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SCIENTIFIC PAPER

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PROPERTIES OF CEMENT BASED COMPOSITE MADE WITH EXPANDED POLYSTYRENE GRAINS AND POLYPROPYLENE FIBERS

This paper deals with the results of experimental research of mortar mixes – composite materials made with Portland cement, expanded polystyrene grains (EPS) and polypropylene fibers. In some series of mortar specimens, ordinary sand (0–4 mm) was used as an aggregate, together with expanded polystyrene grains (divided in two fractions: 0–2 mm and 2–4 mm). By varying the content of the component materials, the mortar mix design was optimized in order to improve certain mechanical properties such as: flexural strength, tensile strength, modulus of elasticity and freeze–thaw durability. The experimental results obtained from the chosen type of mortar indicate that this composite can be successfully used as an advanced structural material with satisfactory technical and economical properties.

Nowadays, lightweight cement based composites – mortar and concrete are increasingly applied in different fields particularly as thermal and acoustic insulation in precast elements (slabs, walls, partitions, etc.). The basic properties of these materials are: low density, relatively high thermal and acoustic parameters and adequate mechanical characteristics. The best way to achieve the above mentioned material properties is to make cement composites using expanded polystyrene (EPS) grains as the aggregate and polypropylene fibers for micro–reinforcement [1]. In order to improve the mechanical properties of these composites, ordinary sand is also used as the aggregate. Figure 1 shows several different types of lightweight cement composites.

Figure 1. Different types of lightweight cement based composites

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The main goal of experimental work was to determin the basic characteristics of lightweight cement based composites and some possibilities of their practical application.

EXPERIMENTAL WORK

Component materials

The mortar mixes contained following component materials:

- Portland cement (with addition of slag) type PC 15 z 45S ''Beočin'';
- EPS grains (divided into 2 fractions: 0–2 mm and 2–4 mm);
- EPS admixture;
- Polypropylene fibers (length 30 mm, diameter 0.2 mm);
- Ordinary sand (grain size 0–4 mm) – used in series 1, 2, 3 and 6;
- Water.

The used aggregate was a mixture of ordinary sand and EPS grains. The granulometric curves of the sand and both EPS fractions (0–2 and 2–4 mm) are presented in Figure 2 [2].

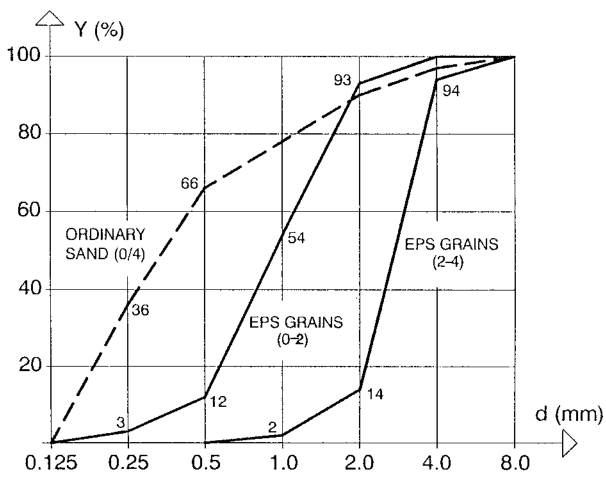

Figure 2. Granulometric curves of the used aggregates

The quantity of cement used in fiber reinforced composites usually exceeds 500 kg/m^3, which is about 10% more than in the case of ordinary mortar and concrete mixes [3]. According to this, the amount of cement adopted for this investigation varied between 500 and 800 kg/m^3.

The following important characteristics of the EPS grains were determined:

	Fraction 0–2 mm	Fraction 2–4 mm
Bulk density	25 kg/m^3	15 kg/m^3
Porosity between grains	42 %	44 %

The EPS admixture is a commercial product made in the form of a powder ready to be used according to the manufacturer's recommendation (quantity of 25–50 kg/m^3). This admixture is applied in order to prevent the expanded polystyrene grains from floating on the surface of the fresh mortar. The specific density of EPS admixture amounts to 2000 kg/m^3.

The usual amount of polypropylene fibers in such mixes varies between 0.1–0.6% (volume fraction). Bearing this in mind, the adopted range of used fibers was 6.6–11.5 kg/m^3. The density of the applied fibers was 910 kg/m^3, the tensile strength 36 MPa, the modulus of elasticity 3.5 GPa and the elongation 25% [4, 5].

Mortar mix design

The mortar mix design was calculated using the well-known relation:

$$\frac{m_c}{\gamma_c}+\frac{m_w}{\gamma_w}+\frac{m_s}{\gamma_s}+\frac{m_{eps}}{\gamma_{eps}}+\frac{m_{ad}}{\gamma_{ad}}+\frac{m_{pf}}{\gamma_{pf}}+v_p=1$$

The symbols used in the upper relation [6] stand for:

m = mass of material (in kg);

γ = specific density of material (in kg/m3);

v_p = volumen of entrained air (in m^3);

index c = cement; index s = sand;

index ad = eps admixture; index w = water;

index eps = expanded polystyrene;

index pf = polypropylene fibers.

Figure 3. EPS grains

In order to achieve the optimum "packing" of the aggregate, the relation 3:1 between the bigger and smaller fraction of EPS grains was adopted, according to the authors' previous investigations [7, 8]. Figure 3 shows the mixture of these EPS grains.

Properties of fresh mortar

In order to optimize the mortar mix, six different types of mortar were made by varying the quantities of certain component materials. The basic parameters concerning these six types of mortar are shown in Table 1.

Table 1. Basic characteristics of the fresh mortar mixes (Series 1–6)

Component materials (kg/m^3)	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Cement	550	600	680	800	660	550
Ordinary Sand	650	500	370	–	–	330
EPS (0–2 mm)	2.25	2.50	2.82	3.30	3.75	4.00
EPS (2–4 mm)	6.80	7.50	8.45	10.00	11.25	12.00
EPS admixture	28.0	30.0	35.0	41.6	47.0	28.0
Polyprop. fibers	6.80	7.70	8.45	10.00	11.50	6.60
Water	240	240	238	260	240	200
Water/Cement Ratio	0.436	0.400	0.350	0.325	0.364	0.364
Density of Fresh mortar (kg/m^3)	1484	1390	1345	1125	974	1130

RESULTS OF EXPERIMENTAL RESEARCH

The mortar samples (dimensions: 4(4(16 cm) were cured in humid conditions (humidity ≥ 90%) for the first 24 hours, and after that in water (temperature ≈ 20°C). Figure 4 shows a prismatic specimen after testing of the basic physical and mechanical properties of hardened mortar (density, flexural strength and compressive strength).

The testing was conducted at the age of 7 days and 28 days. The obtained results are presented in Table 2.

From these results, it can be concluded that mortar N° 6 represents the optimum composite, satisfying the technical and economical demands for application. Bearing this in mind, mortar N° 6 was chosen as a representative and several additional tests were performed. Namely, the modulus of elasticity, shrinkage and freeze–thaw resistance were measured using specimens of this type.

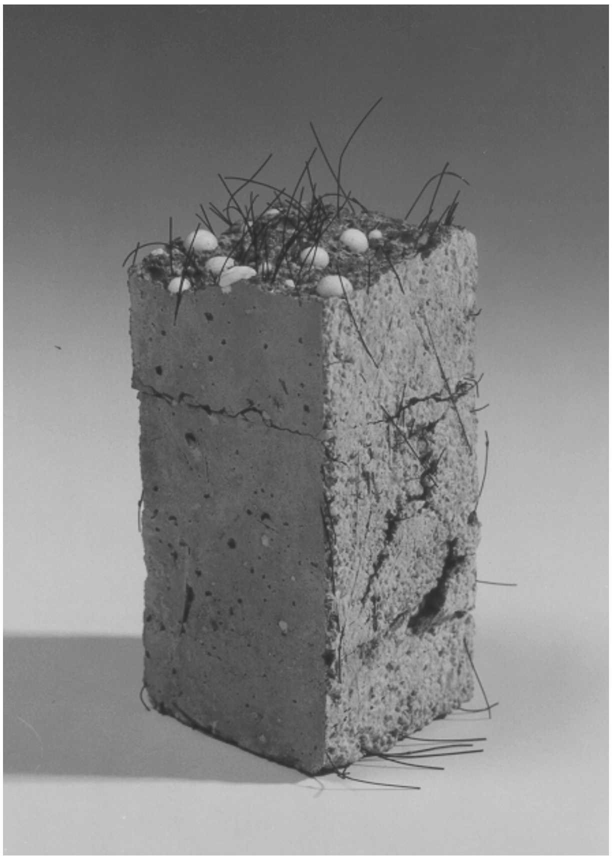

Figure 4. Mortar speciment after testing

The shrinkage test showed a final dilatation of 0.2 mm/m which is acceptable for practical application [9].

After 100 freeze–thaw cycles, is was concluded that the tested mortar had satisfactory frost resistance, which means that specimens subjected to freezing had at least 75% of the compressive strength of reference specimens. The obtained results were as follows:

– after 50 cycles: compressive strength
with freezing = = 7.7 MPa (78.6 %)   without freezing = = 9.8 MPa

– after 100 cycles: compressive strength
with freezing = = 9.1 MPa (79.8 %)   without freezing = = 11.4 MPa

The mortar specimens had a statical modulus of elasticity of E = 6 600 MPa. On the other hand, the dynamic modulus of elasticity had a value of E_{dyn} = 6 800 MPa. Figure 5 shows the stress–strain diagram of the tested mortar.

Finally the content of cement and the quantity of polypropylene fibers quantity was optimized in order to achieve the maximal flexural strength of hardened mortar after 28 days (f_{zs}). The optimization curves are presented in Figure 6.

CONCLUSIONS

According to the results presented in Table 2 mortar type N° 6 was chosen to be the optimal. In addition to mortar N° 6, types N° 4 and N° 5 also satisfied the necessary technical demands, but they were rejected as economically unacceptable (because of the high cement and fiber consumption). This means that a relatively low quantity of cement (550 kg/m^3) and a low fiber content (6.6 kg/m^3) provide satisfactory physical and mechanical properties: density (1100 kg/m^3), compressive strength (7.73 MPa), and ratio f_{fs}/f_{cs} (0.33). During the research, the coefficient of thermal

Table 2. Basic characteristics of hardened mortar (Types 1–6)

Type N°	1	2	3	4	5	6
Age: 7 days						
Density (kg/m^3)	1452	1372	1328	1105	957	1122
Flexural strength f_{fs} (MPa)	2.70	3.14	3.42	3.75	2.80	2.00
Compressive strength f_{cs} (MPa)	10.84	9.98	11.94	8.95	4.02	6.40
f_{fs}/f_{cs}	0.25	0.31	0.29	0.42	0.69	0.31
Age: 28 days						
Density (kg/m^3)	1438	1350	1300	1085	945	1100
Flexural strength f_{fs} (MPa)	2.90	3.17	3.67	4.04	3.11	2.52
Compressive strength f_{cs} (MPa)	14.62	11.12	13.63	10.88	6.22	7.73
f_{fs}/f_{cs}	0.20	0.28	0.27	0.37	0.50	0.33

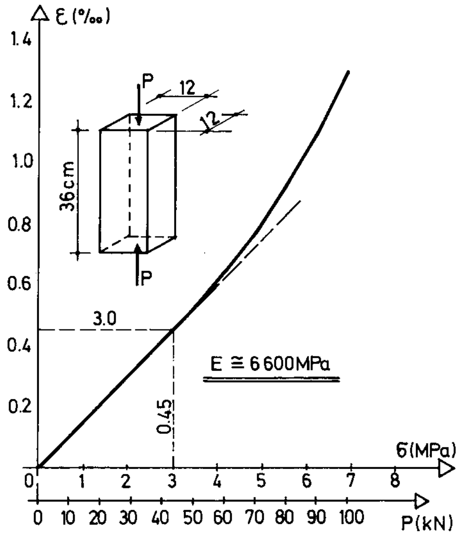

Figure 5. Stress–strain diagram (σ–ε) of mortar N° 6

conductivity (λ) was not measured, but considering the relatively low value of the density (1100 kg/m^3) in can be assumed that this coefficient should be satisfactory, too.

The experimental results obtained during testing of the chosen type of mortar (N° 6) indicate that this composite can be successfully used as an advanced material with acceptable technical and economical properties, particularly as thermal and acoustic insulation in precast elements.

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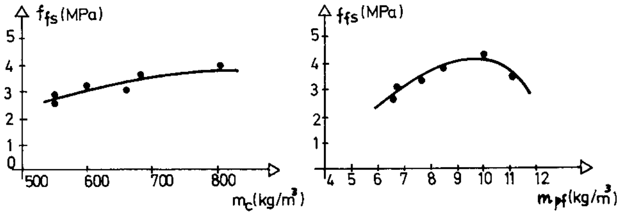

Quantity of cement (kg/m^3) Quantity of fibers (kg/m^3)

Figure 6. Optimization of the content of cement and fibers

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IZVOD

SVOJSTVA KOMPOZITA NA BAZI CEMENTA SPRAVLJENIH SA POLIPROPILENSKIM VLAKNIMA I GRANULAMA EKSPANDIRANOG POLISTIRENA

(Naučni rad)

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U radu se prikazuju rezultati sopstvenih eksperimentalnih ispitivanja sprovedenih na lakim malterima – kompozitima spravljenim na bazi portland cementa, granula ekspandiranog polistirena i polipropilenskih vlakana. Sve mešavine kompozita sadržale su i specijalan dodatak koji se koristi u cilju sprečavanja pojave isplivavanja granula stiropora. Kod izvesnih serija maltera–kompozita bio je prisutan agregat – pesak, krupnoće zrna od 0–4 mm. Upotrebljene granule stiropora bile su separisane u dve frakcije: 0–2 mm i 2–4 mm. Količina cementa kod navedenih kompozita kretala se u opsegu od 500–800 kg/m^3, a vodocementni faktor iznosio je 0,35–0,45.
Variranjem sadržaja komponenata izvršena je optimizacija sastava radi poboljšanja izvesnih mehaničkih svojstava kao što su: čvrstoća pri zatezanju, čvrstoća pri savijanju, modul elastičnosti i otpornost na dejstvo mraza. Pri ovome, osnovni cilj predmetnih ispitivanja bio je usmeren ka izboru kompozita sa najpovoljnijim karakteristikama potrebnim za proizvodnju lakih montažnih elemenata. Dobijeni eksperimentalni rezultati pokazuju da odabrani tip maltera – kompozita može da se uspešno koristi kao savremen termoizolacioni i konstrukcioni materijal koji je pogodan u tehničkom i ekonomskom smislu.

Ključne reči: kompozit • malter • polipropilenska vlakna • ekspandirani polistiren • mehanička svojstva • termoizolacija •
Key words: Composite • Mortar • polypropylene fibers • Expanded polystyrene • Mechanical properties • Thermo–insulation •