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Use of rubberized concrete as a cushion layer in bulletproof fiber reinforced concrete panels

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HIGHLIGHTS

- ▶ This study proposes the use of double layer bulletproof concrete panel consisting of layers of soft and hard material.
- ▶ The soft layer is intended for absorbing impact energy, reducing acceleration and displacement occurred to the plate.
- ▶ The soft layer is made of rubberized concrete produced by mixing crumb rubber particle from wasted tires.

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ABSTRACT

In this study, the ability of rubberized concrete to improve the impact performance of steel fiber reinforced concrete (SFRC) bulletproof panel subjected to direct fire arm is investigated. The rubberized concrete layer (RC) made by replacing fine aggregate at 50%, 75% and 100% by volume fractions is used to replace parts of the thickness of the SFRC panel. The dimensions of the panels are 400 × 400 × 30 mm, the bullet type is 9 mm, and the striking distance is 10 m. For single layer panels, two types of panels are tested: steel fiber reinforced concrete (SFRC) and rubberized concrete (RC). For double layer panels, the RC layer is placed at the front surface by partially replacing part of the SFRC layer at 5, 10 and 15 mm. It is expected that the flexibility and softness of the RC layers will allow the RC layer to act as a cushion layer to absorb the impact energy from the bullet and cause less damage, delay the responding time and reduce the acceleration occurring to the panel.

1. Introduction

Terrorist attack has become a serious threat worldwide. In Thailand, terrorist attacks occur more frequently especially in the southern parts of the country. When a certain area is under attacked, a perimeter control is usually established and enforced. Such perimeter controls include providing access control, diverting traffic movement, or establishing guard posts. Typical guard posts in Thailand are often nonpermanent structures (Fig. 1). Some are constructed of timber or wooden panels and some are constructed of sand bags. In term of bullet resistance, the timber or bamboo structures provide none or little protection to the personnel inside the structure. The sand bag structures, on the other hand, if properly constructed, offer high protection. However, there are some disadvantages on the use of sand bags such as, heavy weight (slow installation), easy to disintegrate (sensitive to moisture and UV), and need a replacement once it has been punctured. In the situation where military units are required to move into the area and quickly construct a bunker or guard post, the weight of the sand bags could become a factor to slowing them down.

In this study, a bullet proof concrete panel with the thickness of about 30 mm made from layers of steel fiber reinforced concrete and rubberized concrete is proposed. The panel is expected to replace wooden structure and constructed with or without sand bags surrounding them. It must also be able to sustain Class 3A fire weapon (handguns) according to the Thailand Department of Defense standard for bullet proof panel or shield [1].

In general, plain concrete is a quasi-brittle material, when subjected to an impact loading (or high rate of loading), it usually fractures catastrophically [2–4]. This causes pieces of broken concrete to take off in all directions. In order to improve concrete brittleness and impact resistance, small fibers are mixed uniformly into concrete mixture (fiber reinforced concrete, FRC). With the ability of fibers to bridge across the cracks, the impact resistance of FRC is much more superior to that of plain concrete [4–7].

Although FRC offers excellent impact resisting property to the bullet proof panel, there are some properties that can be improved, for example, reducing weight and decreasing bullet ricocheting.

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Fig. 1. Examples of temporary military guard post or bunker (http://www.bloggang.com/mainblog.php?id=jbunny&month=09-01-2008&group=21&gblog=9).

This study proposes on the use of rubberized concrete layer to partially replace parts of the SFRC thickness. The rubberized concrete is known for producing lightweight concrete, increasing energy absorption under static [8–12], dissipating impact energy [13–14], and reducing catastrophic failure. It is expected, by replacing part of the SFRC thickness with lighter and highly elastic material such as rubberized concrete, that the weight of the panel can be reduced and the rubberized concrete layer will also act as a cushion layer to dissipate impact energy from the bullet, allowing less energy to act on the panel, and causing less damage (acceleration and deformation) to the panels.

2. Experimental procedure

2.1. Materials

- Type I Portland cement.
- River sand.
- Hooked end steel fiber (Table 1).
- Crumb rubber passing sieve No. 6 (Table 2).

2.2. Specimen preparation

For all specimens, the concrete is mixed in a pan mixer, poured into the mold and vibrated on a vibrating table. After 24 h, the specimens are demolded and cured in water for 28 days. Three types of specimen with dimensions of 400 × 400 × 30 mm are prepared (Table 3):

- *Single layer SFRC plate*: for this specimen, hooked end fibers are mixed with concrete at 2%, 3% and 4% by volume fractions.
- *Single layer CRC plate*: for this specimen, fine aggregate is replaced partially with crumb rubber at 50%, 75% and 100% by volume fractions.
- Double layer SFRC + CRC plate; for this specimen, the thickness divided into two layers. The top layer is made of CRC with the thickness varied from 5 to 15 mm. The bottom layer is made of SFRC with the thickness varied from 15 to 25 mm (Table 3).

Table 1
Fiber properties.

Mat.	SG	Shape	L (mm)	Section (mm)	Aspect ratio (l/d)	Tensile strength (N/mm^2)
Steel	7.8	Hooked end	35	Circle dia. −0.55	64	1000

Table 2
Properties of crumb rubber and fine aggregate.

Categories	Crumb rubber	Fine aggregate
Average bulk specific gravity	0.96	2.43
Average bulk specific gravity (SSD)	0.97	2.47
Average apparent specific gravity	0.97	2.55
Average absorption (%)	0.92	2.04
Finess modulus	4.93	2.90

2.3. Testing

The specimen is placed on the support anvil with four sides secured by a steel frame to provide simple support along the edges as shown in Fig. 2. Two accelerometers are attached at the quarter and at the center location of the back surface to measure the accelerations during the impact. Each specimen is shot by a 9 mm bullet at a distance of 10 m (bullet dimensions and specification given in Table 4). The acceleration is measured and recorded using a computer based data acquisition system.

As a requirement for the class 3 bullet proof shield, in order for the shield to pass the requirement, it must be able to sustain two types of handgun bullets: 9 mm and 11 mm. The term 'sustain' means that the bullet must not penetrate through the thickness of the shield (no perforation failure). In all cases, three samples from each panel type are tested, if just one of the three samples does not pass the requirement, the panel is considered "not pass". It must be noted here also that due to some technical issues, the results from the 11 mm bullet test cannot be reported in this manuscript.

2.4. Data analysis

Using the obtained acceleration data, the velocity and the displacement at any time and at the location of the accelerometer can be calculated using the following equations [5,6]:

$$u(t) = \int_0^t \ddot{u}(t)\,dt \qquad (1)$$

$$u(t) = \int \int_0^t \ddot{u}(t)\,dt \qquad (2)$$

where $\ddot{u}(t)$ is the acceleration at any time t; $\dot{u}(t)$ is the velocity at any time t; and $u(t)$ is the displacement at any time t.

Table 3
Casting details.

Type	Thickness (mm)		Material		No. of spec.
	t1	t2	t1	t2	
R25	–	30	50%RC	–	3
R50	–	30	75%RC	–	3
R75	–	30	100%RC	–	3
S2	–	30	2%SFRC	–	3
S3	–	30	3%SFRC	–	3
S4	–	30	4%SFRC	–	3
R50/S2	5	25	50%RC	2%SFRC	3
R75/S2	5	25	75%RC	2%SFRC	3
R100/S2	5	25	100%RC	2%SFRC	3
R50/S3	5	25	50%RC	3%SFRC	3
R75/S3	5	25	75%RC	3%SFRC	3
R100/S3	5	25	100%RC	3%SFRC	3
R50/S4	5	25	50%RC	4%SFRC	3
R75/S4	5	25	75%RC	4%SFRC	3
R100/S4	5	25	100%RC	4%SFRC	3
R75/S2A	10	20	75%RC	3%SFRC	3
R75/S2B	15	15	75%RC	3%SFRC	3
R75/S3A	10	20	75%RC	3%SFRC	3
R75/S3B	15	15	75%RC	3%SFRC	3