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Characterization of lightweight ferrocement panels containing expanded perlite-based mortar

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HIGHLIGHTS

- The strength and deflection of lightweight ferrocement panels were investigated.
- The period until first cracking decreased as the number of mesh layers increased.
- The ultimate strength of ferrocement panels improved as the cement ratio increased.
- Expanded perlite led to a reduction in the unit weight and strength of the mortar.
- Expanded perlite caused an increment in the pore size of the mortar matrix.

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ABSTRACT

In this study, the deflection and cracking of lightweight ferrocement panels (LFPs) containing expanded perlite based mortar (EPBM) was investigated. For this purpose, twelve LFPs with one or two layers of wire mesh were produced with two different mix designs (M1, M2), and LFPs were subjected to four point loading flexural test. In this test, the first cracking load and ultimate load of LFPs varied depending on the number of the layers and types of wire mesh used in the LFP. The optimum LFP was determined as LFP-D1 containing EPBM2. In addition; compressive and flexural tests were conducted on EPBM specimens, and the characteristics of EPBM were investigated by SEM/EDS, XRD, TG/DTA and BET analysis. It was observed that the compressive strength of EPBM improved as the cement ratio increased. The use of expanded perlite (EP) as aggregate expedited the start of micropore formation in mortar. This led to a decrease in the strength and unit weight of EPBM.

1. Introduction

Ferrocement panel is a thin walled mortar that is produced by cement, sand, water and layers of wire mesh. It is also determined as reinforced mortar used in producing elements which requires small thickness, high durability and resilience [1–4]. The development of lightweight structural elements in construction is important due to their adequate strength, lower weight, and thermal insulation [5–8]. Parameters such as cement type and dosage, wire mesh strength and geometry, aggregate, and number of wire mesh layers determine the mechanical properties of ferrocement. These parameters also affect the ductility, cracking and resilience of ferrocement. LFP mostly consists of sandwich elements, and is used in the construction of roofs, floors, slabs and walls because of their low cost, lightweight character, durability and resistance [9–12]. Sandwich elements are structural members made of skins separated by a lightweight core [3,10]. The technique of lightweight sandwich composite element leads to new areas in the design of sandwich construction technology [3]. Ferrocement has adequate strength, toughness, lightness and durability compared to other thin construction materials [11–14]. Studies conducted on ferrocement have shown great improvement on service and ultimate tensile crack behavior of composite structures [15–20].

The close spacing of wire mesh layers improves ductility, and leads to crack resistance in ferrocement [21]. Thus, ferrocement is usually applied on low cost roofing and flooring, on short spans and for the repair of deteriorated structures [22–25]. The ferrocement technology has been found to be attractive due to its basic raw materials, fabrication in any shape, and durability [26]. In comparison to reinforced concrete, ferrocement has better performance on modulus of rupture, tensile strength and anti-cracking properties [27]. High specific surface of wire meshes leads to large

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bond forces within the mortar matrix, thus both the crack spacing and crack width become smaller [27,28].

Perlite is an amorphous volcanic glass, which is obtained from crude perlite rock by heating and contains mostly silicon dioxide and alumina [6–8]. It occurs naturally and expands greatly when heated. Since ferrocement mortars require lightweight properties, perlite could be suitable as an economical and lightweight material to replace aggregate or pozzolana [7,8]. The countless numbers of micropores in perlite ensure lightweight properties while providing an advantage in terms of thermal and sound insulating [29]. Perlite is generally used in construction materials, agriculture, and the medical and chemical industries, and it has been used within constructional elements such as brick, plaster, pipes, walls and floor blocks [29].

The aim of this study was to investigate the structural behavior of LFPs under flexural loading and examine the effect of variables on the ultimate strength and central deflection of the LFPs. The variables were the mesh type and number, cement ratio, ultimate strength and spacing of wire mesh layers. The performance of LFPs was investigated according to the cracking, ultimate load and load–strain. In this study, the experimental program involves the production of LFPs, measurement of deflection, characterization of EPBM by SEM/EDS, XRD, BET and TG/DTA analysis.

2. Materials and methods

2.1. Mix design of EPBM

The matrix of ferrocement is mortar that consists of cement, sand, water and optionally an admixture. In this study, LFPs were produced with two different mix designs (M1, M2) of EPBM using CEM I 42.5R Portland cement, fine grained sand, EP, admixture, ordinary drinking water and three types of wire meshes. In mortar production, water/cement ratio was 0.50 and the properties of sand, cement, perlite and admixture are shown in Tables 1–5. EP with grain size of 0–2 mm and bulk density of 60 kg/m^3 was used as aggregate to reduce the weight of LFPs. Admixture was used as mortar plasticizer with content of 0.5 kg/m^3 to ensure workability. Thus, the mortar was easily placed in molds despite the small aperture of square wire mesh.

2.2. Characterization of wire meshes

The square woven wire mesh and two types of hexagonal woven wire meshes made of stainless steel were used in LFPs. A sandwich formed structure was prepared by using one or two layers of wire mesh.

Table 1
Properties of sand.

Properties	Value
Specific gravity	2.65
Water absorption	% 1.2
Bulk density	1550 kg/m^3
Grain size	0–2 mm

Table 2
Properties of CEM I 42.5R Portland cement.

Specific weight (g/cm^3)	3.16
Initial setting (min)	161
Final setting (min)	204
Specific surface (cm^2/g)	3826
Bulk density (g/l)	995
Soundness (mm)	1
2 days (MPa)	28.2
28 days (MPa)	57
SiO_3 (%)	2.85
MgO (%)	2.30
Loss on ignition (%)	1.78
Insoluble residue (%)	0.64
Cl^- (%)	0.01<
Alkali equivalent (%)	0.44
Free lime (%)	1.27

Table 3
Physical properties of perlite.

Color	White
Melting point	1250–1350 °C
Specific heat	0.20 kcal/kg °C
Max. free moisture	% 0.50
Loss on ignition	% 3–5
Softening point	900–1100 °C
Specific gravity	2.2–2.4
pH	6.5–8.0

Table 4
Chemical properties of perlite.

Compound	%
SiO_2	70.0–75.0
Al_2O_3	12.0–15.0
Na_2O	3.0–4.0
K_2O	3.0–5.0
Fe_2O_3	0.5–2.0
CaO	0.5–1.5
MgO	0.2–0.7

Table 5
Properties of admixture.

Density	1.045 ± 0.005 kg/l (+20 °C)
Soluble Cl^-	Max% 0.1
pH	9–10.5
Freezing point	−8 °C

Table 6
EPBM mix ratios by weight.

Materials	M1 (%)	M2 (%)
Sand	48	32
Cement	34	44
Expanded perlite (EP)	1	2
Water	17	22

In this study, the square wire mesh used in the production of LFPs is named type 1, and has an aperture of 3 mm and a wire diameter of 1 mm. The yield strength of wire used in the fabric is 450 MPa. The square wire mesh has higher yield strength compared to the two types of hexagonal wire meshes used in this study. It also has a flat surface and long service life and is widely used in construction, industry, and agriculture. Although square meshes are more expensive and need more labor compared to hexagonal meshes, they led to better results on LFPs at flexural loading tests.

The hexagonal wire meshes used in this study are named type 2 and type 3, and they have mesh sizes of 12.7 mm and 25.4 mm, respectively. In addition, they both have wire diameters of 0.7 mm, and the yield strength of wire used in the fabric was 310 MPa. The hexagonal wire meshes are mostly used in poultry and animal housing and fencing, and they are structurally less efficient than the square wire mesh because of un-oriented wires in principal stress directions [25].

2.3. Design and testing of LFPs

In this study, twelve LFPs with sizes of 50 × 300 × 900 mm were produced using special molds. Molds were prepared by wooden frameworks which had different measurements such as 15 mm, 20 mm and 25 mm to obtain difference in thickness between layers. Depending on the composition detail of LFP, two or three frameworks were combined by nailing to form the molds. To produce the LFP, the casting was done gradually by positioning wire meshes at required levels between the frameworks, and a vibrating table was used for 30 s in each casting. The optimum mix ratio was determined after several trials due to the workability of fresh EPBM and compressive strength of hardened EPBM, as shown in Table 6.

The LFPs were covered with sheets for 24 h to ensure moisture. After 24 h from casting, the specimens were kept in a curing room at a temperature of 21 °C and humidity of 98% for 28 days to avoid plastic shrinking. The LFPs were given a serial name and number according to the composition of wire mesh, number of layers,