Letter

Use of a polyarylate-glass fiber composite textile to reduce localized blast damage in concrete plates

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Received: January 5, 2019 Accepted: July 11, 2019

Abstract

The effectiveness of a polyarylate-glass fiber composite textile on the localized failure of blast-loaded concrete plates was examined experimentally. In these experiments, 80-mm thick concrete specimens were subjected to a contact charge of 46-grams of C-4 explosive. Each specimen was reinforced by the textile adhered to the plate on the side opposite of where the contact charge was placed. The experimental results demonstrate that the polyarylate-glass fiber composite textile can prevent ejection of concrete fragments and reduce localized failure. The extent of localized failure decreases as the tensional stiffness of the reinforcement textile increases. This paper provides a brief summary of the test program and an evaluation of the localized damage of the concrete plates reinforced by the textile.

Keywords: localized blast damage, concrete, polyarylate-glass fiber composite textile, tensional stiffness

1. Introduction

Explosive incidents due to terrorist attacks and industrial accidents have gained increasing attention in many cities around the world. When an explosion occurs near a concrete structure, localized failure of a wall or slab can cause injuries to people and/or damage to assets. In such incidents, a particularly important concern is the potential for concrete fragments to be ejected. These ejected fragments are located on the side opposite that which is subjected to an explosive load. This localized failure of concrete on the opposite face of a wall or slab is called spall damage. To protect people or assets in concrete structures, it is essential that spall damage is prevented or minimized.

The dependence of spall damage on wall thickness, explosive charge mass, concrete strength, and arrangement of reinforcing bars is described in the research literature[1)−3)]. In these works, the occurrence of spall and the extent of its size were predicted. Efforts to reduce concrete spall damage by increasing the unconfined compressive strength showed limited effectiveness[1),2)]. Closely spaced reinforcing bars, however, were shown to reduce the dimension of spall. Nonetheless, spall damage and ejection of fragments were not completely prevented with these design modifications.

The effectiveness of using sheet-like material for external reinforcement to prevent spall damage and scatter of concrete fragments was reported in several previous studies[4)−6)]. Some of the sheets were made primarily from synthetic fibers having a high tensional strength and high elastic modulus. Although such textiles can improve the overall strength and stiffness of concrete plates, the effectiveness of high-strength textiles to prevent local failure is still unclear. The study described in this paper examines the effectiveness of a polyarylate-glass fiber composite textile in preventing spall damage on the back face of blast-loaded concrete panels. Additionally, the relationship between localized failure and tensional stiffness of the textile is explored.

2. Experimental

2.1 Specimen

To prevent ejecting fragments from blast-loaded concrete panels, two potential strategies can be

Table 1 Test cases.

Case	Thickness of longitudinal span direction [mm]	Elastic modulus of longitudinal span direction [N mm^{-2}]	Tensile strength of longitudinal span direction per 50 mm width [N]	Tensional stiffness [kN mm^{-1}]
1			No textile	
2	0.42	74.6	23100	31.3
3	0.97	73.4	5050	71.2
4	1.11	74.6	48000	82.1

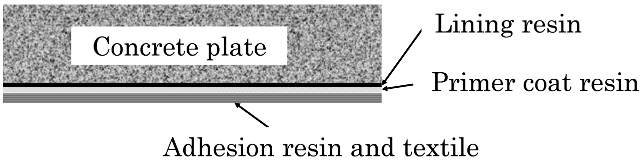


Figure 1 Composition of the specimen.

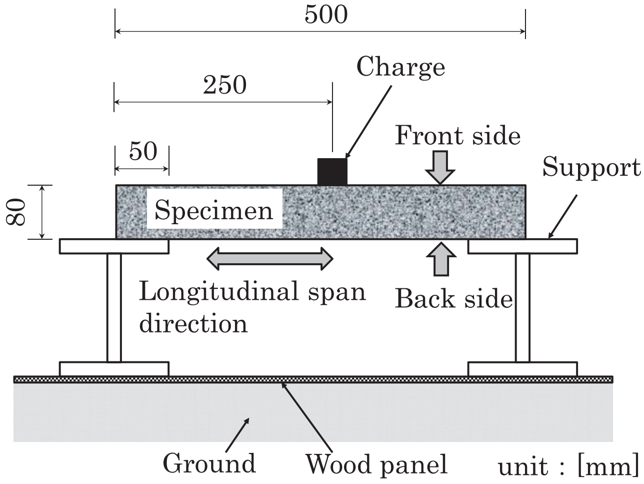


Figure 2 Experimental setup.

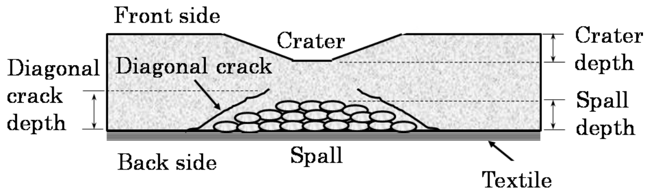


Figure 3 Measurement of local failure.

considered. The first one is mitigating reflection of the induced compression stress wave on the free surface of the back face. The second one is preventing fragment from separating from a concrete wall.

In this study, a cut-resistant textile, which is a composite polyarylate and glass fiber, was used as the reinforcement material for the back surface of a concrete wall specimen. Test cases and characteristics of the textiles are shown in Table 1. To investigate how localized failure depends on the characteristics of the externally applied reinforcement, three kinds of textiles were used in the experiments. These textiles were different in mechanical properties because of differences in thickness, texture, and overall composition. The thickness of the longitudinal span direction varied between 0.42 mm and 1.11 mm. The elastic modulus for the longitudinal span direction was approximately 74 N mm^{-2}. The tensional stiffness per unit width is defined as the product of the elastic modulus and the thickness. Values of tensional stiffness considered in this study were 31.3, 71.2 and 82.1 kN mm^{-1}.

As illustrated in Figure 1, a textile was adhered by a triple-layer of epoxy resin to the back surface of a concrete plate. In attaching the textile, the concrete panel was first covered by a lining resin. After 48 hours, the surface was covered by a primer coat resin to ensure a smooth and level surface. Finally, after another 48 hours passed, a textile was attached using an adhesion resin for the adhesive.

2.2 Test setup

A schematic diagram of the test setup is shown in Figure 2. A concrete specimen having a length of 500 mm, width of 500 mm, and thickness of 80 mm was placed on top of two H-shaped steel members. Preliminary testing confirmed these steel members would have sufficient capacity to remain undamaged in the actual test program. The specimen was idealized as having simple support conditions. The compressive strength of the concrete used for the specimen was 42.8 N mm^{-2}. The maximum diameter of the coarse aggregate was 20 mm. Reinforcing steel along the specimen edge was arranged to prevent damage to the specimen during transportation. Reinforcing steel having a bar diameter of 9.53 mm was placed around the perimeter of the specimen.

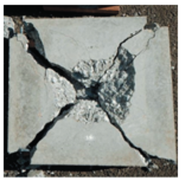
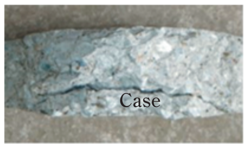
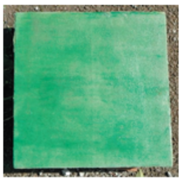
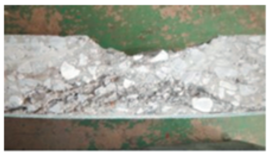
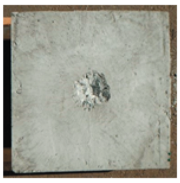
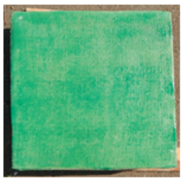
In each test, a thin aluminum tube (with a diameter and height of 35 mm) was filled with composition C-4 explosive, giving a charge mass of 46 g. The explosive was compacted until it had a density of 1.4 g cm^{-3}. The charge was then placed on the specimen as shown in Figure 2 and detonated using an instantaneous electric detonator. The extent of failure was measured as shown in Figure 3. "Crater" is a term used to describe failure on the surface subjected to the explosion. Failures on the opposite surface are termed "spall and "diagonal crack". "Spall" indicates that concrete fragments have completely separated from a specimen. "Diagonal crack" indicates that cracked concrete has not separated from a specimen as fragment. In cases where there is a sufficiently large charge mass, the crater and the spall merge together. Under these conditions, the specimen is said to have been "breached".

3. Results and discussion

3.1 Failure of specimen

The response of the specimens is shown in Table 2.

Table 2 Specimens after blast loading.

Case	Front side	Back side	Cross section (enlarged view)	Kinds of failure
1				Crater Spall Bending
2				Crater Spall Diagonal crack
3				Crater Diagonal crack
4				Crater Diagonal crack

When no textile was used for external reinforcement, crater and spall damage merged, and the specimen was breached. The specimen cracked into four parts as a result of bending failure. Concrete fragments produced by spall damage detached from the specimen.

For cases where a textile was used, ejection of concrete fragments was prevented, and concrete fragments were confined by the textile in all test cases. Thus, these tests demonstrate that using a polyarylate-glass fiber textile for external reinforcement of a concrete plate can effectively prevent ejection of concrete fragments. In Case 2, concrete was crushed into many small fragments. These fragments separated from the concrete specimen. In Cases 3 and 4, although diagonal cracking was observed as indicated in Table 2, the concrete did not separate from the specimen. The internal damage of the Case 4 specimen is less than Cases 2 and 3.

3.2 Relationship between depth of failure and tensional stiffness of the textile

The relationship between local failure dimensions and tensional stiffness is shown in Figure 4. This figure illustrates that local failure dimensions tend to be smaller as tensional stiffness of the polyarylate-glass fiber textile increases. These results show that reinforcement by a polyarylate-glass fiber textile with a high tensional stiffness can effectively reduce spall damage. In Case 4, where the tensional stiffness of the textile is the largest among those considered, the extent of damage is the most effectively minimized. Nonetheless, additional testing is needed to fully understand the relationship between fabric stiffness and blast damage mitigation.

The effects of reinforcement by a polyarylate-glass fiber composite textile on local failure of concrete was compared with other reinforcement materials. Contact explosion tests using various reinforcement materials

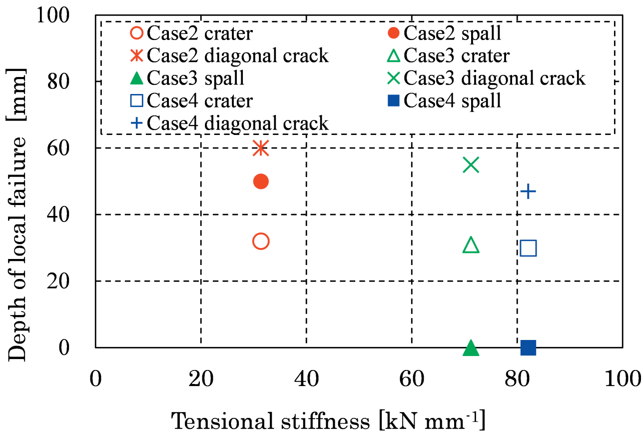


Figure 4 Relationship between tensional stiffness and depth of local damage.

Table 3 Kinds of reinforcement material and their tensional stiffness.

Kinds of material[6]	Tensional stiffness [kN mm^{-1}]	Number of tests
Carbon fiber sheet	13.6 27.2	2 4
Aramid fiber sheet	22.8	6
Stainless mesh and resin sheet	20.2 40.3	2 1
Steel sheet	60.0	1

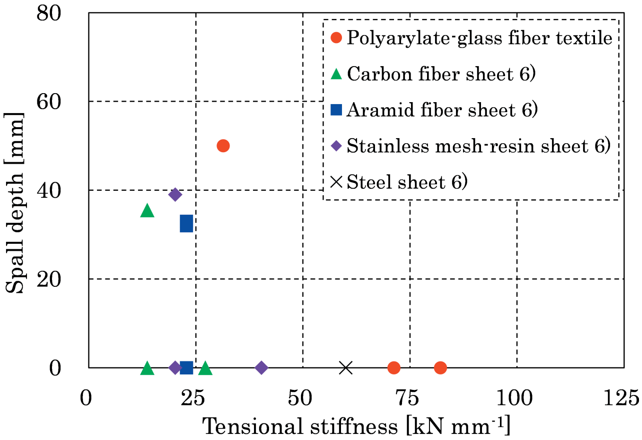


Figure 5 Relationship between tensional stiffness and spall depth.

were conducted previously[6]. In these tests, the dimension of the concrete specimen, support conditions, and mass of C-4 explosive were the same as those in this study. The properties of reinforcement materials used in these tests are shown in Table 3[6]. The relationship between tensional stiffness and spall depth for various reinforcement materials is shown in Figure 5. For the case of a polyarylate-glass fiber composite textile, the spall depth is slightly larger than other materials having similar values of tensional stiffness. The sensitivity of a tensional stiffness might vary in each materials. A concrete plate reinforced by a sheet-like material with a high tensional stiffness, including a polyarylate-glass fiber composite textile, can prevent spall damage.

4. Conclusion

In this study, the effectiveness of using a polyarylate-glass fiber composite textile to mitigate localized blast damage was examined. Tests were conducted using a contact charge of C-4 on the front face and an externally applied composite textile reinforcement on the back face. The test results show that ejection of concrete fragments due to localized failure is effectively prevented by a polyarylate-glass fiber composite textile. Although these tests demonstrate the effectiveness of polyarylate-glass fiber textiles for mitigating blast damage, additional testing is needed to fully characterize its behavior over a wide range of conditions.

Acknowledgment

Textile samples of this work were supplied by Sugimoto Textile Co Ltd. The authors are grateful for the advice provided by Prof. Tomonori Ohno, Professor Emeritus of National Defense Academy. Supports to explosion test by Prof. Makoto Kohga, Professor of National Defense Academy and Prof. Shingo Date, Associate Professor of National Defense Academy are greatly appreciated.

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