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Influence of blocks and grout on compressive strength and stiffness of concrete masonry prisms

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HIGHLIGHTS

- Failure modes of grouted and ungrouted masonry prisms are carefully described.
- Impacts of using low strength and high strength blocks are presented.
- The effectiveness of using grout or increasing grout strength is discussed.
- The experimental results complement the existing database related to the subject.
- Response surfaces, contour graphs, and new empirical equations are presented.

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ABSTRACT

This paper aims to evaluate the influence of concrete blocks and grout's properties on the masonry's compressive strength and stiffness. Prisms were produced with blocks and grouts with different strength levels, and mortars with strength of 70% of the blocks' net area strength. It was possible to understand the effects of using low strength and high strength blocks, check the effectiveness of using grout or increasing its strength, and develop response surfaces, contour graphs, and empirical equations. Predictions about the masonry failure mechanisms are proposed for different block and grout combinations. It helps the designer to associate strength and failure mechanisms, prevent or mitigate their undesirable consequences, and eliminate brittle rupture modes. Results complement the existing database and can be used to properly select blocks and grout for masonry structures.

1. Introduction

In the structural masonry construction system, loads are supported and transmitted to the foundation elements through blocks interconnected by mortar, and filled or not by grout and reinforcement. Sajid et al. [1] state that for centuries, this system has been widely used due to abundant availability of basic materials and ease of construction. In order to better understand the structural masonry behavior and improve design guidelines, research focused on the interaction between masonry components is required.

According to Camacho et al. [2], the proper combination of masonry components is indispensable to maximize and optimize the structure's performance. Thanoon et al. [3] emphasize the lack of research related to the complex interaction between block, mortar joint, and grouting material subjected to different loading stages (elastic, inelastic and failure). Bolhassani et al. [4] point out that the masonry structures behavior is difficult to quantify and characterize due to their non-homogeneous and orthotropic nature.

Ramalho and Correa [5] state that concrete blocks are the main responsible for the strength of structural masonry elements. The authors also affirm that the mortar has the basic functions of joining the blocks, transmitting stresses, absorbing small deformations, and preventing water and wind from entering the buildings. Usually composed of sand, cement, lime, and water, the mortar must present satisfactory workability, strength, plasticity, and durability to guarantee a good performance of its functions.

Grout is a fluid mixture of cement, aggregates, and water, used to fill vertical and horizontal voids of masonry elements, in order to increase their strength and stiffness, and embed reinforcing steel bars. Parsekian et al. [6] indicate that the masonry grout presents

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high slump and water-cement ratio. Grout slump must be adjusted, considering the blocks absorption and environmental conditions, such as humidity, temperature, and the void sizes.

According to ABNT NBR 15961-1:2011 [7] (equivalent to TMS MSJC – 2013 [8]), the influence of blocks, mortar, and grout properties on the masonry's structural behavior can be investigated through compression tests of prisms, small walls or walls. For reinforced masonry elements, this code specifies a minimum grout's characteristic compressive strength of 15 MPa. The code also limits the compressive strength of the mortar by at most 70% of the blocks' net area compressive strength.

Ramalho and Correa [5] state that the mortar's compressive strength does not significantly affect masonry walls' compressive strength, except when the mortar's capacity is lower than 40% of the block's compressive strength. Even when largely increasing the mortar's compressive strength, Parsekian et al. [6] verified a small increase in the masonry's compressive strength. These authors state that when the mortar compressive strength is between 70% and 150% of the block's gross area compressive strength, no great influence of the mortar on the prisms' strength is expected.

Zahra and Dhanasekar [9] investigated the influence of the units and mortars' properties on the compressive strength of ungrouted masonry. They found that using higher strength units with smaller mortar joint thickness is the most effective way of increasing the masonry strength. The authors also found that the effect of the mortar strength on the masonry strength is slightly smaller than the effect of the unit strength. Different authors already described the failure mechanism of ungrouted masonry under compression. When using blocks stiffer than mortars, the mortar joints' lateral deformation is restricted by the friction with the blocks. Consequently, the mortar is in a triaxial compression state, while the blocks are in a tension-compression-tension state. The failure mode of the masonry will depend on the mechanical properties of each masonry component and the interaction between them. For example, Santos et al. [10] mentioned failure modes of ungrouted masonry prisms characterized by localized mortar crushing (when using weaker mortars) or transverse block splitting (when using stronger mortars). Alvarenga et al. [11] observed a different failure mode when mortars much stiffer than blocks were used. In this case, the authors verified that the ungrouted masonry fails suddenly by block's crushing.

The effect of grout in masonry's strength and stiffness is still controversial. Huang et al. [12] investigated grouted double H block prisms under axial compression, and concluded that increasing grout compressive strength is effective in improving the grouted prisms' compressive strength. Vintzileou and Miltiadou-Fezans [13] also verified substantial enhancement of the masonry's compressive strength when filling masonry elements with ternary grouts (mixes of cement, pozzolan and hydrated lime) and hydraulic lime-based grouts. These authors also observed that the strength increase was not followed by significant increase in the masonry's stiffness. Similarly, Sarhat and Sherwood [14] developed an analysis of a database of masonry prisms compression tests and concluded that increases of the grout strength result in increases of the prism strength for all of the different block strengths. On the other hand, Parsekian et al. [6] affirm that the use of grouts much stronger than the blocks does not bring benefits to the masonry strength. A different conclusion was also obtained by Koksal et al. [15]: a sharp decrease in the ultimate load capacity of grouted prisms was verified when the grout was weaker than the blocks.

The effect of the mortar strength in the strength of grouted prisms is also controversial. Huang et al. [12] observed that the influence of the mortar strength on the compressive strength of grouted prisms decreased with the enhancement of the grout strength. In contrast, Koksal et al. [18] concluded that mortar has a negligible influence on the compressive strength of grouted prisms.

Different failures modes were observed in grouted prisms under compression. Bolhassani et al. [16] tested ungrouted and grouted prisms under axial compression. The ungrouted prisms failed by vertical tensile splitting cracks initiated at the middle web of the concrete blocks. In the fully grouted prisms, the authors verified a similar failure mode, but characterized by diagonal tensile splitting cracks. Thanoon et al. [3] developed an experimental and numerical analysis of ungrouted and grouted concrete block prisms under axial compression loads. Cracks in the ungrouted prism' blocks initiated when the principal tensile stress reached the equivalent tensile strength. After that, the ungrouted prism suddenly failed in tension. The grouted prism supported higher load, compared to the ungrouted prism. In the grouted prisms, the authors verified that the grout was confined by the blocks' web-shell faces. This situation caused "additional tensile stresses at the web-shell interface, leading to a splitting crack at this junction before material crushing failure or the full utilization of the grout strength".

Mohamad et al. [17] state that standards and codes allow the determination of masonry strength based on methods that consider empirical equations or experimental test results of masonry elements. According to the authors, "both methods do not account for the masonry failure mode and the onset of the nonlinear stress-strain response of the masonry, which provides an assessment of masonry behavior". Then, it is difficult to predict the masonry's strength and deformability based on simplified analytical models, due to its components' heterogeneity and non-linear behavior. Further research is necessary to evaluate the effects of the relative strength of blocks, grout and mortar in the rupture modes of grouted masonry.

Camacho et al. [2] states that many relevant problems in masonry remain unanswered and require further experimental investigation. In recent decades, extensive efforts have been taken in order to find ways to properly predict the ultimate strength of masonry prisms under compression, but high degree of scatter has been found. It happens because many different factors interfere in the structural behavior of masonry prisms, such as quality of workmanship, environmental conditions during production, curing conditions, joint thickness, and physical and mechanical properties of the components. In addition, there is a huge range of block types, with different geometries and sizes. Blocks, mortars, and grouts are produced with the most diverse types of binders and aggregates. Then, a large number of laboratory tests is indispensable to meticulously investigate the influence of all of these factors on the mechanical behavior of the whole structure. Further research is also required in order to complement the database related to the subject.

This work aims to improve the understanding of the effect of blocks and grout's compressive strength on the strength, stiffness, and failure mechanisms of grouted and ungrouted concrete masonry, focusing on that constructed with materials available in the Southeastern region of Minas Gerais, Brazil. The results of this research enhances existing knowledge by adding a wide range of information to the state-of-the-art related to the structural behavior of masonry produced with cement-lime mortar. A 3x4 factorial experiment was developed, in which the following parameters were varied: net area compressive strength of concrete blocks (10.9, 14.8, and 21.2 MPa), and compressive strength of grout (0.0, 15.0, 20.0, and 25.0 MPa). Given the controversial known facts about this topic, the main objective of the study is to characterize masonry components and analyze the response of masonry prisms made of low strength and high strength blocks, and check the effectiveness of using grout or increasing grout strength. Based