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An experimental study on the temperature and structural behavior of a concrete wall exposed to fire after a high-velocity impact by a hard projectile

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ABSTRACT

Projectiles, such as turbine blades, can be released in an accident and impact structures. Airplanes and other flying objects can also become impact projectiles. These impacts occasionally cause fire when fire loads, such as oil, fuel, and other combustible materials, are present. This study examines the thermal insulation performance of concrete plates and the structural fire behavior of load-bearing reinforced concrete walls that are exposed to fire after a high-velocity impact by a hard projectile. Impact and fire tests were carried out using small-scale concrete plates and reinforced concrete walls. The results show the influence of local damage and the advantage of short-fiber reinforced concrete subjected to impact loads and fire.

1. Introduction

Projectiles, such as turbine blades, can be released in an accident and impact structures. Airplanes and other flying objects can also become impact projectiles. These impacts occasionally cause fire when fire loads, such as oil, fuel, and other combustible materials, are present [1–3]. The high-velocity impact of a hard projectile on a concrete wall can cause local damage [4], such as spalling, scabbing, and perforation (Fig. 1 [5]). Although "spalling" of concrete occurs also when the surface of concrete exposed to fire, "spalling" as used in this paper means local damage of concrete caused by impact.

To protect the people and properties inside a structure, scabbing and perforation must be prevented, and the structure must not collapse under the local damage [6]. Moreover, should a fire break out after an impact, the structure must retain its fire resistance. Fire, whether inside or outside the structure, must not spread to other compartments and spaces or into the structure itself, and the structure must not collapse due to fire. Therefore, the influence of local damage on the fire resistance of structures must be investigated.

In this study, two small-scale tests were carried out because of the difficulty in conducting a full-scale test reproducing the impact of a turbine blade and fire against a full-scale concrete wall. The first test examined the thermal insulation performance of concrete plates that had been damaged by the high-velocity impact of a hard projectile. The second test examined the structural fire behavior of load-bearing reinforced-concrete walls exposed to fire after a high velocity impact by a hard projectile.

2. Setup of tests

Two types of concrete specimens were used in the tests: a concrete plate (CP) and a small-scale reinforced concrete wall (RCW). Both types were subjected to a high-velocity impact and then a fire. The thermal insulation performance of the CP specimen and the load-bearing capacity of the RCW specimen were then evaluated.

2.1. Materials of specimen

The materials used for the normal strength concrete are listed in Table 1. Ordinary Portland cement, crushed sandstone, natural sand, and admixtures were used. Short polypropylene (PP) fibers were added as reinforcement and anti-spalling measures. The concrete mix proportion, compressive strength, and moisture content are listed in Table 2. The CP specimens were constructed of three types of concrete and the RCW specimens of two types. The Plain specimens did not contain short PP fibers, while the PP20 and PP10 specimens contained short PP fibers. For the short-fiber reinforced concrete, the length of the short fibers and the mix ratios are denoted after the "PP" designation. The volumetric mix ratios of the short fibers were 0.5% and 1.0%. The water-cement ratio for the concretes was 55% and the

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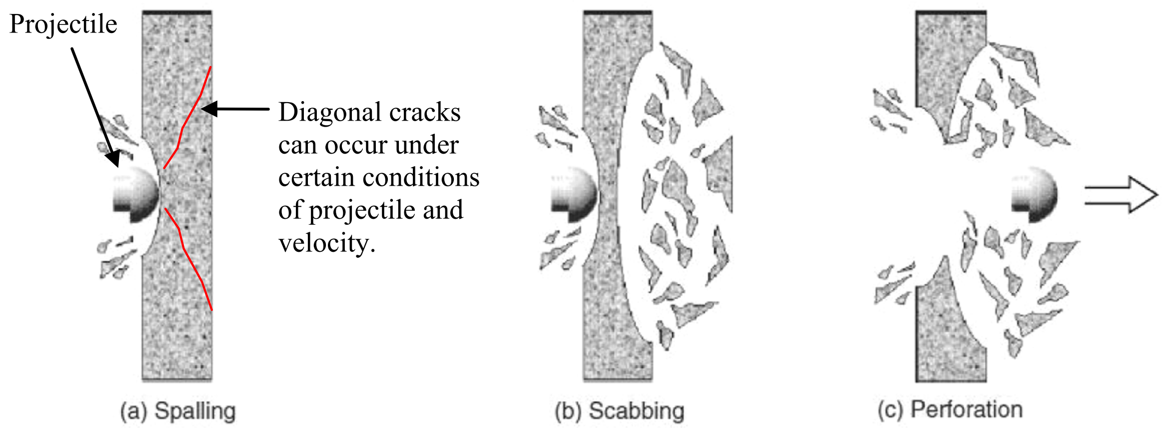

Fig. 1. Failure modes of local damage by a high-velocity impact by a projectile.

Table 1
Materials of concrete.

Material		Type and properties
Cement		Ordinary Portland cement, Density (powder): 3.16 g/cm^3
Coarse aggregate		Crushed sandstone (Oume), Maximum size: 20 mm, Density (saturated and surface-dry condition): 2.65 g/cm^3
Fine aggregate		Natural sand (Kimitsu), Density (saturated and surface-dry condition): 2.63 g/cm^3
Chemical admixture		Air-entraining and water-reducing admixture, Air-entraining admixture, Air control admixture
Short fiber	for CP	Polypropylene, Density: 0.91 g/cm^3, Length: 20 mm, Diameter: 0.05 mm
	for RCW	Polypropylene, Density: 0.91 g/cm^3, Length: 10 mm, Diameter: 0.05 mm

Table 2
Mix proportions of concrete.

Type of concrete and specimen		W/C (%)	Quantity of material per unit volume of concrete (kg/m^3)[a]				PP (vol %)	fc'[b] (N/mm^2)		M[c] (wt %)
			W	C	CA	FA		28d	fire	
Plain	CP	55.0	175	318	817	973	0.0	33.1	41.0	N. M.
	RCW							35.2	45.9	3.7
PP20-05	CP						0.5	31.2	40.0	3.3
PP20-10	CP						1.0	28.3	34.3	3.1
PP10-10	RCW						1.0	24.7	30.6	4.1

[a] W: water, C: cement, CA: coarse aggregate, FA: fine aggregate.
[b] fc': compressive strength of concrete. 28d: 28 days after mixing; fire: the day of fire resistance test.
[c] M: moisture content just before fire resistance test, N. M.: Not measured.

design strength of the concretes was 24 N/mm^2. The air content was adjusted to about 5% by adding chemical admixtures.

The specimens were reinforced with deformed bars (nominal diameter: 6 mm) with a yield strength of 342 N/mm^2.

2.2. Shapes and dimensions of specimens

The thickness of the CP and RCW specimens was set to 80 mm because most impact tests using the launching machine (see Fig. 4) have been carried out on concrete plates with a thickness of 80 mm

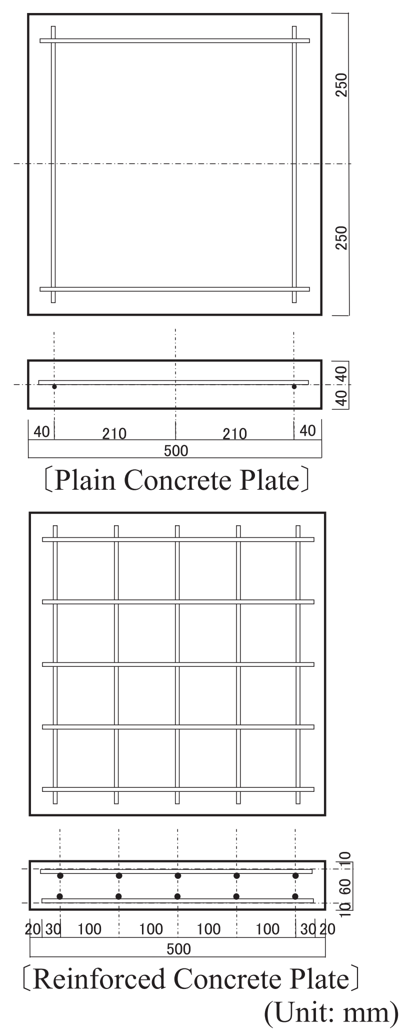

Fig. 2. Shape and dimensions of CP specimens.

[7,8]. Therefore, it was easy to control local failure mode of the CP and RCW specimens.

2.2.1. CP Specimens

The shape and geometry of the CP specimens are shown in Fig. 2. The specimens were 500×500×80 mm (H×W×D) in size. Two types of CP specimens were made: one with reinforcing bars and one without reinforcing bars. The reinforced concrete plate was doubly reinforced with reinforcing bars spaced 100 mm apart in the vertical and