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EFFECT OF POLYCARBOXYLATE SUPERPLASTICIZERS ON THE PROPERTIES OF READY-MIX CONCRETE

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The article analyzes the experience of using Portland limestone cement for the production of ready-mixed concretes. It is shown that polycarboxylate superplasticizers (PCE) play a decisive role in providing required technological and construction-technical properties of concrete. The data show that the most effective PCEs for maintaining the workability of the concrete mixture over time and obtaining the required strength class of concrete are PCE based on modified acrylic polymers. It was found that polycarboxylate superplasticizers provide a significant water-reducing effect ($\Delta W/C$ = 38 %) and was achieved compressive strength class C45/55. It is shown that such concretes are characterized by its rapid strength development (f_{cm2}/f_{cm28} = 0.54). The ready-mix concrete with PCE was used for concreting foundations of wind turbines on the wind power plant with provide the technological properties and of reduce CO_2 emissions.

Key words: ready-mix concrete; Portland limestone cement; polycarboxylate superplasticizers; workability; compressive strength.

Introduction

Concrete, as the main composite building material, due to its high durability and operational reliability is widely used in construction. The design level of strength and the required performance characteristics of concrete is achieved by high-quality design of the warehouse, the choice of manufacturing technology and care with ensuring the required level of technical condition of building structures throughout the service life (Jamrozy, 2000; Fic, 2019). The experience of EU countries shows that high-quality concrete for monolithic construction, which is characterized by improved technological properties that can be obtained on the basis of Portland limestone cement (Giergiczny & Sokołowski, 2008; Sanytskyy et al., 2019). Efficiency of using such binder is shown in increase of workability of concrete mixes and the accelerated increase in durability of concrete. On the other hand, for ready-mixed concrete it is necessary to ensure the preservation of time in combination with the necessary strength and durability. Therefore, the study of the effect of polycarboxylate superplasticizers based on different polymer on the properties of ready-mixed concretes determines the relevance of the work.

Concrete is one of the most important materials used in construction (Aitcin & Wilson, 2014). It is 30–50 % of the total cost of any building under construction. The quality of the used concrete directly affects the strength and durability of the structure (Hooton, 2019; Dvorkin et al., 2018, Plugin et al., 2021). In this context, ready-mixed concrete plays an important role. The advantages of using ready-mixed concrete are varied (Kovler & Roussel, 2011; Seok-Joon & Hyun-Do, 2015; Tolmachov et al., 2019, Markiv, et al., 2021). This helps to increase efficiency and reduce the cost of resources involved in the construction process.

At present, Portland cements of I and II types of strength classes 42.5 are used in the production of ready-mixed concrete. Portland limestone cements are under considerable practical interest. EU experience shows that Portland limestone cement CEM II/A-LL 42.5 R should be used for the production of high quality concrete of compressive strength classes from C16/20 to C50/60, for the manufacture of high-strength and self-compacting concrete (Gołaszewski, 2017). The efficiency of CEM II/A-LL 42.5 R is manifested primarily in increasing the early strength of concrete, as well as in reducing water consumption, increasing the workability of concrete mixtures and reducing their water separation (Kropyvnytska et al., 2021). Concretes based on Portland limestone cement are used for the construction of load-bearing structures of all construction types (Giergiczny & Sokołowski, 2008; Sanytskyy et al., 2019). The increased heat of hydration of Portland limestone cement allows concreting in conditions of low positive temperatures.

At the present stage of construction technology development, the problems of improving the quality, durability, cost-effectiveness of concrete and reinforced concrete are successfully solved by introducing chemical admixtures (Collepardi & Valente, 2006; Runova et al., 2005; Lukowski, 2016). Classic plasticizers have already been successfully used in commercial concrete mixtures, both technically and economically. Currently, the most effective modifiers are polycarboxylate superplasticizers. Note that there is not one type of PCE, but a family of PCE, which can be characterized by quite different actions (Plank et al., 2015). In particular, their tendency to be incompatible with cement due to their molecular structure should be noted. Polycarboxylates may contain groups with polyoxyalkylene, especially polyethylene or polypropylene glycol groups, as well as monomers of carboxylic acid and/or carboxylic acid anhydride (e.g. acrylic acid, methacrylic acid, maleic acid, itonic acid and their anhydrides). In addition, vinyl or acrylate-based monomers can contribute to the chemical structure of PCE (Gamze Erzengin et al., 2018).

The use of efficient PCE allows to optimize high quality concrete "water – cement" and "water – binder" with a significant water-reducing effect ($\Delta W/C$ = 25–35 %) with high strength (Aïtcin & Flatt, 2015). At that time, the task of concrete in the technology of goods is to ensure its manufacturability - maintaining the movement of the concrete mixture over time. The authors found that PCEs derived from acrylic and maleic acid have a longer spine and side chains, as well as carboxylate groups (R – COO-), which increase hydrophilicity, but are able to slow down the hydration process (Liu et al., 2019). The introduction of such modifiers can slow down the hydration of the cement. Modifiers significantly reduce the amount of kneading water to obtain a cast mix of ready-mixed concrete (Flat & Schober, 2012). This allows the transportation of concrete mixtures over long distances while providing the required strength class of concrete.

The purpose of the study – to investigate the effect of polycarboxylate superplasticizers based on different polymers the technological and strength properties of ready-mixed concrete.

To achieve this goal the following tasks were solved:

– to study the effect of polycarboxylate superplasticizers on different polymer bases on the workability and strength of modified concretes;

– to show the practice of using ready-mixed concrete modified with polycarboxylate superplasticizers.

Materials and methods

Portland limestone cement with high early strength DSTU B EN 197-1 –- CEM II/A-LL 42.5 R was used to design the concrete composition. Portland limestone cement CEM II/A-LL 42.5 R was obtained at PJSC "Ivano-Frankivskcement". Portland cement clinker with chemical composition (mass. %: CaO – 66.45; SiO_2 – 20.84; Al_2O_3 – 5.36; Fe_2O_3 – 4.03; MgO – 0.75; SO_3 – 0.87; K_2O – 1.02; Na_2O – 0.11) was used in the investigations. Mineralogical composition of clinker is, mass. %: C_3S – 60.91; C_2S – 14.26; C_3A – 7.07; C_4AF – 12.35. The heat of hydration after 24 and 96 hours is 234 and 328 J/g respectively.

Fine sands and crushed stone of two fractions: 2–4 mm and 4–16 mm were used to design the grain composition of aggregates. The grain composition of the aggregates was determined by dry sieving through a set of sieves in accordance with EN 933-1:2012-03. The selection of the composition of the mixture of aggregates was carried out in accordance with PN-B-06250:1988. Polycarboxylate superplasticizers were used for the study: ordinary polyester type (PCE 1), based on acrylic polymer (PCE 2), based on modified polymer of acrylic acid (PCE 3, PCE 4) of BASF, ATLAS, CHRYSO. The water-reducing effect of superplasticizers was determined in accordance with DSTU B V.2.7-69-98. The effects of admixtures were determined in accordance with DSTU B V.2.7-171:2008. Slump tested concrete mix in accordance with EN 12350-2.

Results and discussion

To obtain ready-mixed concrete, the optimization of the grain size distribution of the components is decisive for the grain packing density. The results of studies of polyfractional grain composition of aggregates (sand fraction 0.125–2.0 mm, crushed stone fractions 2–4 mm, 4–16 mm) allow us to more fully assess the contribution of individual fractions to design the curve of the required particle size distribution of ready-mixed concrete. It was found that for sand the highest content of fractions based on partial residues – 24.6 and 59.8 mass. %. Is concentrated on sieves of 0.50 and 0.25 mm, which indicates an increased content of fine fraction. For crushed stone fractions of 2–4 mm, the maximum size of aggregate on sieves of 4.0 and 2.0 mm is 64.5 and 28.1 mass. %, respectively. When sifting the crushed stone fraction of 4–16 mm, the highest grain content was 34.2 and 59.7 mass. %. On sieves of 16.0 and 8.0 mm selected particle size distribution of the mixture provides a uniform distribution of aggregate fractions. This has a positive effect on the consistency of the concrete mixture with the least possible amount of water and cement (mortar component), and also ensures a minimum air content.

The study of the effect of polycarboxylate superplasticizers on the technological properties and strength of ready-mixed concrete (slump class – S4) was performed on an optimized composition of a mixture of components with material consumption per 1 m^3: Cement – 380 kg, Sand – 405 kg, Crushed Stone (2–4 mm) – 510 kg, Crushed Stone (4–16 mm) – 835 kg. Polycarboxylate superplasticizers on different polymer bases were introduced in an amount of 1.0 mass. %. It is established that for fresh concrete without admixtures the slump 185 mm at $W/C = 0.54$ (Fig. 1). The loss of workability is observed after 60–120 min.

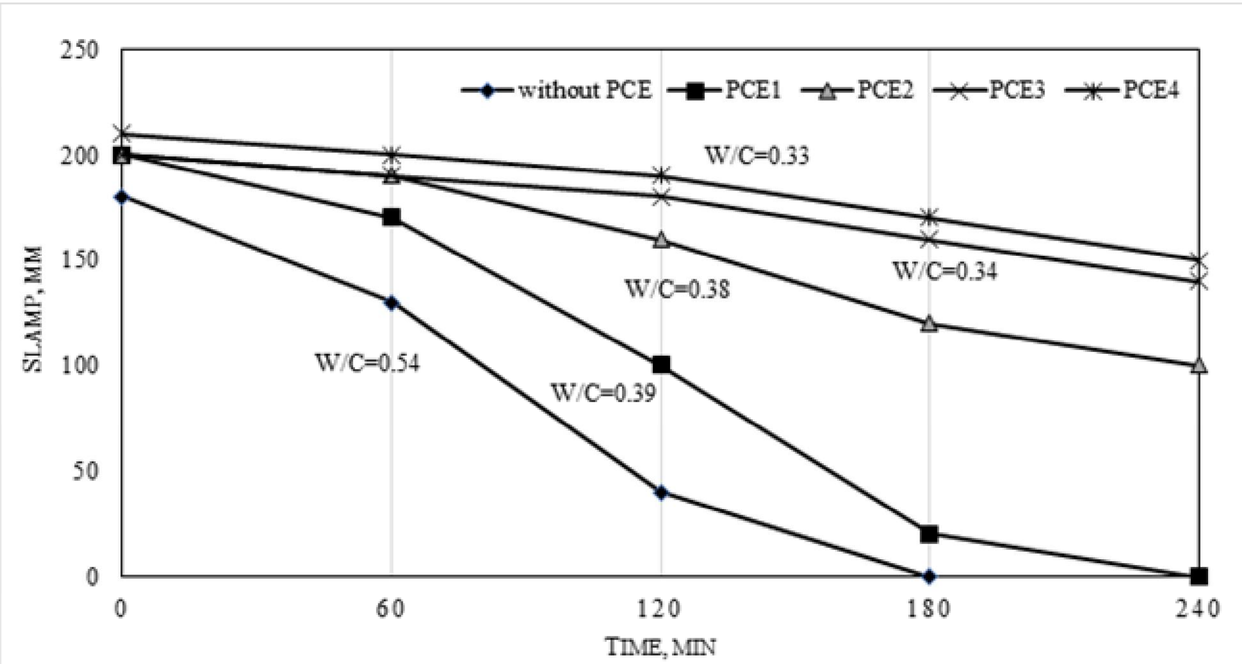

Fig. 1. Slump retention of concrete mix in time with PCE on various polymeric basis

With the introduction of 1.0 mass. % PCE 1 workability of the mixture (slump – 200 mm) is achieved at $W/C = 0.39$ with the preservation of consistency over time for 60–100 min. For fresh concrete modified with superplasticizer PCE 2 at slump 200 mm ($W/C = 0.38$) workability is lost after 120 min. At the same time, the introduction of polycarboxylate superplasticizers of the second generation of PCE 3 and PCE 4 consistence expressed by slump – 200–210 mm is achieved at a water-cement ratio of 0.33–0.34. The workability is maintained for 180–200 min at slump class S4.

It was found that polycarboxylate superplasticizer based on simple polymer PCE is more effective as a water-reducing admixtures ($\Delta W/C$ = 28 %) with high performance of both early (f_{cm1} = 26.2 MPa) and design (f_{cm28} = 67.6 MPa) compressive strengths concrete (Fig. 2). For this composition of concrete the compressive strength class C40/50 is achieved. With the introduction of PCE 2, PCE 3 and PCE 4, there is some slowdown in the kinetics of strength gain at the age of 1 day. At the same time, the introduction of PCE 3 and PCE 4 provides a significant water-reducing effect ($\Delta W/C$ = 38 %) and increase in strength after 2, 7 and 28 days of hardening compared to concrete with PCE 1. This achieves compressive strength classes according to C40/50 and C45/55. According to the estimate of specific strength based on EN 206-1, such modified concrete is characterized by its rapid strength development (strength ratio f_{cm2}/f_{cm28} = 0.54). According to the effects of polycarboxylate superplasticizers are superwater-reducing admixtures in accordance with DSTU B V.2.7-171: 2008.

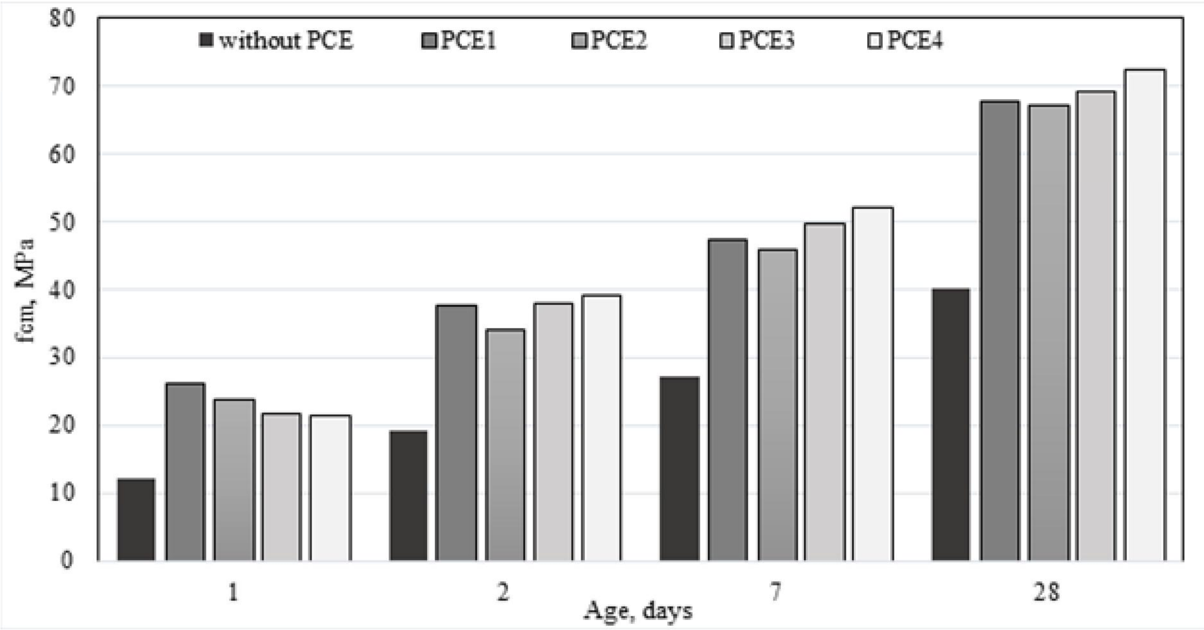

Fig. 2. Compressive strength of concretes based on CEM II/A-LL 42.5 R with PCE

Significant improvements in workability combined with long-term efficiency over time mean that concrete can be adapted to the specific requirements before it leaves the plant. Polycarboxylate superplasticizers PCE 3 and PCE 4 are characterized not only by long-term efficiency over time, but also improve the cohesion of concrete. Superplasticizers are characterized by their wide operational capabilities in all the basic requirements for the production and use of ready-mixed concrete. High plasticity of the modified concrete mixes on the basis of CEM II/A-LL allows to create irregular and free forms, providing appearance, creating a unique form, a monolithic building. During the construction of the wind power plant in Orliv with a capacity of 100 MW, during the construction of monolithic foundations of wind turbines, ready-mixed concrete modified with a polycarboxylate superplasticizer based on a modified acrylic polymer was used.

Portland limestone cement CEM II/A-LL 42.5 R of PJSC "Ivano-Frankivskcement" was used as a binder. Ready-mixed concrete was characterized by the following indicators: the grade of the slump classes – S4-S5, air content – 2.8–3.0 %. For fast-setting ready-mixed concrete of strength class C35/45, the frost resistance grade reached F300, the water resistance class – W12–W14. The problem of ensuring the manufacturability of concrete mixtures (preservation of workability for 3 h, water separation less than 0.2 %) and the rapid strength development of concrete (strength ratio f_{cm2}/f_{cm28} = 0.51) was solved.

As a result, the production of high-tech concrete mixtures based on Portland limestone cement allows to obtain high-quality fast-setting concrete for monolithic construction, which are characterized by improved construction and technical properties.

Fig. 3. Construction of monolithic foundations of wind turbines during the construction of the wind power plant in Orliv using ready-mixed concrete modified with polycarboxylate superplasticizers

Conclusions

Polycarboxylate superplasticizers based on modified acrylic polymers provide the necessary workability of the concrete mixture over time, supply and placement of ready-mixed concrete, combined with high quality and excellent consistency. Ready-mixed concrete based on CEM II/A-LL 42.5 R, modified PCE 3 and PCE 4 are characterized by delayed loss of workability – 200 min, compressive strength classes C40/50 and C45/55 and a rapid increase in strength (f_{cm2}/f_{cm28} = 0.54). Due to the polycarboxylate superplasticizers of the new generation, which improve the plasticization, it is possible to control the compositions for a wide range and type of cements and applications. This will ensure maximum operational reliability of buildings and structures.

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ЕФЕКТ ВПЛИВУ ПОЛІКАРБОКСИЛАТНИХ СУПЕРПЛАСТИФІКАТОРІВ НА ВЛАСТИВОСТІ ТОВАРНОГО БЕТОНУ

У статті проаналізовано досвід використання портландцементу із вапняком і модифікаторів під час виготовлення важких бетонів. Дані свідчать, що застосування CEM II/A-LL 42,5 R забезпечує збільшення ранньої міцності бетону. Показано, що для покращення технологічних і будівельно-технічних властивостей бетону вирішальне значення мають полікарбоксилатні суперпластифікатори. Виявлено, що найефективнішими PCE для збереження рухливості бетонної суміші в часі та досягнення необхідного класу міцності бетону є полікарбоксилатні суперпластифікатори на основі модифікованих акрилових полімерів. Встановлено, що в разі введення PCE на основі модифікованих акрилових полімерів забезпечується істотний водоредукувальний ефект (ΔВ/Ц = 38 %) із досягненням високої ранньої та проєктної міцностей бетону. Показано, що модифікований товарний бетон характеризується покращеними технологічними та міцнісними показниками: клас за осадкою конуса S4, вміст повітря – 2,8 %, збереження рухливості в часі – 200 хв, швидке наростання міцності – f_{cm2}/f_{cm28} = 0,54, клас міцності на стиск C45/55. Встановлено, що PCE на основі модифікованих акрилових полімерів істотно зменшують кількість води замішування з одержанням литої суміші товарного бетону, що уможливлює транспортування на тривалі відстані. Товарні бетони на основі портландцементу з вапняком та із полікарбоксилатними суперпластифікаторами на основі модифікованих акрилових полімерів застосовано для бетонування монолітних фундаментів вітротурбін під час будівництва Орлівської ВЕС із забезпеченням зменшення викидів CO_2 на 400 тис. т/рік.

Ключові слова: товарний бетон; портландцемент з вапняком; полікарбоксилатний суперпластифікатор; рухливість; міцність на стиск.