LOCAL DAMAGE RESPONSE OF HFRC

ABADEL Aref [1], ALMUSALLAM Tarek[2], HUSAIN Abbas[3],
AL-SALLOUM Yousef [4], SIDDIQUI Nadeem[5]

Abstract

This paper presents a sequence of tests involving the impact of hemispherical nosed steel projectile on hybrid fiber reinforced concrete (HFRC) slabs. The main objective of the study was to investigate the local damage behavior of hybrid fiber reinforced high strength concrete slabs. The control slabs were 600 mm square, 90 mm thick reinforced with 8 mm diameter steel rebars, whereas different proportion of steel and polypropylene fiber were added in HFRC slabs. The velocity of 40 mm steel projectile was varied within sub-ordinance range and the projectile was made to strike normal to the slab using a gas gun. The slabs were also tested under static load for assessing the punching resistance of RC and HFRC slabs using the same projectile. The energy absorption in punching of HFRC slab was enhanced compared to control specimens. The test results showed that the use of hybrid fibers in RC slabs substantially increase the local impact damage resistance and ballistic limit velocity of RC slabs, and also significantly reduce the flying of concrete fragments from the rear face of the slab.

Keywords: Local damage, Punching strength, hybrid, Slab, Projectile impact.

1. Introduction

Structural impact problems have become increasingly important for the construction industry. In the design of reinforced concrete (RC) strategic structures, account is taken of accidental loads such as dropped objects, collisions, explosions, aircraft crash and penetration of fragments. Some of these accidental loads are also pertinent in the design of protective structures which are mainly of RC in the process industry [1-5] or fortification installations for defense purposes. The general public is increasingly concerned about the safety of structures, specially, after September 11, 2001 attack on world trade centre. Therefore it is necessary to assess the safety of various RC structural members in the structural engineering, nuclear engineering and offshore engineering etc., when struck by a mass, which produces extensive cracking, inelastic deformation and damage to RC

[1]ABADEL Aref, Dept. of Civil Eng., King Saud Univ., Riyadh, Saudi Arabia, aabadel@ksu.edu.sa

[2]ALMUSALLAM Tarek, Dept. of Civil Eng., King Saud Univ., Riyadh, Saudi Arabia, musallam@ksu.edu.sa

[3]ABBAS Husain, MMB Chair for Research and Studies in Strengthening & Rehab. of Structures, Dept. of Civil Eng., King Saud Univ., Riyadh, Saudi Arabia, abbas_husain@hotmail.com

[4]AL-SALLOUM Yousef, Dept. of Civil Eng., King Saud Univ, Riyadh, Saudi Arabia, ysalloum@ksu.edu.sa

[5]SIDDIQUI Nadeem, Dept. of Civil Eng., King Saud Univ., Riyadh, Saudi Arabia, nadeem@ksu.edu.sa

members and/or RC structural system. These assessments require better estimate of the material characteristic of concrete at high rate of loading and local damage and global response of RC structures produced by the impact of projectile and information on their fracture modes.

The analysis of structures, subjected to static and dynamic loads producing large displacements and large plastic strains, is nowadays a routine task of structural analysts for which they employ finite element method and other numerical techniques as well as the rigid–plastic methods of analysis. However, regardless of the method used, the prediction of failure is usually difficult. The problem gets further complicated when the load is impact load which causes large displacements, large strains, interaction of various modes of failure, and strain rate effects in materials. The mechanics of material deformation and ultimate failure have so far not been understood properly. The behavior of such structures especially of RC which are subjected to impact loads producing large inelastic strains and fracture is important for a broad class of engineering problems. Zhang et al. [6] studied 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. It was indicated that the penetration depth and crater diameter in target specimens exhibit nonlinear overall reduction with an increase in the compressive strength of the concrete.

The use of a single and a mixture of two or more types of fibers in different proportions (hybrid-fibers) in improving the impact response of reinforced concrete (RC) targets can be very promising [7-8]. These fibers can substantially improve penetration resistance, decrease crater sizes, control crack development, reduce damaged area, and improve the ductility of RC targets (e.g. beams and slabs) [9-15].

The available impact studies on fiber reinforced concrete targets are primarily limited to the use of steel fibers, but other types of fibers have also been used in improving the impact resistance of plain and reinforced concrete targets [12-19]. Farnam et al. [16] investigated the behavior of high-performance fiber-reinforced cement based composite (HPFRC) under low velocity impact. The results showed that HPFRC has higher impact resistance than plain concrete. Soe et al. [17] experimentally investigated the impact resistance of a hybrid-fiber ECC material reinforced with steel and polyvinyl alcohol (PVA) fibers. The panels were subjected to the impact of an ogive-nose steel projectile. The impact velocity of the projectile was ranging from 300 to 657 m/s. The damage to the panels was studied in terms of penetration depth, crater diameter and scabbing diameter. They concluded that the hybrid-fiber ECC material has an excellent resistance against projectile penetration. Yildirim et al. [18] studied the performance of Hybrid Fiber Reinforced Concrete (HFRC) under repeated impact loads. They observed that HFRC impact performance increases with increase in steel fibers proportion. They also concluded that the hybrid-fibers have positive effect on the performance of concrete.

The present study was carried out with the objective of studying the local damage behavior of fiber reinforced concrete against projectile impact. Reinforced concrete (RC) slabs with and without steel fibers were tested under the impact of 40 mm diameter projectile with hemispherical nose. The slabs were also tested under static load for establishing their punching resistance against the same projectiles. The results presented in this paper are the part of a funded research project.

2. Experimental Program

The main purpose of the experimental program was to generate data to investigate the influence of different combinations of macro-sized steel and synthetic fibers (hybrid-fibers) on the impact resistance of singly reinforced RC slabs

The experiments involve testing of reinforced concrete slabs under the impact of projectiles at varying strike velocities. The size of reinforced concrete (RC) slabs was kept as 600 × 600 × 90 mm. The slabs were reinforced with ϕ8@100 mm c/c rebars (0.71% steel) provided on the rear face of slab. The reinforcement details of the slabs are shown in Fig. 1. The fiber reinforced concrete (HFRC) slabs were prepared by adding different proportion of steel and Polypropylene fibers to RC slabs as shown in Table 1. The physical and mechanical properties of fibres are shown in Fig. 2 and Table 2. Five slabs of each type were prepared thus making a total of ten slab specimens. Two slabs were tested for static load and the remaining slabs were tested under the impact of projectile at varying striking velocity.

The evolution of the state of deformation of slabs was recorded using LVDTs for static tests. Ready mixed concrete with 10 mm maximum size of aggregate and a slump of 180 mm was used for casting of the slabs. The 28-days cylinder compressive strength of concrete was 63 MPa.

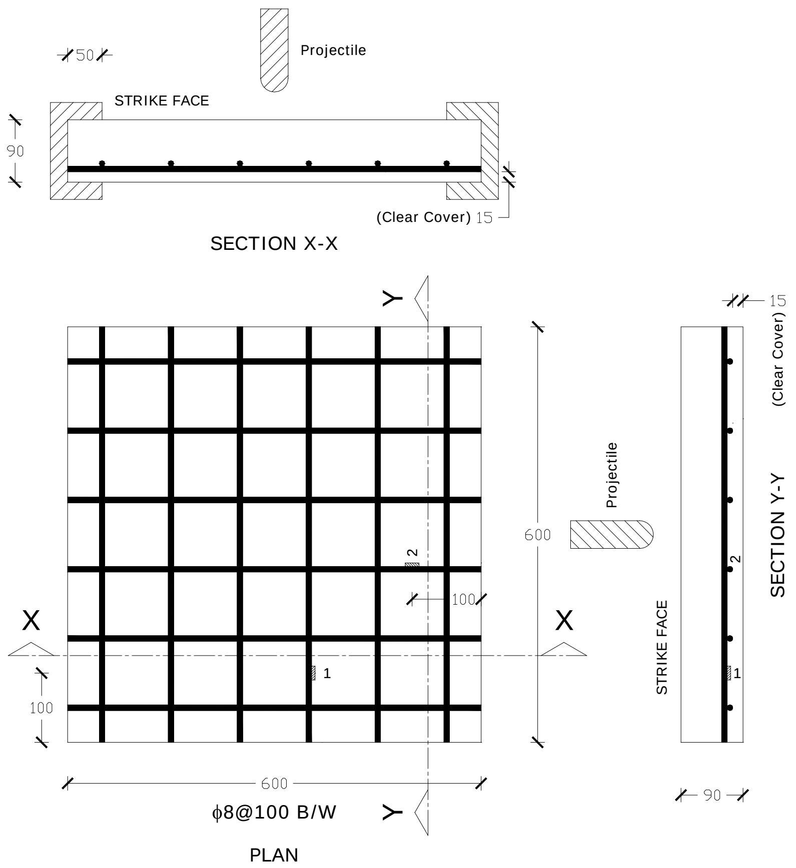


Fig. 1: Reinforcement and instrumentation details of the concrete slabs

Tab.1: Fiber percent in different concrete mixes.

Mix	Fiber percentage by volume* (by weight)		$f_c^{'}$ (MPa)
	Steel	Polypropylene	
M0	0.0	0.0	64.5
M1	1.2	0.0	73.5
M2	1.0	0.2	70.0
M3	1.4	0.0	74.4
M4	1.2	0.2	71.9

Tab.2: Physical and mechanical properties of fibers

Fiber length (mm)	Fiber diameter (mm)	Tensile strength (MPa)	Elastic modulus (GPa)	Specific gravity	Shape
60	0.75 ϕ	1225	200	7.85	Hooked ends
50	1×0.6 (Rectangular)	550	4	0.9	Crimped

(a) (b)

Fig. 2: (a) Hooked-end steel (b) Polypropylene type-2

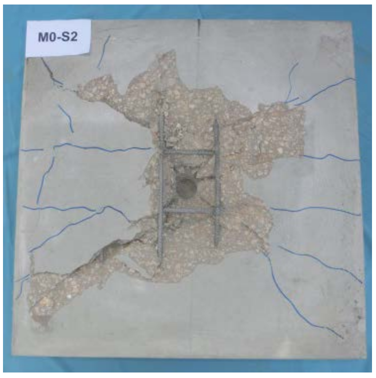
3. Test Results

The structural testing involved the testing of concrete slabs under static and impact loads. Thus the details are given under the heads: (i) static testing of slabs; and (ii) Impact testing of slabs.

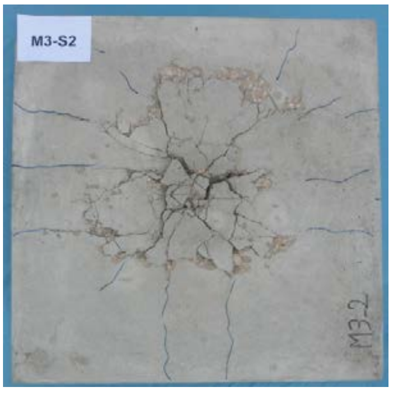
3.1 Static testing of slabs

The static testing for the penetration of projectile was performed using 40 mm diameter steel projectile of hemispherical nose, which was the same as used in the impact tests. The projectile was placed at the center of slab and the slab was clamped on two opposite edges. The vertical displacement of projectile and the vertical displacement at different locations on the slab was measured using LVDTs. The strains in the rebars were also recorded. The test setup for static testing of slabs is shown in Fig. 3. The projectile was pushed upward and normal to the slab. One tested slab of each type is also shown in Fig. 3, wherein the damage occurring to the top surface of the slab is shown. The variation of load against the vertical displacement of penetrator is plotted in Fig. 4.

(a) Test setup



(b) Tested slab (no fiber)



(c) Tested slab (with fiber)

Fig. 3: Static testing for punching of RC and FRC slabs

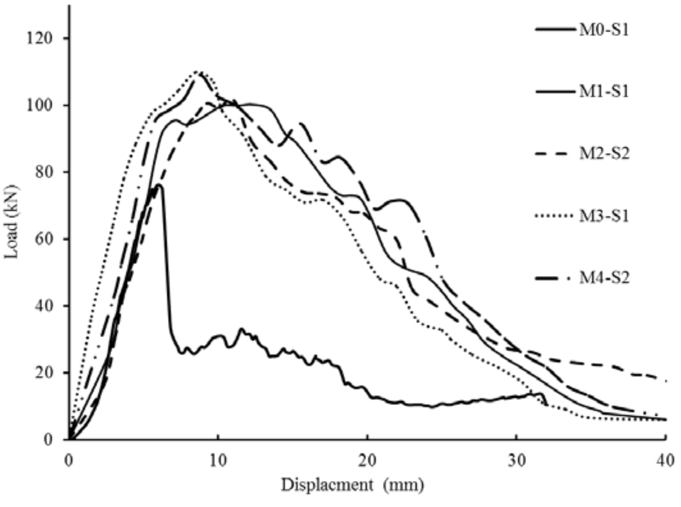


Fig. 4: Load-displacement variation for static testing of RC and HFRC slabs

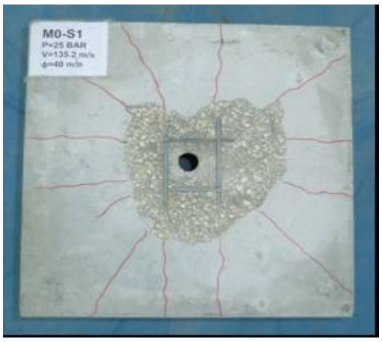
3.2 Impact testing of slabs

The two opposite edges of slabs were clamped as in the static tests and the slab was centred so that the projectile strikes the center of slab. The projectile used in the study was 40 mm in diameter with hemispherical nosed steel projectile thus requiring the use of 400 mm diameter barrel. The projectile was 0.8 kg in weight. The slabs were tested for increasing impact velocities till there was perforation in the slabs. One slab of each type, wherein ballistic limit perforation, was observed is shown in Fig. 5.

(a) Slab without fibers (Front face)

(b) Slab without fibers (Back face)

(c) Slab without fibers (Front face)



(d) Slab without fibers (Back face)

(e) Slab with fibers (Front face

(f) Slab with fibers (Back face)

Fig. 5: Damage of slabs at impact velocity of 135 m/s.

4. Discussion of Results

4.1 Static tests

It is observed from Fig. 3 that the damage pattern under static load for HFRC and RC slabs is slightly different. The back face concrete of RC slabs failed in brittle manner with higher degree of fragmentation thus giving rise to small size fragments whereas the back face concrete of HFRC slab failed by forming larger size fragments which is due to the fiber in concrete. Figure 4 shows that though the peak load at failure for the HFRC slabs for mixs M1, M2,M3 and M4 are slightly higher (31%,34%,38%,46%) respectively compared to control specimen but the energy absorption in HFRC slab were much higher than the RC slab as shown in Fig 6. Energy absorption capacity of the test specimens was evaluated based on the area under the normalized punching shear stress versus deflection response. For each HFRC mixes, the calculated energy was normalized by that of the corresponding control specimen. As can be seen, the addition of fibers to the concrete led to an increase in energy absorption, particularly in the specimens with 1.2% steel fiber and 0.2% Polypropylene fiber (volume fraction) by about 114%. The results also show that the polypropylene fibers play a significant role in improving the energy absorption in the punching failure of the slabs. Addion of 0.2% polypropylene fibers increases energy absorption capacity approximately by 30%.

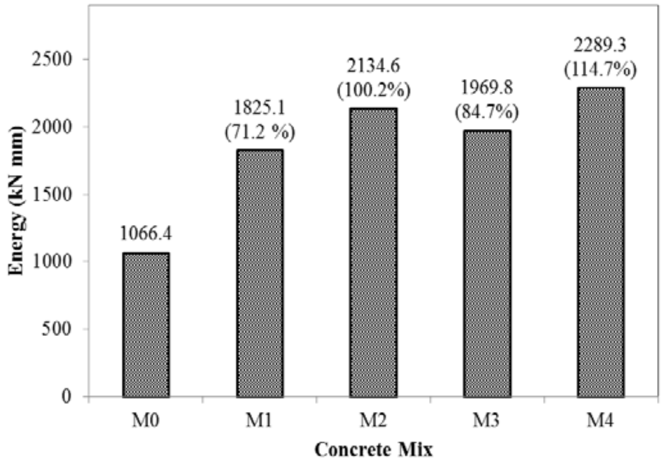


Fig. 6: Energy absorption in punching of control and HFRC slabs

4.2 Impact tests

It is noted that the different levels of damage of the specimens are indicative of the amounts of energy dissipated during impact. Consideration of this criterion as a measure of the slabs' response was also valid because the hardened-steel projectiles were not deformed during the impact tests. Although in certain cases, the projectiles noses were scratched, their shape remained un-deformed and therefore, the energy dissipated in scratching the projectiles was considered negligible with respect to the energy dissipated in inflicting the damage to the target.

The ballistic limit velocity for the RC slabs was found to be 135.0 m/s. For HFRC slabs the ballistic limit for M1, M2, M3 and M4 were found 160.2, 160.2, 178.5 and 168.2 m/s respectively. The damage pattern of slabs observed from Fig. 5 at the same velocity shows that the front face crater in HFRC is smaller than that in RC slab. It is also observed from Fig. 5 that the addition of fibers has considerably reduced the scabbing damage of slab as compared to the RC slab. It may be seen from Fig.1 that the point of strike of projectile, which is at the center of slab, is not striking the rebars.

The damage observed in slab specimens is shown in Figure 5. These figure illustrate that on the front face, damage was completely local with the minor cracks in radial directions. There was some spalling of concrete around the hole created by the penetrating projectile. However, there was no global deformation/damage on the front face. On the back face the damage was more compared to the front face damage. This can be attributed to the influence of the global deformation (along with the local damage) that caused the damage of the larger area on the back face.

Figure 7 shows the variation of the ejected concrete mass from the front and the rear face of the slab for 135m/s striking velocity of the projectile. This figure highlights the effect of hybrid fiber on ejection of concrete mass from the front and the rear faces of the specimens. The addition of fibers reduces the detached mass from front and rear faces of concrete slabs which illustrate the role of fiber in limiting the ejection of the fragments from the concrete mass.

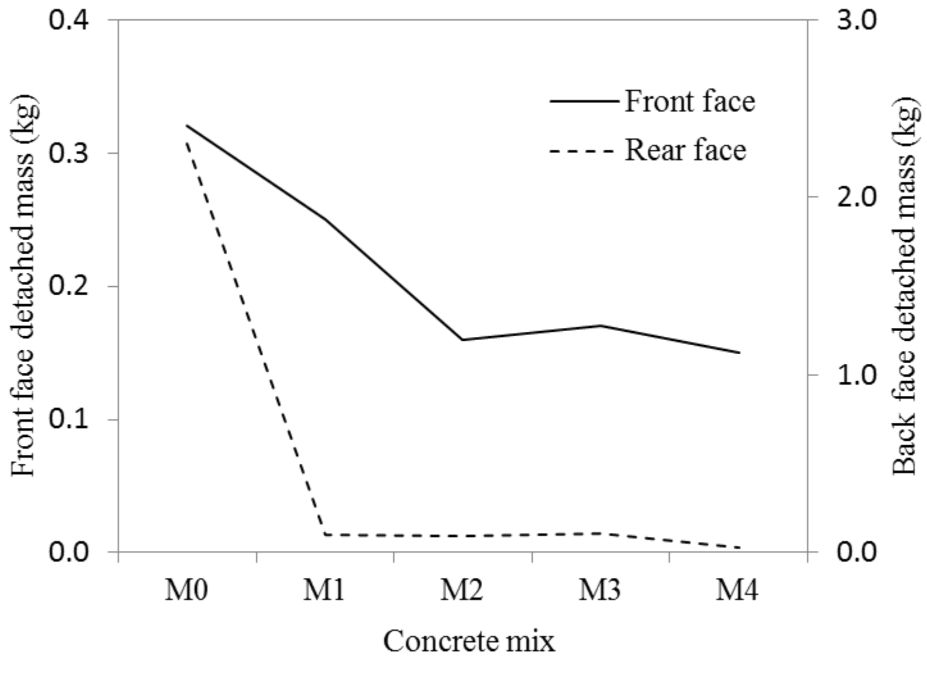


Fig. 7: The ejected concrete mass impacted by the projectile at impact velocity of 135 m/s.

5. Conclusions

The following conclusions can be drawn from the results of the present study.

- Addition of polypropylene fibers plays a significant role in improving the energy absorption in the punching failure of the slabs.
- Fibers increase the resistance of RC slabs against projectile impact and thus increase their ballistic limit velocity substantially.
- The addition of hybrid-fibers considerably reduces the local damage and concrete mass ejection from the front and rear faces of RC slabs.

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