Construction and Building Materials 152 (2017) 394–405

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Evaluation of prism and diagonal tension strength of masonry form-block walls reinforced with steel fibers

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HIGHLIGHTS

- A form-block reinforced with steel fiber was introduced and its structural capacity was verified through a series of tests.
- Between long and short fibers, long fiber is more contributable to increase the prism strength and diagonal tension stiffness of form-block wall.

ARTICLE INFO

Article history:
Received 20 April 2017
Received in revised form 25 June 2017
Accepted 28 June 2017

Keywords:
Prism and diagonal tension strength
Form-block
Steel fiber
Grout concrete and mortar
Joint mortar

ABSTRACT

In this paper, the prism and diagonal tension strength of the form-block reinforced with steel fiber developed for improvement of tensile stiffness and crack control performance are evaluated through a series of test. The key parameters of the tests are the steel fiber types that were used for reinforcing block, the strength of concrete and grout mortar as fillers, and the strength of joint mortar. Also, by comparing the design equations in Architectural Institute of Japan (AIJ) Code for block masonry, the performance of the proposed form-block was evaluated.

As a result, when the steel fiber is incorporated into the block, the prism strength increases, and in particular, the long-fiber-reinforced block shows the highest strength. However, the diagonal tension strength of the block wall did not show any significant change even though the steel fiber was incorporated, but the stiffness was improved. In particular, the use of long-fiber-reinforced blocks improves initial tensile stiffness compared with short-fiber-reinforced blocks.

1. Introduction

Masonry walls and concrete blocks have been used for a long time and much research has been conducted on these structures [1–10]. Walls using concrete blocks include those with and without concrete grouting in the hollow of the blocks. The grouted concrete block wall is normally used as a bearing wall with reinforcements. In a reinforced block structure, there is some difficulty in attaining sufficient compaction of the grout concrete if the cavity section inside the block is small. Furthermore, a relatively small cavity section will lead to a small amount of concrete, which may result in poor rebar placing and integration between concrete and rebar. If the block is extremely thin to address such issue, the resistive capacity of the concrete may be degraded during pouring of the concrete, making the blocks susceptible to fracture during the transportation and construction process. Therefore, the size of the hollow section should be determined based on a comprehensive review of the constructability and the required strength.

A form block with an optimized dimension was recently developed [11]. It offers convenience in building construction and seismic retrofit. Form blocks have been widely used in the construction of new buildings or for seismic retrofit in Japan. A form block has a wider cavity section than a typical block. In other words, as it can increase the volume of the grout concrete, if the strength of the grout concrete is enhanced, the structural performance of the block wall after construction can be enhanced as well. A wider cavity section, however, results in reduction of the web thickness. Seo et al. [11] developed a form block with optimized web and flange sizes and evaluated the resisting force during the design of the developed block wall by conducting a prism test and finite element analysis. The test verified that the form block failed because the grout concrete under pressure expanded horizontally, which led to brittle shear failure of the block webs ate. The flanges of the block showed few cracks but the grout concrete on the side exhibited vertical cracks, and the web shear failure of the block resulted in separation of the flanges, leading to the final

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http://dx.doi.org/10.1016/j.conbuildmat.2017.06.168

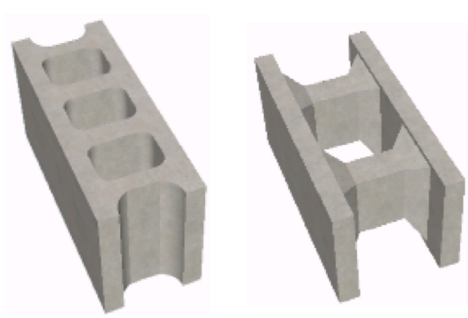
failure. Because such failure are brittle patterns, if a form block is used as seismic reinforcement, its resisting performance against lateral force will become drastically lower than that of a monolithically reinforced concrete wall.

Steel fibers have been known to reduce the occurrence of brittle tensile failure in concrete. There has been much research on steel-fiber-reinforced concrete [13–20], and since recent times, the ACI 318 Code [21] has allowed the use of deformed steel fibers to improve the shear resisting capacity of concrete. Moreover, the fib Model Code 2010 [22] and Australian Bridge Code for Concrete Structure DR AS5100.5 [23] also consider the use of steel fiber to improve the shear resistance.

As reported by Seo et al. [11], steel fibers are expected to improve the tensile or shear strength of the form block and reduce its brittleness. Accordingly, in this study, blocks reinforced with steel fibers, which offer excellent tensile stiffness and crack control performance, were produced, and their structural performance was verified by conducting a compressive test on the blocks as well as a prism test and a diagonal shear test on the form-block wall. The key parameters of the tests were the steel fiber types that were used for the block reinforcement, the strength of the concrete and the non-shrinking grout mortar as fillers, and the strength of the joint mortar. The form-block in this paper is an improvement of the block currently produced in Japan. According to the study by Seo et al. [11], the prism strength of this form-block was shown to be suitably predicted using the equation defined in AIJ code. Therefore, in this paper, it is evaluated whether the strength of form-block with steel fiber as AIJ code can be predicted appropriately.

2. Shape of the form block

The shape of the form block is shown in Fig. 1. Its shape and dimension were determined through a series of finite element analyses. The main feature of the form block with a void ratio of 54% is that, it has a sufficient amount of concrete filling compared to the commonly used concrete block with a void ratio of 42%. Accordingly, it is easy to arrange the vertical reinforcements in the hollow portion and attain an excellent integration between the reinforcing bars and concrete. By increasing the section of the web connected to the flange, the rigidity of the joint is increased, and the integrity of the filled concrete and block is improved.



(a) General concrete block (Void ratio of 42%)   (b) Form-block (Void ratio of 54%)

Fig. 1. Shape of form-block.

The construction procedure of the reinforced form-block wall involves reinforcing the cavity section of the block with rebar and grout concrete using the vertical joints of the block wall as the straight joints. Subsequently, horizontal rebars are placed, and the blocks are laid on the 10-mm-thick joint mortar. For retrofitting a frame structure as infill wall, a certain gap is provided at the uppermost part of the wall for the grout concrete, and the gap is filled with non-shrinking grouting mortar.

3. Experiment on the prism strength

3.1. Test plan

As shown in Table 1, the key parameters considered in the prism specimens are the strength and materials of the grout concrete, the use and types of fiber, and the strength of the joint mortar. The dimensions of the form block used in this study are shown in Fig. 2. Three specimens per parameter were produced, and cubic specimens were made for the blocks and the non-shrinking grouting mortar. For the grout concrete, three cylinders were made, and a compressive strength test was performed. As reported by Seo et al. [24], a steel fiber-block mixing ratio of up to 1.0% of the total weight can increase the compressive and flexural strength, and a difference in the compressive and flexural strength between 1.0 and 1.5% is negligible. Therefore, in this study, non-reinforced form blocks and form blocks reinforced with 1.0% steel fiber considering constructability are used as specimens. As shown in Fig. 3, two types of steel fibers are used in this test: short fiber with an aspect ratio of 50 (0.2 mm diameter × 10 mm length) and long fiber with an aspect ratio of 60 (0.5 mm diameter × 30 mm length). Table 2 shows the basic mix for the block, and as to the manufacturing process of typical blocks, vibration compaction was used. The fibers were mixed and spread out so that they could be mixed evenly with the aggregate and cement.

The produced blocks underwent a compressive test, as shown in Fig. 4, and Fig. 5 illustrates the resulting load–displacement curve. Compared to the non-reinforced block, the block reinforced with short fibers does not show any difference in the initial stiffness, but its overall strength improved. The block reinforced with long fibers shows an improvement in both the initial stiffness and maximum load.

The production of the prism test specimens followed KBC 2016 [25]. That is, the single block was divided into halves, and 10-mm-

Table 1
Specimen list for prism test.

Specimen name	Form-block		Compressive strength of grout concrete or mortar (MPa)	Compressive strength of joint mortar (MPa)
	Steel fiber	Compressive strength (MPa)		
PGL-ML-F0	None	22.76	22.52	13.61
PGH-ML-F0			28.65	
PGH-MH-F0				33.54
PGM-MH-F0			52.52*	
PGH-MH-FS	Short fiber	27.52	30.71	
PGH-MH-FL	Long fiber	26.11		

* Mortar.