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CHARACTERIZATION OF NEW FILLER ADDITIONS AFFECTING THE MECHANICAL STRENGTH OF CONCRETE

KARAKTERIZACIJA DODAJANJA NOVIH POLNIL, KI VPLIVAJO NA MEHANSKO TRDNOST BETONA

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In this work, the results of a chemical modification of concrete based on Portland cement by zeolite, metakaolinite and micrometakaolinite in amounts of (5, 10 and 15) *w*/%, and mass fractions of the concrete amount included in the mixture as a filler were summarized. The influence of the *w*/%, or mass fractions, of new commercial fillers on the concrete's mechanical strength was measured. The reference recipe of concrete contained three parts of aggregates: 0.125–0.250 mm, 0.250–0.500 mm and 0.500–1.000 mm. For the concrete production, white cement (42.5 MPa), water and a deflocculant based on polycarboxylate were used. To characterize the basic properties of the studied concrete, SEM observations, chemical compositions, slump-cone test results and time setting were widely investigated. Samples of the concrete were characterized with the compressive-strength and bending tests after (1, 7, 14 and 28) d of the curing process. The obtained results were compared with the reference samples of the concrete without chemical additions. This study proved that all the chosen modifiers had an increased effect on the final mechanical strength of the researched concrete samples and that they are very promising for applications in civil engineering and new building technologies in the future.

Keywords: concrete strength, zeolite, metakaolinite, micrometakaolinite, admixtures

Avtorji opisujejo rezultate kemičnih modifikacij betona na osnovi portland cementa z dodatkom (5, 10 in 15) masnih deležev zeolita, metakaolinita oz. mikrometakaolinita. Raziskovali so vpliv teh dodatkov na mehansko trdnost novih betonov. Referenčni recept betona brez dodatkov je vseboval tri velikostne deleže agregatov: 0,125–0,250 mm, 0,250–0,500 mm in 0,500–1,000 mm. Za izdelavo betona so uporabili cement (42,5 MPa), vodo in deflokulant na osnovi polikarboksilata. Osnovne lastnosti izdelanega betona so analizirali s pomočjo SEM. Določili so tudi kemijske sestave betonov in izvedli testa posedanja s stožcem in utrjevanja betona. Vzorcem betona so določili še tlačno in upogibno trdnost po različno dolgem času staranja, to je po (1, 7, 14 in 28) dneh. Rezultate so primerjali z referenčnim betonom, ki ni imel dodanih polnil. S študijo so dokazali, da so vsa polnila izpolnila pričakovanja glede izboljšanja končne mehanske trdnosti ter opozorili na perspektivnost njihove uporabe v gradbeništvu in v prihodnosti novih gradbenih tehnologij.

Ključne besede: trdnost betona, zeolit, metakaolinit, mikrometakaolinit, domešavanje

1 INTRODUCTION

According to the definition, admixtures are natural or manufactured substances, which can be added to concrete to maintain or modify its properties. Admixtures are added to concrete immediately before or during the mixing process.

The reason for using admixtures is to obtain special properties of fresh or hardened concrete. Admixtures may enhance the durability, workability or strength of a given concrete mix. They are used to overcome difficult construction situations, such as hot or cold weather placements, early-strength requirements or very low water-cement ratio specifications.[1–3]

In conclusion, the major reasons for using admixtures are:

- to reduce the costs of concrete constructions;
- to maintain certain properties of concrete more effectively than by other means;
- to maintain the quality of concrete during the stages of mixing, transporting, placing and curing in adverse weather conditions;
- to overcome certain emergencies during concreting operations.

Another important issue is the fact that admixtures are usually provided in the liquid form. Some admixtures, such as pigments, pumping aids and expansive agents, are typically added manually from pre-measured containers as the amounts used are very small.[3–5]

Chemical admixtures are classified according to the basic effects obtained with their use – listed in the European standards:[6]

- reduction in the amount of mixing water,
- significant reduction in the amount of mixing water,
- increase in the water binding,
- aeration,
- acceleration of the binding,

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- acceleration of the hardening,
- delay in the binding,
- increase in the water resistance (sealing),
- multifunctional (comprehensive) effect.

Nowadays, chemical components are very important elements of concrete mixtures. In contrast to the old components, modern admixtures are designed and manufactured to be used in cement slurries, mortars or concretes to obtain a specific effect of the final product. The main purposes of using chemical admixtures are to change the properties of a fresh mix and to modify the parameters of a hardened cement paste, mortar or concrete. The correlations given in the literature usually differ from one another and are valid only for limited ranges of operating parameters, e.g., an admixture addition allows us to produce a concrete mix with a relatively small amount of water, but a sufficient degree of liquidity allows us to mix it correctly into the concrete.[7–9]

A relatively small amount of water used to produce a mixture based on a given mass of cement may contribute to the improvement of several parameters of hardened concrete, including:[4]

- strength,
- waterproofness,
- resistance to environmental impacts,
- resistance to corrosion, including corrosion of the concrete reinforcement,
- absorbability.

On the other hand, when using chemical admixtures, sometimes more than one property of a fresh or hardened mixture are modified. An example is the use of aeration admixtures, which, on the one hand, contribute to the improvement of the hardness of concrete and, on the other hand, reduce the density and strength of the material. Chemical admixtures are mostly added during the production of a concrete mix (during the mixing process). According to the PN-EN 934-2 standard, admixtures should be used in an amount not greater than 5 % of the cement mass in concrete. However, new research about the chemical modification of concrete shows that an admixture addition of more than 5 % increases some of the properties. At the same time, a reduced amount of cement is needed for the production of concrete.[10–13]

There are no universal methodologies describing how to select chemical admixtures to obtain optimal final properties. The dosing of many products can be direct – into the mixer, after the cement, water, possible additives and aggregate have been introduced. Some products need to be mixed with water (technological), then this water is added to the other ingredients during the mixing process. In any case, a proper distribution and dispersion of the chemical admixture in the volume of a mixed material is important to obtain the required and reproducible parameters.

In this paper, the effects of an admixture addition (zeolite, metakaolinite and micrometakaolinite) in amounts of (5, 10 and 15) *w*/% and mass fractions were characterized. The obtained results are very promising for future applications in new civil-engineering technologies.

2 MATERIALS AND METHODS

This study presents the effects of three commercial admixture additions – zeolite, metakaolinite (MK) and micrometakaolinite (MMK) – on the final properties of concrete samples.

Parameters such as the morphology and chemical composition were analysed with a SEM JEOLJSM-6610 at a voltage equal to 5 kV. Additionally, the particle size of the used admixtures was determined with the laser-diffraction method.

Concrete mixtures were fabricated using aggregates of Portland cement (42.5 MPa), water and quartz sand (0.125–0.250 mm; 0.250–0.500 mm and 0.500–1.000 mm), a deflocculant based on polycarboxylate and an admixture addition in amounts of (5, 10 and 15) *w*/%. A reference sample was prepared without the admixture addition. The time of mixing was 5 min in laboratory conditions (52 % humidity and 22 °C). After the mixing process, the concrete mixture was transformed into steel and compacted with the vibration method in 45 sec. Time setting and slump-cone test results for the concrete mixtures were analysed according to the PN-EN 12350-2:2011 standard.

The compressive strength of concrete depends on many factors such as water-cement ratio, cement strength, quality of the concrete material, quality control during the production of concrete etc. The compressive strength is the ability of a material or structure to carry loads on its surface without getting any cracks or deflection.

The conditions and method of performing a compressive-strength test of concrete are described in the PN-EN 12390-3:2011 standard. The samples for the testing were cube-shaped. The dimensions of the samples were as follows: 150 mm × 150 mm × 150 mm. Concrete was poured into moulds and tempered properly to eliminate any voids. After 24 h, the moulds were removed and test specimens were put into water for curing. To measure the compressive strength, 10 specimens were tested after (1, 7, 14 and 28) d of the curing process.

The compressive-strength test of concrete was carried out using a Form + Test Prűfsysteme testing machine in laboratory conditions of 21 °C and 52 % humidity. The samples were loaded with a displacement of 0.5 kN/min.

The bending-strength test was carried out using the same testing machine and conditions, in accordance with the PN-EN 12390-5:2011 standard. The bending force was analysed after (1, 7, 14 and 28) d of the curing process. For this research, 10 steel samples were prepared (40 mm × 40 mm × 160 mm). The section below discusses bending force vs time observed during the curing

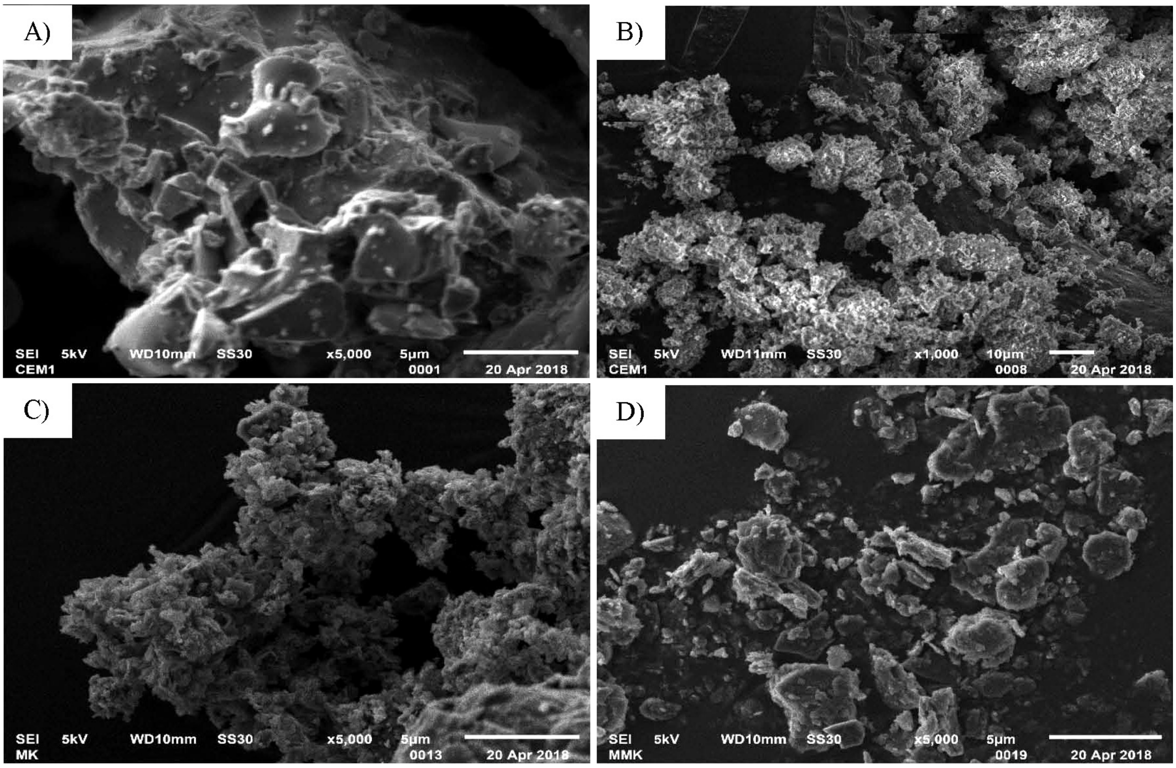

Figure 1: Morphology of the investigated admixtures – (a – cement, b – zeolite, c – MK, d – MMK)

process. The bending force was calculated with Equation (1):

$$F = f_c \cdot A_c \tag{1}$$

where

F – the final bending force [kN]

f_c – the bending strength [MPa]

A_c – the cross-sectional area of a sample [mm^2]

3 RESULTS

The morphology and chemical composition of the investigated admixtures (cement, zeolite, microkaolinite – MK and micrometakaolinite – MMK) are presented in **Figures 1** and **2**.

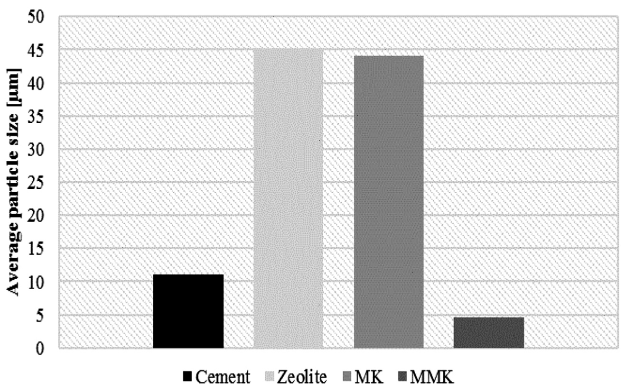

Figure 2: Chemical composition of the investigated admixtures – (a – cement, b – zeolite, c – MK, d – MMK)

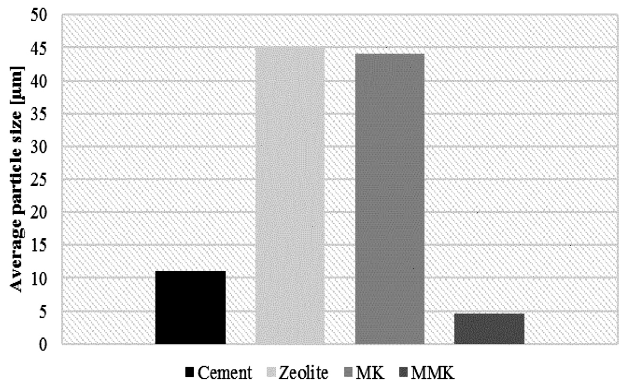

Figure 3: Average particle sizes of the investigated admixtures

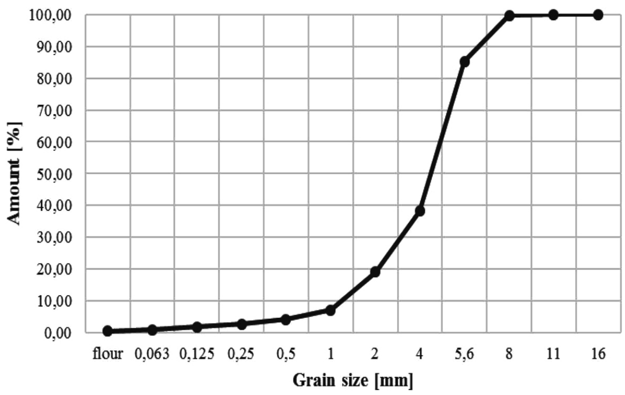

Figure 4: Sieve curve of the used aggregates

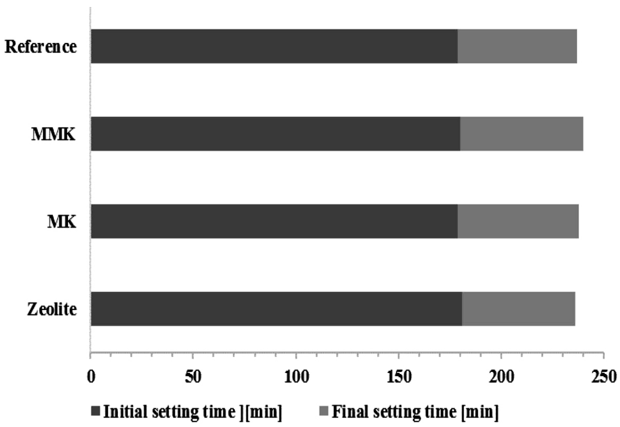

Figure 5: Time distribution for the investigated admixture additions

The average particle sizes of the researched admixtures are shown in **Figure 3**. The sieve curve of the used aggregates is shown in **Figure 4**. Additionally, the time is presented in **Figure 5**.

The basic characterizations of this study are shown in **Figures 1–4**. The morphologies of the tested admixtures are very significant. Sharp-edge particles and agglomerates were observed on SEM images. The chemical compositions of all the chosen admixtures are based on oxides of silicone and aluminium. The rest of the compound was formed during the production process. Only the zeolite admixture comes from a natural environment, additionally including Ca, Mg and K.

The average particle sizes of the investigated admixtures are different. For zeolite and MK, they are similar – 45 µm. MMK exhibits the smallest particle size – 5 µm. The sieve curve was prepared for the quartz sand of Polish origin. The most common particle size was observed to be in a range of 1–8 mm. Its highest amount, 47 *w*/%, was found for 5.6-mm grains.

To characterize the basic parameters of the concrete mixture, a slump-cone test was done and time setting was widely examined. The concrete mixture exhibits the S1 class of consistency. No significant changes were observed in the time setting of the concrete samples. All the tested admixtures needed almost 240 min to be fully cured.

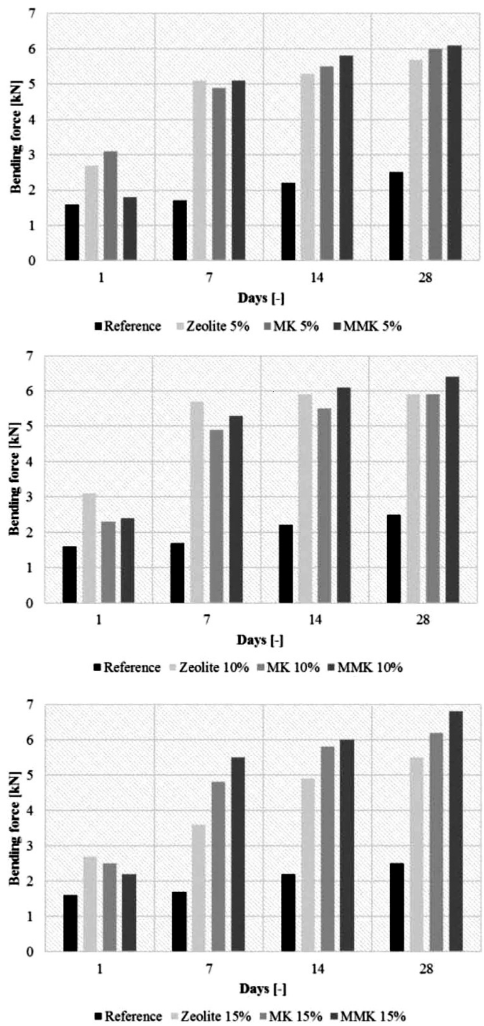

Figure 6: Bending-strength distribution for the investigated samples

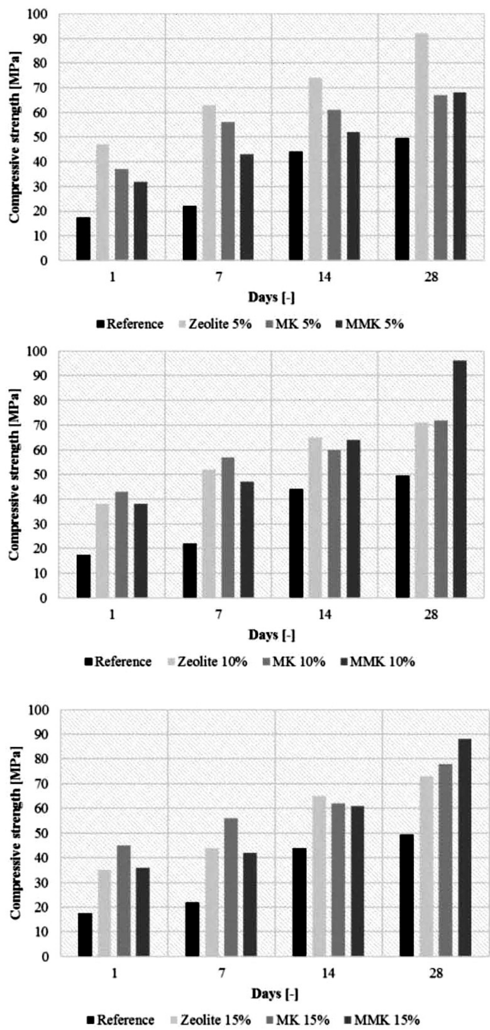

Figure 7: Compressive-strength distribution for the investigated samples

The mechanical-strength characterization including the bending force and compressive strength is presented in **Figures 6–7**.

The obtained results show that the chemical modification of the concrete significantly changes the final mechanical properties of the concrete samples. All the added admixtures exhibit an increased effect on the mechanical strength of the samples. As it can be seen, the relative values of the bending force are small in relation to the compressive strength. The highest effect on the mechanical compressive strength was measured for the 10 *w*/% MMK, amounting to almost 100 MPa. The lowest effect was observed for the sample with the 5 *w*/% MK addition.

4 DISCUSSION

This paper summarizes the results of the chemical modification of the concrete samples including zeolite, metakaolinite and micrometakaolinite. The application of this type of compounds allowed us to obtain the highest values of mechanical strength already after 1 d of the curing process. The presented results (**Figures 6-7**) show that the admixture addition significant increases the final mechanical properties of the tested samples. For the MK and MMK materials, the highest level of increase was noted. During the bending test, values three times higher than that of the reference sample were observed. Cement can also be replacement with a new commercial filler. In accordance with the PN-EN 934-2 standard, more than 5 *w*/% of admixtures were added into the matrix of the concrete samples and no damage of the concrete structure was observed. It was proven that the fabrication of a new concrete composite with the highest amounts of admixtures is possible and does not require a special method of production. New synthesized commercial admixtures available on the international markets meet the requirements of new building technologies in civil engineering.

5 CONCLUSIONS

In line with our assumptions, the final effect of the addition of new commercial admixtures to the matrix of concrete on the composite properties was proven and characterized in this paper. An addition of admixtures significantly improved the mechanical strength of the concrete composite. No problems were noted in the process of mixing and the composite could be prepared under ordinary environment conditions. This study proved that it is possible to produce a new concrete composite using new commercial admixtures and obtain higher values of its final mechanical properties. Additionally, the cement replacement is more environmentally friendly, emitting less CO_2 gas (produced in the process of cement fabrication) into the atmosphere.

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