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Experimental investigation of in-plane shear behaviour of grey clay brick masonry panels strengthened with SRG

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ABSTRACT

Textile reinforced mortar (TRM) composites have received much attention as they are a superior sustainable material and physically compatible with masonry and historical structures. Among the numerous materials used in TRM composites, steel reinforced grout (SRG) which is produced with high strength steel cords embedded in a cementitious mortar matrix, demonstrates exceptional mechanical performance at a relatively low cost. In this paper, an experimental investigation is carried out on their use as in-plane shear reinforcement of masonry wall panels. The masonry panels are constructed with grey clay bricks (GCBs), a unique construction material widely used in traditional Chinese architecture. Diagonal compression tests are carried out on two unreinforced panels and six strengthened panels with different reinforcement configurations. The contribution of the SRG system to strengthening is assessed by examining the shear stiffness, shear strength, ductility under shear, and changes in failure mechanisms. A comparative analysis is carried out by using results from the previous literature, and the analytical methodologies and the practical use of the SRG system are also discussed.

1. Introduction

Grey clay bricks (GCBs) are a unique Chinese construction material, and their use was especially prevalent in the southern part of China. They were widely used in traditional Chinese architecture until the 1950 s and then gradually replaced by other modern construction materials (Fig. 1a) [1–3]. In China, GCBs were fired in traditional brick kilns with a roof for water injection, which differs from Roman brick kilns which generally have an opening at the top so that the clay can be fully oxidized after firing. As water is injected into the roof during firing, the hypoxic environment of the kiln results in the blue-grey colour of the bricks [2]. However, most of the masonry constructions that use GCBs are not in compliance with modern design codes. Moreover, deterioration of these brick masonry constructions caused by either environmental factors or past loading events poses potential risks to safety. Therefore, there is a real need for relevant intervention technology that reinforces these masonry constructions. However, existing solutions are lacking; for instance, a relatively new strengthening/retrofitting technique for externally bonding fibre reinforced polymer (FRP) composites by directly applying epoxy resin to glue the FRP composites onto a structure shows poor thermal performance and incompatibility with old masonry substrates. Recently, a novel textile composite has emerged, which is embedded in a mortar matrix. This composite has received much attention because it is considered to be a sustainable solution for strengthening historical masonry structures. In the literature, these novel textile composites are referred to as fabric reinforced cementitious matrix (FRCM), textile reinforced concrete (TRC), or textile reinforced mortar (TRM) [4] composites, of which TRM will be the term used in this study. Among the various types of materials used in TRM, steel reinforced grout (SRG) which is produced with high strength steel cords embedded in a mortar matrix, demonstrates exceptional mechanical performance at a relatively low cost [5–11].

There are many studies in the extant literature on how externally bonded TRM composites improve the structural behaviour of unreinforced masonry (URM) panels. For instance, Prota et al. [12], Parisi et al. [13] Balsamo et al. [14], Faella et al. [15] and Marcari et al. [16] carried out a series of diagonal compression tests on tuff masonry panels to examine the strengthening effectiveness of different types of TRM composites, with respect to different textile and mortar matrixes. The results showed significantly enhanced shear strength and shear ductility of the tuff masonry panels. Almeida et al. [17] and Babaeidarabad et al. [18] investigated the ability of carbon based TRM to strengthen hollow or solid clay brick panels under in-plane diagonal monotonic or cyclic loading. Borri et al. [11] carried out a series of diagonal compression tests on solid clay brick panels strengthened with SRG strips. Again, all of the test results showed that TRM (carbon-TRM and SRG) substantially improves both the strength and shear ductility

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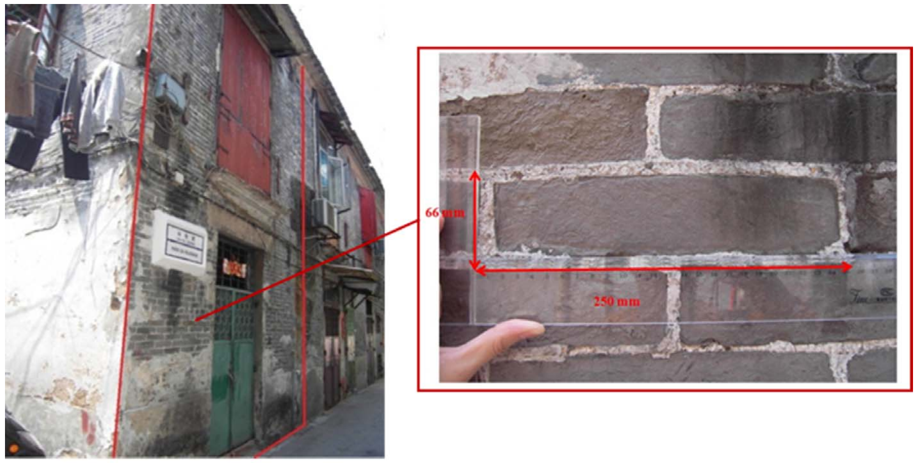

(a)

(b)

Fig. 1. The solid GCBs used in: (a) a typical historical masonry building in Southern China; (b) this study.

of the shear panels.

This study presents an experimental investigation on the in-plane shear behaviour of GCB masonry panels and the strengthening effectiveness of SRG composites. Although the use of SRG systems is already found in field work and research work [11,19–20], a more in-depth understanding is still needed to understand the actual strengthening effectiveness. The strengthening effectiveness with respect to shear stiffness, shear strength, ductility under shear and failure mechanisms due to by the SRG layers with different reinforcement densities and configurations are comprehensively investigated in this study.

2. Material characterization

2.1. Masonry

In this study, solid GCBs are used to build the masonry specimens. The nominal dimensions of these brick units are $220 \times 55 \times 110\,mm^3$ (Fig. 1b). The masonry joints were filled with 10 mm of thick mortar, which was prepared by mixing water, medium grade river sand and Portland cement 32.5 N with a weight ratio of 0.6:3:1, while the mortar used in the mortar matrix of the SRG also comprised the same materials but with a weight ratio of 0.5:2:1.

Compression tests were performed on mortar samples that were 100 cubic mm in size in accordance with ASTM C109M-07 [21] to characterize the compressive strength of the mortar. Splitting tensile tests were performed on cylindrical mortar samples with a diameter of 150 mm and height of 300 mm in accordance with ASTM C496M-11 [22] to characterize the tensile strength of the mortar. Compression tests were also performed on brick specimens that were 40 cubic mm in size (cut from the original solid GCBs) in accordance with BS EN 772-1 [23] to characterize the compressive strength of the bricks. Masonry prisms were constructed with five bricks and underwent compression testing in accordance with CRD-C 643-01 [24]. Approximate height of masonry prism with 10-mm-thick mortar joints was 315 mm. The stress-strain curves for the six masonry prisms are presented in Fig. 2a. Noted that, load and displacement were obtained from the Mechanical Testing Machine, and stress and strain are calculated by dividing the cross-sectional area and the height of the prism, respectively. The start of several cracks in masonry introduced nonlinearity of stress-strain curve. The ultimate failure mode as shown in Fig. 2b is very typical for masonry prism in compression test that the development of vertical cracks (splitting failure) propagate excessively throughout central masonry, while relatively slight damage was observed for the bricks next to machine platens due to the confinement effect. All of the tests were performed after 28 days curing and test results are summarized in Table 1.

2.2. Steel cord reinforced textile and SRG composites

Two different unidirectional ultra-high tensile strength steel cord textiles (Hardwire™) are used as the embedded reinforcements in the cementitious mortar matrix in this study. Each steel cord was made by