Development of Component Composition of Engineered Cementitious Composites

Nazar Sydor(✉), Uliana Marushchak, Serhii Braichenko, and Bohdan Rusyn

Lviv Polytechnic National University, Lviv 79013, Ukraine
nazar.sydor@ukr.net

Abstract. The use of engineering cementitious composites – a specially developed cement-based material reinforced with fibers – allows to enhance the bearing capacity, stability under static and dynamic influences, as well as durability of building structures. The effect of component composition of engineering cementitious composites on workability, flexural and compressive strength was investigated from micromechanics principles point of view. It is shown that the optimal cement to sand ratio, partial replacement cement by fly ash, incorporation of polycarboxylate superplasticizer, as well as reinforcement of the engineered composites structure with dispersed fibers contribute to their mechanical properties both at early and later hardening period. The modified engineered cementitious composites are characterized 28-days compressive strength 61 MPa, flexural strength – 14.5 MPa and crack resistance coefficient 0.24. Partial replacement of Portland cement by fly ash causes formation of needle and fibrous hydration products in unclinker part that reinforce the matrix on the micro- and nanolevel and the phenomena of "self-reinforcement" is realized.

Keywords: Engineered Cementitious Composite · Fiber reinforcement · Fly ash · Polycarboxylate superplasticizer · Flexural strength

1 Introduction

The progress in the construction industry gives a new impetus to the development of hybrid, layered, thin-walled profile and other types of building structures of the new generation. Strict requirements to the safety and reliability of buildings and structures lead to the need of performance and durability increase of concrete used in the construction, reconstruction and repair of construction [1, 2]. However, high strength concrete is a brittle material in which strains are localized in place of first crack appearance after the limit loads. Cracking, which evolves in concrete structures subjected to in-service loading, reduces their bearing capacity as well as corrosion resistance, increases the possibility of water and other chemicals penetrating, which can lead to decrease durability of composites.

The destruction of conventional concrete due to its brittle behaviour was important factor for the development of Engineered Cementitious Composites (ECC). The design of ECC of Engineered Cementitious Composites is based on principles of

Z. Blikharskyy (Ed.): EcoComfort 2020, LNCE 100, pp. 459–465, 2021.
https://doi.org/10.1007/978-3-030-57340-9_56

micromechanics and fracture mechanics to provide high tensile strength and ductility [3–6]. The advantage of ECC compared with fiber-reinforced concrete is the ability to use them in thin-walled structures and for infrastructural applications where they are majorly fit comfortably for the repairs and retrofitting of existing structures [3].

The theory of micromechanics involves the optimization of the component composition and microstructure of material, taking into account the interaction of cement matrix and fibers, which provides cross linking of the structure [4]. However, after the appearance of the first crack, the load-bearing capacity of the ECCs does not change, which leads to deformation strengthening and accompanied by multiple cracking. To control this process, ECC do not contain coarse aggregate, as well as a limited content of fine aggregate, as ones lead to increase in the opening width of crack [5]. However, the increased cement consumption in the ECC compared to the concrete can lead to increase of crack formation, which is caused by increased heat release and shrinkage as well as cause negative effect on material cost [3].

Reduction of heat release and shrinkage is provided by partially replacement of cement by supplementary cementitious materials, in particular fly ash, crushed glass, chalk, zeolite [7–12]. The effect of multiple cracks is provided by dispersed reinforcement. The fiber in the composites works to stretch or prevent displacement, ensuring the integrity of the system. The fibers perceive the load and absorb energy of external loading. Polypropylene fibers are characterized by a low modulus of elasticity, therefore, they prevent particle displacement, dampens secondary strains and increase impact resistance [5, 13, 14]. To control the rheological properties of ECC mixtures, high effective polycarboxylate superplasticizers are used, which allows to reduce the porosity, increase the strength of composites [15, 16]. The aim of present study is to development ECC compositions focused on flexural ductility of cementitious composites.

2 Experimental Program

2.1 Materials

The Portland cement CEM I 42.5 R JSC “Ivano-Frankivskcement” (Ukraine), fly ash from Burshtyn thermal power plant, fine aggregate – natural quartz sand (M_f = 1.24) were used to prepare Engineered Cementitious Composites. Polypropylene fiber (f) 5 mm in length was used for disperse reinforcement. The Glenium ACE430 polycarboxylate (PCE) with dosage by 0.7 wt% was used as a modifier of rheological properties of composites.

At the first investigation stage the mix proportions (Portland cement and sand) are variated from 1: 0 to 1: 1.5 with step 0.5. The binary binder system contained Portland cement and fly ash in a ratio 1:1 and polypropylene fiber were used at second investigation stage. Then effect of polycarboxylate superplasticizer on consistency, flexural and compressive strength was investigated.

2.2 Experimental Process

The ECC components were mixed according to EN 196-1 procedure. Fibers are added into the mortar matrix and mixed until all fibers evenly distributed. The consistency of the ECC mixture was determined using the flow table test according to EN 1015-3. The flowing of compositions variated from 150 to 158 mm. The samples 20 mm × 20 mm × 80 mm were unformed after 24 h and cured in normal condition (90–100% RH at 20 ± 2 °C). After 2, 7 and 28 days the samples were tested on flexural and compressive strength. The scanning electron microscopy was carried out to investigate the fibermatrix bonding and the hydration characteristics of the mix.

3 Results and Discussion

The consistency test result of cement-sand compositions is shown that increase sand content cause decrease workability fresh mix. In this case the water consumption increase by 13.3; 30.0 and 43.3% respectively for mixes with cement:sand ratio 1:0.5; 1:1 and 1:1.5 for obtaining alike mix consistency (150–158 mm) (Fig. 1a). Using of binary binder system contained Portland cement and fly ash in a ratio 1:1 provides increase mix workability compared to mix based on CEM I 42.5 due to the roller bearing effect of spherical shape of fly ash particles (Fig. 1b). The water consumption decrease by 17.6% in this case. Therefore, when fiber was added, the viscosity of mixes increases and water consumption enhances. It is necessary to use superplasticizer. Modifying of fiber reinforced composite based on binary binder system (binder to sand ratio is 1:1) with polycarboxylate superplasticizer provide necessary workability at W/B ratio 0.24.

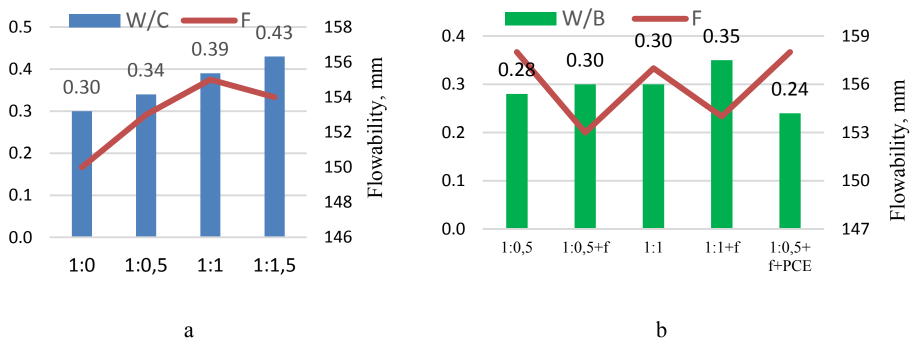


Fig. 1. Flowability and water-cement W/C (a), water-binder W/B (b) ratio of composites

Result of flexural test shows that increasing of sand content causes decreasing of flexural strength (Fig. 2). Thus, mix, in which cement to sand ratio is 1:1, characterizes by flexural strength reducing by 9.3% and 19.7% respectively after 2 and 28 days compared to cement paste. At same time, mix with cement to sand ratio is 1:0.5 shows insignificant strength reducing by 5–7%. For further research compositions with a cement to sand ratio of 1:0.5 and 1:1 were used.

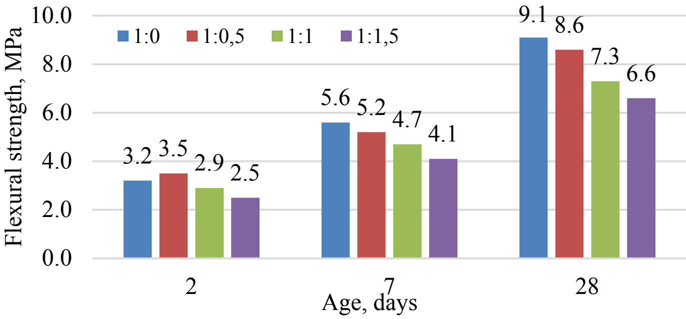


Fig. 2. Flexural strength of cement composites

From the point of view of micromechanical modelling the fly ash content effect on material microstructure and mechanical properties altering process was investigated. Cement in the amount of 50% was replaced by fly ash and binary binder system (the cement to fly ash ratio is 1:1) was used. The flexural strength of this composite after 2 days decrease by 17.1% (Fig. 3). Experimental results shown that mix with addition high volumes of fly ash characterize by decrease long-term flexural strength by 9–11%. The significant enhancement of flexural strength is observed for ECC fiber reinforced by polypropylene fiber and modified by polycarboxylate superplasticizer. In this case flexural strength after 2 days is 6.2 MPa and after 28 days – 14.5 MPa. The strength ratio f_{fl2}/f_{fl28} which indicates the flexural strength development is 0.43.

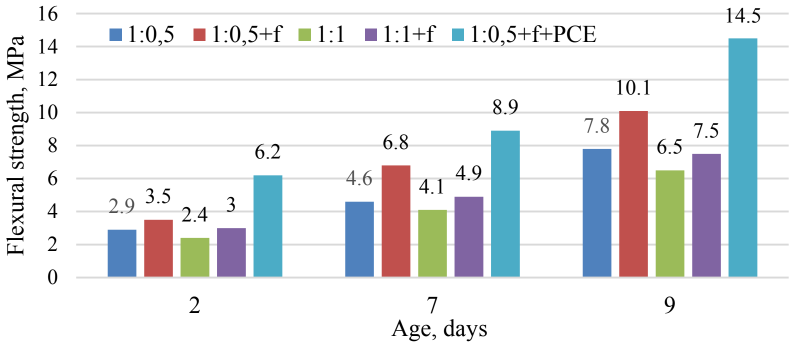


Fig. 3. Flexural strength of cementitious composites based on binary binder system

Compressive strength of disperse reinforced ECC increases by 6–14% compared to nonreinforced composite. Compressive strength of ECC modified by polycarboxylate superplasticizer increases by 1.5 time after 2 days and by 1.1 time after 28 days compared to ECC without modifier due to more amount of particle contact in hydrated system. The 28-days strength of modified ECC is 61 MPa and crack resistance coefficient 0.24. The enhancement of compressive strength of modified ECC could be related with efficient dispersion effect of polycarboxylate ether based superplastisizer and important microstructural aspects: the packing effect, pozzolanic reaction of fly ash (Fig. 4).

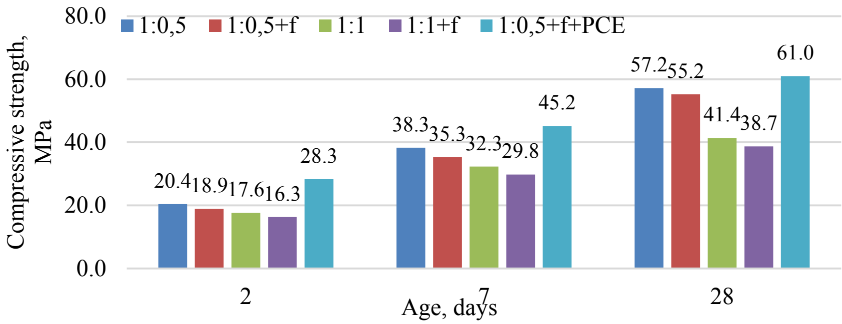
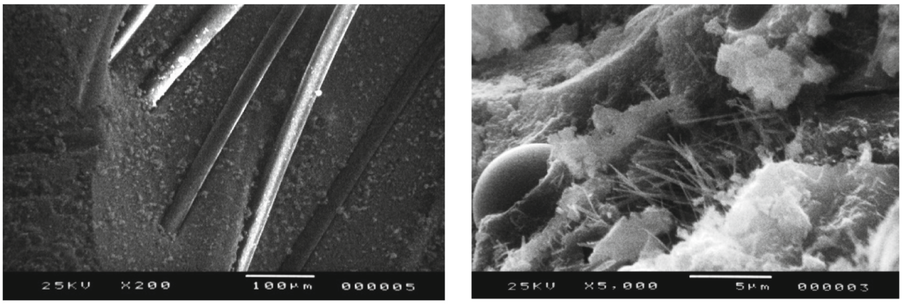


Fig. 4. Compressive strength of cementitious composites based on binary binder system

The microstructure of the ECC modified with polycarboxylates superplastisizer after 7 days is homogeneous. Polypropylene fiber provide three-dimensional reinforcement of cementitious matrix (Fig. 5a).



a b

Fig. 5. SEM images of the ECC

Partial replacement of Portland cement by fly ash causes binding of $Ca(OH)_2$ with formation of needle and fibrous habitus hydration products in unclinker part that reinforce the matrix on the micro- and nanolevel (Fig. 5b). In this case the phenomena of "self-reinforcement" is appeared [17].

4 Conclusions

Micromechanical modelling analysis was used for Engineered Cementitious Composites composition development. The compressive strength of ECC becomes higher by 1.1–1.5 time and flexural strength – by 1.4–1.8 time when superplasticizer is incorporated into cement matrix. It is revealed that a high volume faction of fly ash tends to reduce the fiber and matrix interface due to multilevel reinforcement. Enhance of matrix toughness is in the favour of attaining high flexural strength. ECCs show an improvement mechanical properties and while the use of industrial waste instead of cement results in reducing environmental impact.

References

1. Torres, A., Burkhart, A.: Developing sustainable high strength concrete mixtures using local materials and recycled concrete. Mater. Sci. Appl. **7**, 128–137 (2016)
2. Sanytsky, M., Marushchak, U., Olevych, Y., Novytskyi, Y.: Nano-modified ultra-rapid hardening Portland cement compositions for high strength concretes. In: Lecture Notes in Civil Engineering, vol. 47, pp. 392–399 (2020)
3. Chethan, V.R., Ramegowda, M., Manohara, H.E.: Engineered cementitious composites – a review. Int. Res. J. Eng. Technol. **2**(5), 144–149 (2015)
4. Li, V.C.: On engineered cementitious composites (ECC). A review of the material and its applications. J. Adv. Concr. Technol. **1**(3), 215–230 (2003)
5. Kewalramani, M.A., Mohameda, O.A., Syed, Z.I.: Engineered cementitious composites for modern civil engineering structures in hot arid coastal climatic conditions. Proc. Eng. **180**, 767–774 (2017)
6. Halvaei, M., Jamshidi, M., Latifi, M., Behdouj, Z.: Performance of low modulus fibers in engineered cementitious composites (ECCs): flexural strength and pull out resistance. Adv. Mater. Res. **687**, 495–501 (2013)
7. Ondova, M., Stevulova, N., Estokova, A.: The study of the properties of fly ash based concrete composites with various chemical admixtures. Proc. Eng. **42**, 1863–1872 (2012)
8. Kotsay, G.: Pozzolanic activity diagnostics of fly ash for Portland cement. Chem. Chem. Technol. **10**(3), 355–360 (2016)
9. Chung, S.-Y., Elrahman, M.A., Sikora, P., Rucinska, T., Horszczaruk, E., Stephan, D.: Evaluation of the effects of crushed and expanded waste glass aggregates on the material properties of lightweight concrete using image-based approaches. Materials **10**(12), 1354 (2017)
10. Chepurna, S., Borziak, O., Zubenko, S.: Concretes, modified by the addition of high-diffused chalk, for small architectural forms. Mater. Sci. Forum **968**, 82–88 (2019)
11. Borziak, O.S., Plugin, A.A., Chepurna, S.M., Zavalniy, O.V., Dudin, O.A.: The effect of added finely dispersed calcite on the corrosion resistance of cement compositions. In: IOP Conference Series: Materials Science and Engineering, vol. 708, p. 012080 (2019)
12. Markiv, T., Sobol, K., Petrovska, N., Hunyak, O.: The effect of porous pozzolanic polydisperse mineral components on properties of concrete. In: Lecture Notes in Civil Engineering, vol. 47, pp. 275–282 (2020)
13. Marushchak, U., Sydor, N., Braichenko, S., Margal, I., Soltysik, R.: Modified fiber reinforced concrete for industrial floors. In: IOP Conference Series: Materials Science and Engineering vol. 708, no. 1, p. 012094 (2019)

14. Plugin, A., Kostiuk, T., Plugin, O., Bondarenko, D., Sukhanova, Y., Partala, N.: Interaction of mineral and polymer fibers with cement stone and their effect on the physical-mechanical properties of cement composites. Int. J. Eng. Res. Afr. **31**, 59–68 (2017)
15. Tolmachov, S., Belichenko, O., Zakharov, D.: Influence of additives on flexural strength of concrete. In: MATEC Web of Conferences, vol. 116, p. 01019 (2017)
16. Marushchak, U., Sanytsky, M., Pozniak, O., Mazurak, O.: Peculiarities of nanomodified portland systems structure formation. Chem. Chem. Technol. **13**(4), 510–517 (2019)
17. Marushchak, U., Sanytsky, M., Sydor, N., Braichenko, S.: Research of nanomodified engineered cementitious composites. In: Proceedings of the 2018 IEEE 8th International Conference on Nanomaterials: Applications and Properties, p. 8914835 (2018)