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Resistance of high-strength concrete to projectile impact

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Abstract

This paper presents the results of an experimental study on the impact resistance of concrete with compressive strengths of 45–235 MPa when subjected to impact by 12.6 mm ogive-nosed projectile at velocities ranging from ~620 to 700 m/s. The results indicate that the penetration depth and crater diameter in target specimens exhibit an overall reduction with an increase in the compressive strength of the concrete. However, the trend is not linear. Further increase in the compressive strength requires a reduction in the water-to-cementitious material ratio and the elimination of coarse aggregates. However, doing these does not result in reduction of the penetration depth and crater diameter. The presence of coarse granite aggregates appears to be beneficial in terms of reducing penetration depth, crater diameter, and crack propagation, thus contributing to impact resistance. Incorporation of steel fibers in the concrete reduced the crater diameter and crack propagation, but did not have a significant effect on penetration depth. An increase in the curing temperature from 30°C to 250°C did not alter the impact resistance of the concrete significantly. Based on the present findings and cost consideration, high-strength fiber-reinforced concrete with a compressive strength of ~100 MPa appears to be most efficient in protection against projectile impact.

Keywords: Concrete; Crater diameter; Fiber; High-strength; Penetration depth; Projectile impact

1. Introduction

Concrete structures subjected to impact by projectiles or shell fragments exhibit responses that differ from those when they are under static loading. Projectiles or fragments generate localized

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Nomenclature

C_3A	calcium aluminate ($3CaO \cdot Al_2O_3$)
CRH	caliber radius head
w/c	water-to-cement ratio
w/cm	water-to-cementitious material ratio

effects characterized by penetration or perforation, spalling and/or scabbing, as well as more widespread crack propagation. The magnitude of damage depends on a variety of factors such as impact velocity, the mass, geometry and material properties of the projectile or fragment, as well as the material properties and reinforcement of the concrete target structures.

This paper presents results from an experimental study on the impact resistance of concrete with compressive strengths of 45–235 MPa impacted by 12.6 mm ogive-nosed projectile at velocities ranging from ~620 to 700 m/s. The effects of the compressive and flexural tensile strength of the concrete, the presence of coarse aggregate or steel fibers, and the curing temperature of the concrete are discussed. (In this study, composites without coarse aggregate are also referred to as concrete for simplicity.)

2. A review of impact resistance of high-strength concrete

Resistance to penetration and perforation of plain and reinforced concrete by non-deformable projectiles has been studied long before the technology of high-strength concrete was developed. Most of the work published so far has been based on concrete with compressive strengths of up to ~200 MPa.

In a review on penetration resistance of concrete by Clifton [1], it was reported that some studies showed that the volume of the crater produced when concrete is subjected to impact or impulsive loading, varies approximately inversely with the square root of the compressive strength of concrete. However, other works referenced by him did not show any correlation between compressive strength and impact resistance.

Results from perforation experiments by Hanchak et al. [2] on concrete with compressive strengths of 48 and 140 MPa showed that at lower impact velocities of ~300 m/s, the concrete targets (610 × 610 × 178 mm) with a compressive strength of 48 MPa were perforated, whereas similar sized targets with a strength of 140 MPa were not. However, for impact velocities between 300 and 1100 m/s, a three-fold increase in unconfined compressive strength resulted in relatively minor improvement of the perforation performance, based on the residual velocity of the projectiles. It was postulated that penetration resistance in the crater region was not sensitive to compressive strength.

In another experimental study by Dancygier and Yankelevsky [3] on the response of concrete to hard projectile impact, it was observed that the projectile penetration depth in concrete with a compressive strength of ~100 MPa was smaller than that in concrete with a strength of ~35 MPa. This showed that a higher compressive strength enhances