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Experimental investigation of brickwork behaviour under shear, compression and flexure

J. Wang *, A. Heath, P. Walker

BRE Centre for Innovative Construction Materials, Department of Architecture and Civil Engineering, University of Bath, Bath, UK

HIGHLIGHTS

- Shear strength increases linearly with normal stress for brick/mortar interface.
- Brickwork wall shows linear behaviour under normal compressive load.
- There is a breaking of the bond and a decrease in friction once failure commences.
- Eurocode 6 is conservative for this masonry type.

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ABSTRACT

This paper presents the basic material performance data for an engineering blue brick and a hydraulic premixed mortar which can be used to validate numerical models. The shear behaviour of brickwork mortar joints under normal compression was studied and the influence of specimen moisture content at the time of testing on strength was investigated. Tests were performed on brickwork walls to study the shear failure under flexure and different shear loading configurations. A linear relationship between the shear strength and applied normal stress has been established, with different parameters defined for the mortar and the brick/mortar interface. The experimental results are compared to Eurocode 6 predictions and theoretical calculations. It is concluded that Eurocode 6 is conservative for this masonry type.

1. Introduction

Masonry's strength, durability and resilience to water and fire have contributed to its widespread and continued use throughout history. The relative ease of construction was particularly important before the development of a highly mechanised construction industry. Today historic masonry structures continue to play an important role in transportation infrastructure; it is estimated that there are over 40,000 masonry arch bridges still in service in UK [1]. The primary function of structural masonry is to carry the compressive loads, although it is also capable of resisting lateral forces derived from wind, earthquake or other applied loading. Masonry can resist relatively high compressive stresses, but it has lower shear and flexural capacity, both of which are a function of applied normal stress. In recent decades, some historic masonry transportation infrastructure, including masonry arch bridges, have exhibited shear failure [2].

The results presented in this paper are from an on-going study to investigate the spandrel wall failure in masonry arch bridges. The present work focuses on the contact behaviour between brick and mortar units under compression, flexure and shear, and the deformations associated with this loading in compression and shear. The mechanical properties of the brick and mortar materials are presented. Triplet shear test were performed to access the behaviour of brick/mortar interface, the cohesion and internal friction angle are then derived from the Mohr–Coulomb criterion. Small masonry walls were constructed and tested under compressive load until failure to determine their stiffness and strength. Two unreinforced masonry walls with dimensions of 665 mm × 740 mm × 102 mm were prepared and tested for shear failure in different loading conditions. Flexural strength tests were performed on masonry walls with planes of failure parallel and perpendicular to the bed joints.

Although some previous research work has been completed investigating the shear wall failure [3] and [4], there is a general scarcity of high quality published data on the mechanical properties of bricks, mortar and masonry under simple loading states that can be used to validate numerical modelling work. Because of the

* Corresponding author. Tel.: +44 1225385943.
E-mail address: J.Wang@bath.ac.uk (J. Wang).

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nature of masonry, deformations are often localised to mortar joints, particularly when high strength engineering bricks are used with weak lime mortars. The measurement methodologies in standard tests can ignore this and measure deformations across a number of mortar joints. In order to validate numerical models, simple tests are required as many real structures contain a combination of loading conditions which complicates validation. The presented data can be used for future numerical studies of traditional masonry structures such as masonry arch bridges and retaining walls.

2. Material testing

The materials used in this study were solid (unperforated) Staffordshire Engineering blue bricks and premixed hydraulic lime mortar. Preliminary laboratory tests were performed on these materials to determine their mechanical properties. These were selected as they are representative of the products used in some masonry arch bridges with a very high strength brick and a weak lime mortar. The fired clay bricks were of standard size (215 mm × 102 mm × 65 mm) supplied by Ibtock Brick Ltd. The following material properties were tested in the lab: compressive and flexural strength, modulus of elasticity, thermal expansion and water absorption.

2.1. Brick properties

Three brick specimens were tested for both vertical and horizontal direction according to the BS EN 771-1 [5] until crushing. The average normalized compressive strength was 145.0 N/mm^2. Four engineering bricks were fully immersed in water to determine 24 h water absorption according to BS EN 772-11 [6]; the average value of 1.5% was obtained. Four brick specimens were also used for the determination of thermal expansion. A temperature range from 20 °C to 100 °C was used and a mechanical strain gauge was used to measure the change in length. The whole test consisted of three cycles until stable results were obtained, each time three readings were taken for each specimen. An average value of 8.22×10^{-6}/°C was found for the thermal expansion coefficient of the bricks, and this is a little higher compared with the value reported by Ross [7], where the thermal expansion coefficient of 90% tested bricks ranged between 5×10^{-6} and 7×10^{-6}/°C.

Four specimens were tested under uniaxial compression load to investigate the elastic properties of the brick. Linearly Variable Differential Transducers (LVDTs) were attached onto the face of units to measure the longitudinal displacement (Fig. 1). Load was applied using a 100 kN compressive machine in three load cycles for two of the specimens with a 0.1 kN/s loading rate, while the other two specimens experienced only one load cycle. Test results (Fig. 2) indicated a linear relationship between the stress and strain in the range of stresses tested up to 15 N/mm^2, an average Young's modulus of 2.5×10^4 N/mm^2 was calculated from thetests.

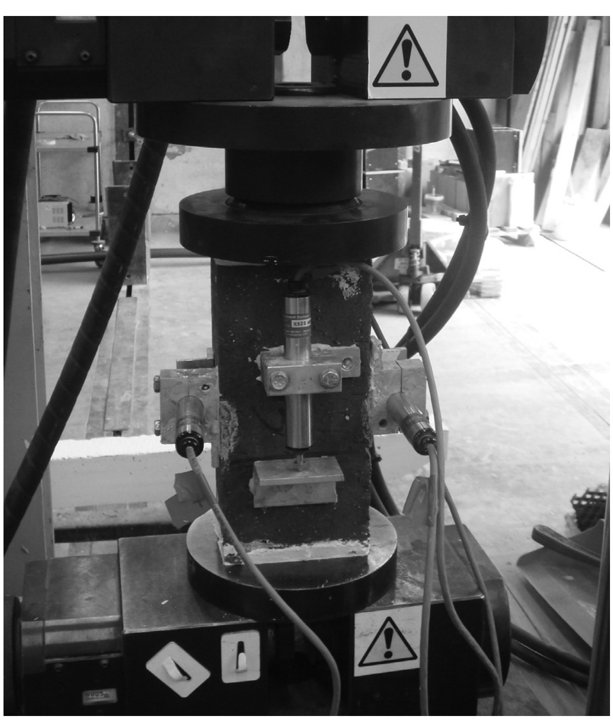

Fig. 1. Experimental set up showing brick strain measurement.

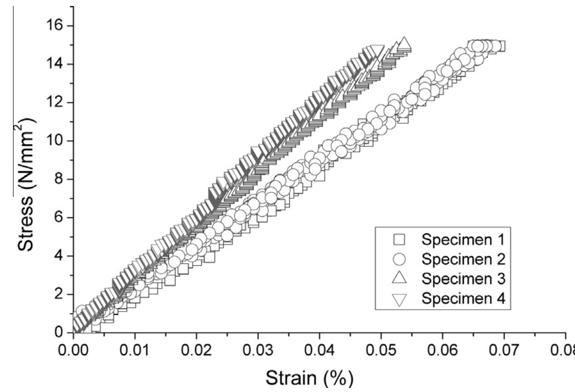

Fig. 2. Stress strain relationship of brick unit.

The flexural resistance ability of the brick unit was studied by three point bending test with a span of 175 mm. Ten specimens were prepared and tested and the flexural strengths ranged from 4.5 to 9.5 N/mm^2, with an average value of 7.2 N/mm^2.

2.2. Mortar tests

The mortar used in the study is premixed hydraulic lime mortar which supplied by Lime Technology Ltd. Advantages of this mortar are its consistent quality, and its long working life. A water/mortar ratio of 0.19 was maintained throughout during the production of the specimens, and it gave a flow value between 170 and 180 mm, the standard value for a mortar of this density, when measured in accordance with BS EN 1015-3 [8]. After 28 days storage in the laboratory conditions (20 °C, 65% relative humidity), the specimens were tested for compressive and flexural strength, modulus of elasticity and also subjected to triaxial tests. The influence of moisture content on the strength of mortar at time of testing was also studied using 91 days old mortar specimens; 91 day strength has become the widely accepted '28 day' equivalent used widely for Portland cement materials.

Three prisms measuring 40 mm × 40 mm × 160 mm were cast in steel moulds for the compressive and flexural strength test in accordance with BS EN 1015-11 [9]. They were tested after 28 days storage under 20 °C and 65% relative humidity. The loading rates for compression and flexural were 0.5 mm/min and 0.2 mm/min respectively. Average compressive and flexural strengths were 0.74 N/mm^2 and 0.44 N/mm^2 respectively. Two prisms (135 mm × 75 mm × 75 mm) were made for testing of elastic properties, the same set up for the bricks were applied to the mortar. The test was carried out under load control with a loading rate of 0.02 kN/s. The stress and relationship is shown in Fig. 3. The stress increases linearly at the beginning and the gradient decreases gradually to zero as it undergoes plastic deformation. The maximum strain during the test for the two specimens was 0.27% and 0.38%, with an average elastic modulus of 700 N/mm^2 based on the linear stage under 0.05% strain.

In addition to the conventional unconfined tests used for mortars, the mortar was subjected to triaxial testing, commonly used to define the strength of soil materials, in order to determine its stiffness, cohesion and frictional properties under

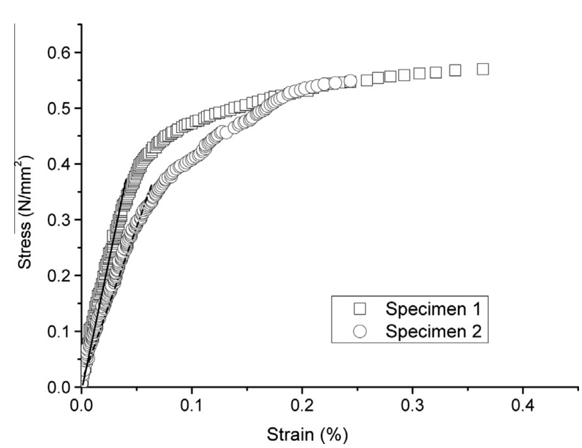

Fig. 3. Stress strain relation of mortar unit.