139:2003 [6]. Tap water meets the requirements of PN-EN 1008:2004 [7]. The mortars were prepared in a standard laboratory mixer. The purpose of the laboratory tests was to determine the impact of replacement with Portland cement in the amount of 10%, 20%, 50% of aluminium cement. Rheological characteristics of fresh mortar and parameters of hardened mortars were investigated. The mortar consistency test was performed and the parameters of hardened mortars were determined, i.e. compressive strength, bending strength, capillary rise and absorbability. The compressive strength was tested after 1, 7, 28 days after being formed on standard bars with dimensions 4x4x16cm. Absorption and capillary rupture were tested on mortars after 28 days of maturation. A reference series of mortar made of aluminium cement was also made. The mortar was prepared with the composition given in Table 1.

| Table 1. Mortar composition |
|-----------------------------|
| Mortar ingredients, [g]     | Series | Series | Series | Series |
|                            | ident. 10% | ident. 20% | ident. 50% | ident. SG |
| Alumina cement              | 450     | 400     | 250     | 500     |
| Portland cement             | 50      | 100     | 250     | ------- |
| Sand 1-2mm                  | 1350    | 1350    | 1350    | 1350    |
| Water                       | 200     | 200     | 200     | 200     |

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 - Al₂O₃ | Fire retardation usual 128 sP | basic phase: |
| min. 40% | Specific gravity 3.0 g / cm³ | calcium monoglinate CA |
| Content - CaO | Bulk density 1.1 g / cm³ | accompanying phases: |
| min. 36% | Specific surface area according to Blaine 3100 - 3800 | C₆AF brownmillerite |
| Content - SiO₂ 2 - | | C₄AF twelve-calcium |
| 4% | The grain size in the range 0 - 63 μm min 80% | rootstock |
| Content - Fe₂O₃ | Temperature at which work can be done minus 10 °C | C₂AS gelenite |
| 14% | | | |
3. Results and discussions

The first rheological examination of the fresh mortar was to determine the consistency according to PN-EN 1015-3:2000 [8]. The arithmetic mean of diameters in two directions of the spilled mortar cake should be taken as the result of the measurement. The measurement is given in centimetres.

![Figure 1. The diameter of a spilled spot for tested mortars.](image)

Testing the consistency of fresh mortars has shown that the replacement of Portland cement with Portland cement causes a slight deterioration in consistency with the amount of Portland cement added to the mortar. Mortar made of aluminium cement, in which cement was replaced with 50% Portland cement, is characterized by the worst workability.

Compressive strength was tested on samples of $4 \times 4 \times 16$ cm beams. The samples were formed in water at a temperature of $+18$ °C throughout the maturation period. Compressive strength was tested 1, 7, 28 days after being moulded. The test was carried out in accordance with PN-EN 1015-11 [9]. The result is the arithmetic mean of the six measurements obtained.
The analysis of the compressive strength increase shows that the highest compressive strength is characterized by mortar, in which aluminium cement was replaced with Portland cement in the amount of 10%. The compressive strength of this mortar after 28 days of ripening under standard conditions is 59 MPa. The same compressive strength after 28 days of ripening is characterized by two mortars, i.e. from aluminium cement alone and from aluminium cement with the addition of 20% Portland cement. The lowest compressive strength was found in mortars in which 50% Portland cement was replaced with Portland cement. Compressive strength of this series after 28 days of maturation was 27.9 MPa.

Flexural strength was carried out on standard bars measuring 4x4x16cm according to PN-EN 1015-11 [9]. 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. At the same time, three samples were pressed together. The result is the arithmetic mean of the measurements obtained.
alone. The lowest bending strength is found in mortars in which aluminium cement has been replaced with Portland cement in the amount of 50%.

\[ y = 11,142x - 34,903 \]

**Figure 4.** Linear relationship between the increase of bending strength and the increase in the compressive strength of mortars after 28 days of maturation

Figure 4 shows the linear dependence of the increase in bending strength after 28 days of ripening under standard conditions and the increase in compressive strength of mortars aged for 28 days under standard conditions. This dependence allows estimating two parameters interchangeably, instead of performing time-consuming laboratory mortar tests.

The samples for the capillary elongation test were made with the dimensions 4x4x16 cm. The samples were formed after storage in water at +18°C for a period of 7 days. The next days the samples were in an air-dry environment at +18°C. The weight gain of the samples was tested after 28 days of maturation. Before the test, the samples were placed in an air conditioning chamber for 48 hours. Mass measurements were made every 24 hours. The samples were immersed to a height of approximately 1 ÷ 3 mm. The sides of the samples were insulated against uncontrolled absorption of moisture from the environment. The water was successively topped up.

**Figure 5.** Growth of mortar mass in capillary pull, [kg/m²]
The largest increase in mass in capillary pull is characterized by mortars made of aluminium cement alone. The same weight increase is characterized by mortars in which aluminium cement was replaced with Portland cement in the amount of 10% and 20%. The drop in the weight gain for these mortars compared to mortar made of aluminium cement alone is 27.1%.

The absorbability testing for mortars was performed on samples with dimensions of 40x40x160mm according to PN-88 / B-06250 [10]. Samples for testing were stored for 7 days in water at +18ºC, and subsequent days for testing in air at +18ºC. The samples were dried to a constant mass for 48 hours in an air-conditioning chamber. The samples were placed in water up to half the height for a period of 24 hours. After this time, water was added to the height of +1 cm above the height of the sample. The weight gain was tested every 24 h, to obtain two identical measurements [11].

![Figure 6](image)

**Figure 6.** Percentage decrease in the mortar mass in the absorbability test in relation to the reference mortar of aluminium cement alone, [%]

In the test of mortar absorbability, in which aluminium cement was replaced with Portland cement in the amount from 10% to 50%, the weight gain decreased throughout the laboratory testing period in relation to the reference mortar. The decrease in weight gain is from 18.9% to 20.5% throughout the laboratory test. The absorbability test was completed after 7 days because identical weight measurements were obtained.

![Figure 7](image)

**Figure 7.** Dependence of the mass decrease in the absorbability test on the weight gain in capillary pull for the tested mortar series expressed in a polynomial formula
On the basis of the polynomial dependence, having an estimated one parameter, the second value can be estimated without doing a time-consuming laboratory test procedure.

![Polynomial dependence of the mortar compression strength increase after 28 days of maturation, in which aluminium cement was replaced with Portland cement in the amount from 0 to 100%](image)

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

The above relationship estimates the increase in compressive strength after 28 days of mortar maturation in laboratory conditions depending on the amount of Portland cement in the mortar, which replaced the 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
Laboratory tests have shown that the replacement of Portland cement with Portland cement in the amount of 10% increases the compressive strength after 28 days of maturation by 20% compared to the reference mortar made of aluminium cement alone. A similar 28-day strength was noted for mortar made of aluminium cement and mortar alone, in which aluminium cement was replaced with Portland cement in the amount of 20%. The lowest compressive and bending strength is characterized by a series made of mortar, in which aluminium cement was replaced with 50% Portland cement. The highest bending strength is obtained from mortars made of aluminium cement and aluminium cement with the addition of 10% Portland cement. The flexural strength for these series is 8.3 MPa. The decrease in the mass gain in the absorbability test in relation to the reference mortar made of aluminium cement alone is from 18.9% to 20.5% throughout the laboratory test period for the tested mortar series. The largest increase in mass in capillary pull is characterized by mortars made of aluminium cement alone. A similar increase in weight is marked by mortars in which aluminium cement was replaced with Portland cement in the amount of 10% and 20%. The drop in weight gain for these mortars compared to the reference mortar is 27.1%.

Summing up the obtained results of laboratory tests, it can be stated that the mortar in which the Portland cement was replaced with Portland cement in the amount of 10% is characterized by the best parameters of hardened mortars.

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