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THE EFFECT OF CRUMB RUBBER ON THE PROPERTIES OF MODIFIED PORTLAND CEMENT SYSTEMS

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The use of rubber crumb from used tires in concrete as a partial replacement of natural aggregates is an ecologically oriented direction of their utilization. When rubber crumb was added to Portland cement, a decrease in strength was observed. Modification of rubber-containing Portland cement systems with a complex organic and mineral additive makes it possible to compensate for the loss of compressive strength and provide increased impact strength. Samples without rubber show high strength but are characterized by fragility and sudden destruction of the material. Samples containing rubber show relatively low mechanical resistance but also exhibit elastic behavior where slow fragmentation and slow failure of the material after crack initiation are observed. They also are characterized by additional load resistance after reaching the failure stress, which is associated with the bridging effect of rubber particles.

Key words: crumb rubber; Portland cement system; superplasticizer; microsilica; compressive strength; impact strength.

Introduction

The modern development of the construction industry is characterized by a rapid increase in the use of concrete, which has become the main material for various types of capital construction. Concrete structures are used in a variety of conditions due to their high degree of durability and reliability. Mass production and use of concrete leads to excessive extraction and consumption of natural raw materials, which has a significant impact on the environment (Habert et al., 2020; Torres et al., 2021). Innovative approaches of the production of concrete are needed to reduce the negative impact of this industry field, in particular, the use of alternative raw materials, the reuse of waste, and the development of more environmentally friendly production technologies. The use of wastes and recycled products in concrete has been an active area of research in recent years, and more concrete is made from recycled materials (Tavakoli, Hashempour & Heidari, 2018; Momotaz et al., 2023).

Worn tires are a big, serious problem that grows in proportion to the increase in the number of vehicles. One of the reasons for this is the lack of landfills for tire disposal and health hazards (Al Adwan & Alzubi, 2023; Abdelmonem, El-Feky, El-Sayed & Kohail, 2019). Rubber tires belong to the II class of danger according to DsanPiN 2.2.7.029-99. They are able to significantly disrupt the ecological balance with the environment with a recovery period of at least 30 years, which is due to their cross-linked structure and the presence of stabilizer additives to increase durability (Rashad, 2016). Thermal disposal of used tires leads to the release of toxic substances and significant environmental pollution (Rahman, Usman & Al-Ghalib, 2012). The reuse of rubber waste in building materials is a promising environmentally friendly solution. Replacing natural aggregate in concrete is one of the areas of application (Al Adwan & Alzubi, 2023; Youssf, Mills & Hassanli, 2016; Siddika, 2019).

The advantages of using crumb rubber in concrete are a reduction in the weight of structures due to the low density of rubber; improving flexibility and reducing cracking, increasing sound insulation, reducing noise pollution (Sofi, 2018). Also, rubber-based aggregates can be used to improve impact resistance, energy absorption and harmful radiation of concrete (Youssf, Mills & Hassanli, 2016; Bompa & Elghazouli, 2019; Cruz et al., 2021). Rubber crumb is characterized by elastic properties. Therefore, its introduction into concrete allows to change the character of destruction from brittle to ductile as a result of the redistribution of stresses between the matrix and rubber particles (Al Adwan & Alzubi, 2023; Cruz et al., 2021).

Reduced compatibility at the interface between the cement matrix and rubber, which is caused by the hydrophobic nature of rubber and the hydrophilicity of cement particles, has been found to affect the final characteristics of concrete (Villa et al., 2020). The flexural and compressive strength of concrete decreases with the introduction of rubber crumb. Also, the workability of fresh concrete may deteriorate and segregation may occur (Najim, & Hall, 2010; Rahman, 2012). When the rubber content increases to 30 %, there is a systematic decrease in compressive, tensile and bending strength by 50–78 % (Rashad, 2016). methods of strengthening the "rubber-Portland cement" interphase transition zone have been proposed to improve the properties of composites with the addition of crumb rubber (Medina et al., 2018). A hydrogen peroxide and Fenton treatment method to oxidize rubber particles from worn tires to introduce hydrophilic groups to the surface of the particles to improve interfacial compatibility is described by scientists (Villa et al., 2020). Research (Pocklington & Kew., 2019) showed that the use of coarse rubber aggregate coated with cement paste demonstrated an increase in compressive strength of almost 20 % at a rubber content of 30 % by volume of the coarse aggregate compared to conventional coarse rubber. Compatibility of increased stiffness between rubber and cement paste has been described (Pocklington et al. 2015).

The introduction of complex organic and mineral additives containing a polycarboxylate superplasticizer and an active mineral additive is a promising way to solve the problem of reducing the rheological and physical-mechanical parameters of concrete (Sanytsky, Marushchak, Olevych & Novytskyi, 2020; Sanytsky et al., 2021; Marushchak et al., 2019). The positive effect of additional binding materials on the properties and microstructure of concrete based on ordinary Portland cement is due to an increase in the viscosity of the liquid phase with increased resistance to segregation; densification of the matrix due to the packing effect, acceleration of the hydration process due to the seeding effect, pozzolanic reaction with the formation of additional strong phases and causing densification of the microstructure (Lothenbach, Scrivener & Hooton, 2011).

Silica-based materials have been introduced into the rubberized cementitious material to overcome the loss of strength. Also used natural zeolite as a partial replacement of cement (5 %, 10 % and 15 %) to improve the mechanical properties of concrete containing rubber particles (1–6 mm) as a partial replacement of coarse aggregate (Jokar, Khorram, Karimi & Hataf, 2019). Micro-quartz silica and graphene nanoplates were used to improve the microstructure of the rubberized construction mortar at the micro- and nano-levels (Algaifi et al., 2023). However, the results available in the literature describe the effect of crumb rubber on the behavior of concrete or mortar, but there is no data on its effect on the properties of Portland cement.

The purpose of the research is to determine the influence of rubber crumb on the properties of the Portland cement system "Portland cement – microsilica – superplasticizer".

Materials and Methods

The Portland cement CEM II/A-LL 42.5R JSC "Ivano-Frankivskcement" according to EN 196-1 was used to prepare a modified Portland cement system "Portland cement – microsilica – superplasticizer". Microsilica (MS) with a specific surface area of 18600 cm^2/g is used as a supplementary cementitious material. A polycarboxylate superplasticizer from BASF Construction Chemicals Master Glenium ACE430 (PCE) was used. The superplasticizer's dosage was 1.0 mass. % and it was added with mixing water. The mechanical grinded rubber crumb (RC) 1–3 mm was used (Fig. 1, *a*). Bulk density of crumb rubber was 349 kg/m^3. Rubber particles have an elongated shape (Fig. 1, *b*).

Setting time and compressive strength tests was carried out for evaluation of the influence of admixtures on the Portland cement properties. The modified cement systems was prepared by mixing the dry components with an aqueous solution of the superplasticizer. The experiment was carried out for cement pastes of standard consistency. Cube-shaped samples (30×30×30 mm) were produced for compressive strength and impact resistance testing. The samples 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 testing for compressive strength. Impact strength test was carried out after 28 days. The impact test was carried out by dropping a hammer weighing 5 N from a height of 600 mm repeatedly on a 15 mm diameter hardened steel ball, which is placed on the top of the center of a cubical specimen. Impact resistance was estimated as specific energy absorption capacity for initial visible crack and impact failure energy.

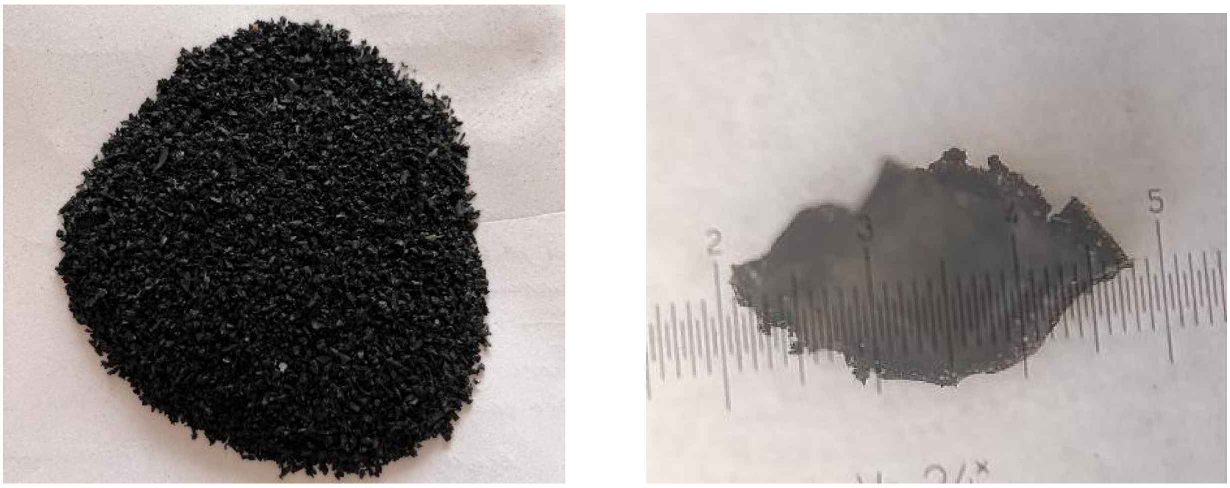

Fig. 1. Crumb rubber 1–3 mm

Results and Discussions

The results of the research established that the introduction of 5 mass. % of rubber does not cause an increase in the water consumption of the Portland cement modified with 1 mass. % PCE, but accelerates the initial setting time up to 60 min, while the initial setting time Portland cement with PCE additive is 140 min. The final setting time is also accelerated with the introduction of rubber crumb by 80 min compared to Portland cement with PCE additive.

The test results of cement paste based on Portland cement modified with a polycarboxylate superplasticizer indicate a decrease in its strength with the introduction of 5 mass. % of rubber crumb in whole hardening periods (Fig. 2). Thus, after 2 days, the strength of the paste based on system “Portland cement – PCE – RC” decreases by 43.6 % and 46.9 % when 5 and 10 % rubber crumb are introduced, respectively compared to the system “Portland cement – PCE”. After 28 days, the strength of the modified system “Portland cement – PCE – RC” system decreases by 23.1 % compared to the “Portland cement – PCE” system with the introduction of 5 % rubber crumb and by 31.6 % with the introduction of 10 % rubber. The strength of the modified system with the organo-mineral additive based on microsilica and a highly effective polycarboxylate plasticizer “Portland cement – PCE – MS – RC” increases by 5–33 % compared to the system “Portland cement – PCE – RC”.

It is shown that when rubber crumb is introduced, the impact strength of modified cement paste increases both at the appearance of the first crack and at complete destruction. Thus, the specific impact energy before the appearance of the first visible crack increases to 2.4 J/cm^3 for the modified system “Portland cement – PCE – RC”, which is 2.1 times higher than the paste based on Portland cement modified with the PCE additive. The formation of a dense structure of Portland cement system modified with an organic and mineral additive and rubber crumb makes it possible to increase the impact resistant index up to 2.8 J/cm^3.

He brittle character of the destruction with the formation of a main crack and the instant loss of the integrity of the sample after its appearance was observed during tests of samples of modified Portland cement systems without rubber crumb (Fig. 3, *a*). The destruction of Portland cement systems with rubber crumb under the action of shock loads was characterized by the appearance of multiple cracks, which, with further deformation, expanded until the loss of integrity (Fig. 3, *b*). Rubber particles act as inhibitors of rapid crack growth in this case. They fasten the opposite sides of the crack. This is called the bridge phenomenon (Fig. 3, *c*). The energy of complete destruction of Portland cement systems increases to 3.0 J/cm^3.

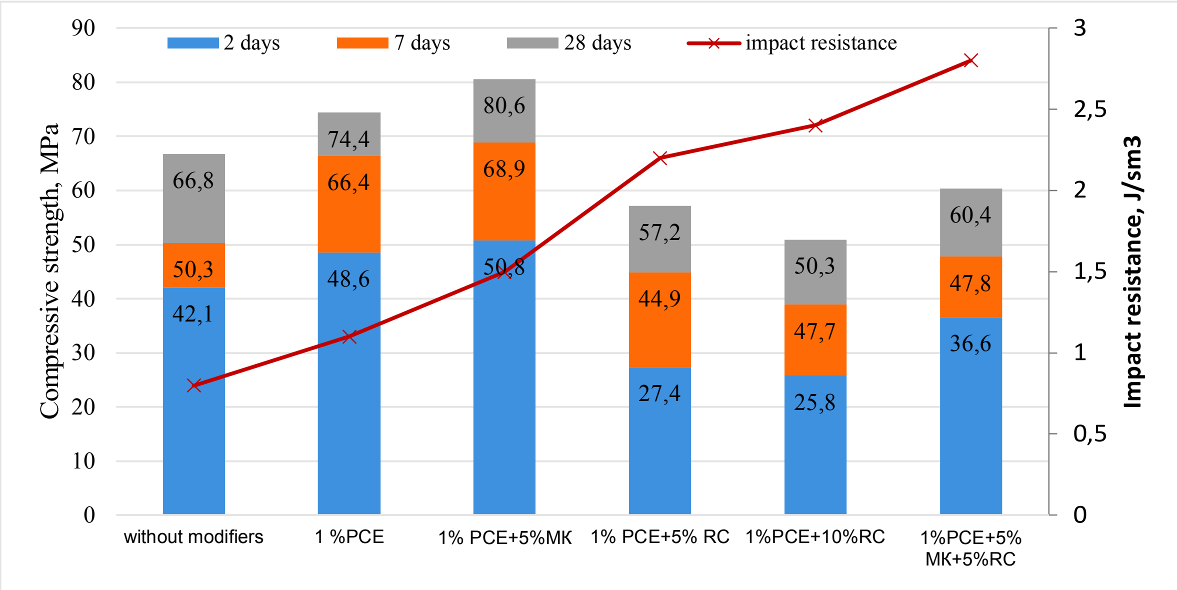

Fig. 2. Strength of modified Portland cement systems

a *b* *c*

Fig. 3. Samples of modified Portland cement systems after testing for impact strength: without rubber (a), with rubber (b, c)

Conclusions

The use of crumb rubber in concrete contributes to the efficient use of resources and the reduction of negative impact on the environment. The influence of rubber crumb on the properties of modified Portland cement systems was investigated. The introduction of crumb rubber does not affect the penetration value in the case of the normal consistency test. The setting time of Portland cement systems, both initial and final, is accelerated with the use of rubber crumb. The compressive strength of paste with rubber crumb decreases sharply compared to control samples (without rubber crumb). The impact strength of rubberized modified Portland cement systems is increasing. The use of recycled tires in modified Portland cement systems creates additional load resistance after reaching failure stresses due to the bridging effect of rubber particles, which provides increased resistance to impact load.

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ВПЛИВ ГУМОВОЇ КРИХТИ НА ВЛАСТИВОСТІ МОДИФІКОВАНИХ ПОРТЛАНДЦЕМЕНТНИХ СИСТЕМ

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Бетон залишається основним матеріалом для різних видів капітального будівництва, що зумовлено його універсальністю та довговічністю. Виробництво та застосування бетону в різних технологіях будівництва зростає щороку, що призводить до надмірного видобування та споживання природної сировини. Вирішення цієї проблеми вбачаємо в площині використання твердих відходів як наповнювачів і заповнювачів у бетоні або пошуку екологічно чистішої сировини.

Більшість продуктів, отриманих із каучуку, після закінчення терміну використання викидають як відходи, закопують на звалищах або спалюють. Для природного розкладання таких матеріалів потрібно багато років, що зумовлено складною зшитою структурою і наявністю добавок, які додають під час виробництва для продовження терміну служби гуми. Використання відпрацьованих шин у вигляді заповнювачів для виробництва інноваційних композитів у будівництві є перспективним екологічно чистим рішенням, що відповідає концепції сталого розвитку та циркулярної економіки.

Використання гуми в модифікованих портландцементних системах пришвидшує процеси раннього структуроутворення. Введення гуми змінює опір руйнуванню цементних систем. У разі введення у систему гуми спостерігалося зменшення міцності, що зумовлено еластичністю гуми. Зразки без гуми виявляють високу механічну стійкість, але характеризуються крихкістю, швидким дробленням і руйнуванням матеріалу після появи тріщини, що призводить до раптового руйнування. Зразки, що містять гумову крихту, демонструють порівняно низьку міцність на стиск, але характеризуються пружною поведінкою. У них спостерігаються повільне фрагментування та повільне руйнування матеріалу після появи тріщин. Портландцементні системи з гумою характеризуються додатковим опором після досягнення напруження руйнування, що пов’язано з мостиковим ефектом частинок гуми.

Ключові слова: гумова крихта; портландцементна система; суперпластифікатор; мікрокремнезем; міцність на стиск; ударна міцність.