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Digital image correlation to characterize the flexural behavior of lightweight ferrocement slab panels

Amirhossein Madadi [a,*], Hamid Eskandari-Naddaf [a,*], Rasoul Shadnia [a], Lianyang Zhang [b]

[a] Department of Civil Engineering, Hakim Sabzevari University, Sabzevar, Iran
[b] Department of Civil and Architectural Engineering and Mechanics, University of Arizona,Tucson, AZ, USA

HIGHLIGHTS

- DIC technique is used for the first time on perlite-contained FSPs.
- Effect of volume fraction of reinforcement and expanded perlite on mechanical properties of FSPs is investigated.
- DIC technique can appropriately monitor flexural behavior, crack properties and ductility of FSPs.
- Effect of expanded perlite on porosity of ferrocement mortar is evaluated.

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ABSTRACT

Digital image correlation (DIC) is a relatively new technique for measuring whole-field displacements and strains. In this study, the DIC technique was used to characterize the flexural behavior of ferrocement slab panels containing expanded perlite lightweight aggregate (LWA). Specifically, 12 slab panels containing different number of expanded rib lath layers (1, 2, and 3) and different amount of expanded perlite LWA (55, 35, 15, and 0 vol%) were produced and subjected to three-point loading flexural test. Then the load-deflection curves obtained from displacement sensors were used to verify the DIC results. Afterward, the DIC results were used to evaluate the cracking behavior of all specimens. Scanning electron microscopy (SEM) imaging along with energy dispersive spectroscopy (EDS) analysis was also performed to characterize the microstructure of the mortar of various mixture designs. As expected, the DIC results are in close agreement with those obtained from displacement sensors. The DIC results indicate that the flexural behavior of lightweight ferrocement slab panels is influenced by the number of expanded rib lath layers. The DIC results also show that, although the load bearing capacity of the slab panels were enhanced by increasing the number of expanded rib lath layers, the specimens containing two layers of expanded rib lath has the smallest crack width. The results of the SEM imaging indicate that the increased amount of expanded perlite LWA has resulted in increased porosity (95–380%) and thus decreased density (18–37%) of the lightweight ferrocement mortar.

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1. Introduction

Ferrocement panel is a thin slab reinforced by layers of mesh and used to produce thin structures with high strength and flexibility [1,2]. The characteristics of the ferrocement slab panel heavily depend on numerous parameters such as cement type, dosage of cement and aggregate, wire mesh strength, geometry and number of layers [3–7]. For example, closer placement and distribution of mesh layers reduces the crack spacing and width in the ferrocement panels [8]. In addition, ferrocement slab panels show better performance regarding the modulus of rupture, flexural strength, and cracking behavior compared to reinforced concrete slabs [9,10].

Although ferrocement productions are typically suggested as lightweight structures [11,12], there is still a need to utilize the alternative building materials like lightweight aggregates (LWAs) as partial replacement of sand. LWAs are available in abundance worldwide and can be utilized in producing cementitious materials in a wide range of suitable strength values and with reduced weight [13–15]. One of these LWAs is expanded perlite, which

* Corresponding authors.
E-mail addresses: Madadihsu@yahoo.com (A. Madadi), Hamidiisc@yahoo.com (H. Eskandari-Naddaf).

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has attracted significant attention in recent years. Perlite is a glassy volcanic rock used to form crude perlite rock and is easily accessible worldwide. It contains mostly silica and alumina [16,17] and expands naturally with exposure to heat. Previous researches have shown that the structure in which the expanded perlite LWA is utilized has some valuable technical and economical advantages such as light weight, thermal isolation, freeze-thaw resistance and low cost [14,18–21]. Therefore, expanded perlite is suitable to be employed as a partial replacement of sand in the construction of cementitious materials like ferrocement elements [22,23]. Due to this, the mechanical behavior of such structures has been evaluated in several studies [24–27]. For example, Işıkdağ [27] studied the effect of expanded perlite on the flexural behavior of ferrocement panels and the results indicate that an increase in the volume content of expanded perlite leads to decrease of the ultimate strength and increase of the crack width of the specimens.

Although much research has been conducted on ferrocement slab panels, more detailed studies are required in order to better understand their behavior at various conditions. Digital image correlation (DIC) is a powerful non-contact photomechanical technique for full-field measurement of surface motion parameters in various materials. The method is based on the comparison of images of the specimen surface before and after loading (known as the reference and deformed images, respectively). DIC can be used to assess the deformation field by comparing and matching the selected images using correlation algorithms by numerical differentiation [28,29]. To date, various studies have been conducted to investigate the capability of the DIC method in cement and concrete materials. For instance, this approach was successfully applied to evaluate the behavior of concrete beams [30–32] and slabs [33] in terms of crack pattern and propagation, damage and fracture mechanics. Recently, the DIC method was applied to assess the compressive behavior of lightweight ferrocement mortar containing expanded perlite and clay LWAs, where the results have suggested the accuracy and capability of this method in such material characteristics determination [34]. Due to the various advantages of the DIC method, including high accuracy and precision, non-contact, prompt analysis of data and wide range of measurements, it can be superior to traditional strain and deformation measurement systems, especially in the cases of cementitious materials by observation of large non-uniform deformation.

With reference to the increasing demand for the development of lightweight, cost effective and sustainable housing and with respect to the current development in the field of characterization of ferrocement slab panels, very little research has been conducted to investigate the structural response and cracking behavior of ferrocement slab panels incorporating LWAs, particularly using capable methods like DIC technique. Therefore, this paper aims to investigate the flexural behavior of ferrocement slab panels containing expanded perlite LWA using the DIC technique. To this end, 12 slab panels containing different layers of expanded rib lath and different amount of expanded perlite LWA were constructed. Then, three-point flexural tests and imaging analyses were conducted simultaneously on the specimens. The results were further analyzed in terms of load-deflection curves. Finally, the cracking behavior of all specimens was evaluated with respect to the flexural tests and DIC results.

2. Materials

Ordinary Portland cement (OPC), sand, expanded perlite, expanded rib lath, and rebars were used to produce the slab panels. The OPC (CEM II 52.5 R) procured from the Torbat Cement Plant was used in this study. The physical properties and chemical composition of the utilized cement are summarized in Tables 1 and 2, respectively.

The normal sand with a specific weight of 2600 kg/m^3 and a maximum nominal size of 4.75 mm was used as fine aggregate in the production of ferrocement mortar. The gradation of sand was quantified following ASTM C 778-06 [35].

Perlite mainly contains silica and alumina with a volume content of 70–75% and 12–16%, respectively, and other minor components including potassium oxide, sodium oxide, manganese oxide, titan oxide, ferro oxide, and sulfide [36]. The physical properties and chemical composition of the expanded perlite LWA used in this study are summarized in Table 3. The expanded perlite LWA particles are also shown in Fig. 1(a).

Natural drinking water was used in all mixture designs to produce the specimens.

The expanded rib lath layers made from galvanized steel with the weight and size of 1.84 kg/m^2 and 100×600 cm^2, respectively, were used to reinforce the slab panels. The expanded rib lath has a rib height of 10 mm and a mean wire diameter of 0.8 mm. Two longitudinal rebars with a diameter of 10 mm were also used at the edges of each slab panel. The proposed rebars were wire-tied every 15 cm to the corresponding layers of expanded rib lath (Fig. 1 (b)). The specifications of the reinforcement system utilized in ferrocement slab panels are represented in Table 4.

Fig. 2 represents the schematic view of the placement of reinforcement system in ferrocement slab panels. As seen, the rebar provides a space between the first and second layers. In order to improve the tensile capacity of the reinforcement system, the third layer was placed under the first layer.

3. Methods

3.1. Design and construction of the slab panels

Four different mixture designs, 55, 35, 15, and 0 vol% of expanded perlite LWA, were considered in this study (Table 5). A water/cement ratio of 0.5 was used in all mixtures. All materials were mixed using a laboratory mixer with a vertical rotation axis. To make a slab panel, first a 1 cm-thick layer of mortar was applied as the initial cover and permitted to achieve some initial setting. Then the second layer of mortar was applied after the placement of the reinforcement system. The construction process was ended with smoothing the entire surface of each slab panel. In order to evaluate the effect of the number of reinforcing layers on the flexural behavior of the slab panels, each mixture design was applied in the construction of the slab panels with various number of expanded rib lath layers, i.e. one, two, and three. Twelve lightweight ferrocement slab panels with the dimension of 100×60 cm^2 and the thickness of 4 cm were thus constructed. The details of the ferrocement panels are shown in Table 6, where a serial name is given to each specimen according to its related mixture design and number of expanded rib lath layers. The volume fraction of reinforcement was calculated according to the ACI 549.1R-93 [37]. Finally, the panel specimens were placed outside at the ambient temperature for curing before scheduled tests.

3.2. Test procedures

To investigate the flexural behavior of the slab panels, a three-point loading method was utilized according to ASTM C78 [38] by means of a closed-loop servo-controlled universal testing machine at a controlled displacement rate of 5 mm/min. Simultaneously, the DIC procedures were conducted on the test specimens. The DIC is an imaging technique for measuring the whole-field displacements and strains [39,40]. The technique is based on the frequent images of a specimen surface pattern before loading (as a reference) and during loading and deformation of the specimen. Light intensity distribution along with a random scattering is required for preparing the specimen surface. Some errors might be included in the process of recording the surface motions, which can be reduced by making the sample surface perfectly flat and parallel with the camera lens and adjusting the imaging parameters. In this study, in order to eliminate probable vibration caused by the testing machine, complete video imaging was captured from each slab panel during loading using a camera with a resolution of

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