High-Velocity Impact Strength of Plain and Fiber- Reinforced Polymer-Modified Concrete

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الخلاصة:

تتعلق هذه الدراسة بتاسيس خواص الصدم عالي السرعة للخرسانة المطورة بالبوليمر المتضمنة بوليمر مطاط ستايرين – بيوتادين (SBR) ، وبنسبة وزنية ٤% ،٨% و ١٢% من السمنت . تم ادخال الاليياف الحديديةايضاً في الدراسة. ستة عشر قرصاً خرسانياً بقطر ٥٠٠ ملم وبسمك ٥٠ ملم لتجارب الصدم عالي السرعة وبالاضافة الى ذلك فان مقاومة الانضغاط و مقاومة الشد الانفلاقي ومقاومة الانثناء اجريت كفحوص مرافقة . في كل الفحوص كانت الخرسانة غير حاوية او حاوية على الالياف الحديدية بنسبة١% حجماً.

عند تدقيق بحث الصدم عالي السرعة ، فأن نسبة النقصان لعمق الاختراق عن الخرسانة المرجعية تتراوح بين (٥-١٧) % ولمساحة التقشر (١٥-٣٥) % وعند اضافة الياف حديدية بنسبة ١% حجماً فان نقصاناً اضافياً قد سجل في مساحة التقشر تراوح بين (٦٤-٩٥)% ولعمق الاختراق (٢٨-٣٩) % عن الخرسانة المرجعية وقد كان مدى مقاومة الانضغاط المناظرة بين MPa (٤٨-٦٤) ومقاومة الشد الانفلاقي بين MPa (٤.٢ -٧.٨) ومقاومة الانثناء MPa (٥-٨).

Abstract

This study deals with establishing high-velocity impact properties of polymer –modified concrete (PMC) including Styrene-Butadiene rubber (SBR), with different weight ratios of polymer to cement: 4%, 8% and 12%. Steel fibers were also included. Sixteen (500mm) diameter, (50mm) thick discs for high-velocity impact tests were used. In addition compressive strength, splitting tensile strength, and flexural strength (modulus of rupture) were companionly recorded. In all the tests, concrete was with and without crimped steel fibers of ratio 1% by volume.

In investigating high-velocity impact strength, the decrease in projectile penetration depth was (5-17%) and the scabbing area reduced (15-35%) over reference concrete.

In studying PMC including 1% by volume steel fibers, an additional increase was observed in all properties.

The increases were quite significant in high-velocity impact strengths. Further reduction was recorded in scabbing area of (64-95%) and penetration depth reduced (28-39%) over control specimens. The fragmentations were reduced also. The range of corresponding compressive was (48-64)MPa ,of splitting tensile strength (4.2-7.8) MPa, and of flexural strength (5-8) MP

1. Introduction

The Styrene-Butadiene rubber (SBR) latex, combined with low water-cement ratio produces concrete that has improved flexural, tensile, bond strength, lower modulus of elasticity, and reduced permeability characteristics compared with conventional concrete of similar mix design. [1].

Folic, R. J. and Randonjanian V. S. [2], tested (180) concrete samples, different in size and shape. All properties of modified concrete were analyzed depending on the quantity of polymer used. Styrene butadiene rubber was used as a cement modifier.

The following results were obtained from the tests:

- The greatest effect on physical and mechanical properties of latex modified concrete was achieved at the optimal combination of wet and dry curing, i.e, curing in dry environment.
- Compressive strength was slightly increased with the increase of the polymer-cement ratio (1 to 7 percent).
- Tensile strength increased with the increase of polymer- cement ratio and the correlation is in the form of a straight line. The increase of flexural

strength for concrete modified with 7.5 percent of polymer admixture was (40) percent in relation to the reference concrete.

- Water absorption decreased with the increase of polymer cement ratio.
- Shrinkage of the modified concrete with 7.5 percent of polymer - admixture on the cement mass was almost 50 percent less than the shrinkage of the reference concrete.
- Adhesion between reinforcement and concrete increased with the polymer-cement ratio increase.
- The effect of latex quantity of 7.5 percent on the cement mass has not significantly influenced the values of static and dynamic modulii of elasticity.

Abdulkader [3] studied the properties and behavior of no-fines concrete using (10mm) maximum size of aggregates improved by SBR polymer. The polymer was added as percentages of cement weight 5%, 7.5% and 10%. It was recorded an appreciable improvement in compressive, & flexural strength and density of polymer modified no- fines concrete corresponding to reference no-fines concrete.

Qusay [4] studied the effect of (SBR) polymer on stress- strain relationship of no-fines concrete under compression and also the effect of polymer cement ratios on density .The polymer was added as percentages of cement weight and the ratios of polymer were 5%, 7.5% and 10%, and reference mixes were made for every case. He found that the (SBR) had improved the compressive strength and made no- fines concrete less strained than that in reference mixes. The density increased when P/C ratio increased.

In recent years, progress in a wide range of researches and development concerning concrete- polymer and fibrous composite materials, has been made in Japan.

Ohama et. al. [5] studied the drying shrinkage reduction effect on concrete brought by steel fiber reinforcement and polymer modification. Steel fiber reinforced polymer- modified concrete (SFRPCC) with styrene- butadiene rubber (SBR) latex is prepared, and tested for drying shrinkage. It was concluded from the test results that the drying shrinkage of (SFRPCC) tends to decrease significantly by increasing steel fiber content and polymer- cement ratio, and the drying shrinkage reduction effect is remarkable at the steel fiber content of 1% by volume and the polymer cement ratio 5% or more. The drying shrinkage of (SFRPCC) with the steel fiber content of 2% by volume and the polymer- cement ratio of 20% reduced to about one- half of that of unreinforced unmodified concrete .The drying shrinkage is strongly affected by steel fiber content, polymer- cement ratio and water ratio.

Ohama et. al. [(6)] studied the flexural behavior of steel fiber reinforced polymer- modified concrete (SFRPCC) which is made by adding polymer dispersion to conventional steel fiber reinforced concrete. (SFRPCC) specimens with (SBR) latex were prepared and tested for flexural strength, load- deflection curve and toughness. It was concluded from the test results that the flexural strength of (SFRPCC) with the steel fiber content of 2% by volume and the polymer- cement ratio of 20% attains to about 2.5 times that of ordinary cement concrete, and other properties in flexural of (SFRPCC) are also extremely improved with the increase in steel fiber content and polymer- cement ratio.

Fukuchi et .al. [(7)] studied the properties of steel fiber reinforced polymer modified concrete using polycyclic ester (PAE) emulsion and steel fibers (size, 0.5×0.5×30mm). It was concluded from the test results that the consistency of (SFRPCC) is reduced with the increase in the steel fiber content and is improved remarkably by rising the polymer- cement ratio. The direct tensile, flexural, impact strength and toughness of (SFRPCC) are elevated remarkably by increasing both the steel fiber content and the polymer-cement ratio .The steel fiber reinforcement hardly contributes to the compressive strength of (SFRPCC).

Ohama et. al. [(8)] studied the properties of steel fiber and polyethylene fiber Hybrid reinforced polymer modified concrete (S-PE/FHRPCC), using steel fibers (size 0.25*0.55* 25mm) and polyethylene fibers (diameter, 0.9 mm; length, 40mm) with (SBR) latex. It was concluded from the test results that the flexural toughness and maximum tensile strain of S-PE/FHRPCC tend to be remarkably improved with an increase in polyethylene fiber content, and this trend is promoted with an increase polymer- cement ratio. The maximum flexural load, direct tensile strength and compressive strength of (S-PE/FHRPCC) are affected by polymer latex modification rather than polyethylene fiber reinforcement, and generally increase with rising polymer-cement ratio

Soroushian et. al. [9] investigated the effects of latex modification on the performance characteristics of carbon fibers mortars incorporating silica fume. Two styrene butadiene latex were considered in this investigation. The results indicated major gains in the bond strength between carbon fibers and cementation materials resulting from Latex modification. Flexural toughness was also increased through latex modification. Latex modification resulted in reductions in water absorption and drying shrinkage.

Ohama et. al. [10] studied the physical properties of steel fiber reinforced polymer- modified mortars using steel fibers (size 0.25×0.55×25 mm) and (SBR) latex and ethylene vinyl acetate (EVA) emulsion. It was concluded from the test results that the flexural and compressive strengths of steel fibers reinforced polymer modified mortars increase with the increase in steel fiber content and polymer-cement ratio.

2. Previous Investigations of Concrete Structures Subjected to High Velocity Impact and Explosive Loading

The available studies and researches about the resistance of high velocity impact and explosive loads of concrete, are much less than the studies and researches of low velocity impact. Also most of these researches were carried out on normal reinforced concrete. However, there are some studies concerning concrete reinforced with steel and polypropylene fibers also on Ferro cement.

Raouf (11) declared the importance of fibers in resisting the dynamic tensile stresses generated by impact wave reflected by small explosive charges. He explained also that the glass fibers are the first in spalling resistance than the polypropylene fibers, steel fibers and carbon fibers. He declared also that the high resistance of cement compounds reinforced with glass fibers might be related to the uniform distribution of fibers in addition to the high tensile strength of these fibers

Williamson (12) carried out explosive tests on fiber- reinforced concrete slabs. He observed that the result of shock loading applied to plain concrete by explosives, was reduction in spall velocity of the fragment when the matrix was reinforced with 1.75% nylon fibers.

The tests conducted by **Robins** and **Calderwod** (13) also showed that the inclusion of steel and polypropylene fibers significantly reduces the size and particle velocity of fragment caused by subjecting slabs to explosive loading.

Manfred et. al. (14) studied the effect of deformable projectiles impact on reinforced concrete slabs at velocities up to 400 m/sec. It was found that the penetration depths were smaller than those corresponding to undeformable projectiles impact, and the difference was increased as the velocity was increased.

Nada (15) studied the impact strength of polypropylene fiber reinforced concrete by using different bullets of (12.7, 7.62, 9mm) caliber to investigate the role of this fiber when used in the fortified structures. The analysis of the results showed the importance of polypropylene fibers in enhancing impact resistance and improving the energy absorption mechanism. It also has a significant influence in reducing spalling and the back face scabbing area of the reinforcing plates in addition to radial cracks.

Although there are many researches and studies concerning the high-velocity impact resistance, but the impact resistance of latex modified concrete, and steel fibers latex modified concrete had not been studied yet. Hence, this study is considered, locally, new, since there are no similar researches found in the references.

3. Experimental Program.

3.1 Materials.

3.1.1 Cement

Table (1) presents the physical properties of the cement used in this research.

Table (1) Physical Properties of Cement *

Physical Properties	Test Result	Limits of Iraqi Spec. No.5/1984
Specific surface area Blain method, m^2/kg	379	$\geq$230 m^2/kg
Setting time, Vicat's method: Initial setting hrs: min. Final setting hrs: min.	 3:17 4:45	 $\geq$1 hour $\leq$10 hours
Soundness	0.2%	$\leq$0.8%
Compressive strength of mortar, N/mm^2: 3-day 7- day	 15.8 27.5	 $\geq$15 N/mm^2 $\geq$23 N/mm^2

* Chemical tests and physical properties were made by the National Center for Construction Laboratories (NCCL).

3.1.2. Fine Aggregate

Al-Ukhaider natural sand of 4.75 mm maximum size was used for concrete mixes of this investigation. The grading of fine aggregate is shown in Table (2) . Results indicated that the fine aggregate grading and the sulfate content were within the requirement of the Iraqi specification No. 45/1984 . Table (3) shows the specific gravity, sulfate content and absorption of fine aggregate.

Table (2) Grading of Fine Aggregate

Sieve Size (mm)	Cumulative Passing (%)	Limits of Iraqi SpecificationNo.45/1984 for Zone (3)
4.75	100	90-100
2.36	90.4	85-100
1.18	85.6	75-100
0.6	68.8	60-79
0.3	22.4	12-40
0.15	8.15	0-10

Table (3) Physical Properties of Fine Aggregate*

Physical Properties	Test Result	Limits of Iraqi Specification No. 45/1984
Specific gravity	2.66 %	--
Sulfate content	0.08 %	≤0.5%
Absorption	0.75 %	--

*Physical properties of fine aggregate were made by (NCCL).

3.1.3 Coarse Aggregate

The washed coarse aggregates of 10mm maximum size were brought from Al- Nibaey region. The sieve analysis of this aggregate is given in Table (4). It conforms to the Iraqi specification No.45/1984.

Table (4) Grading of Coarse Aggregate

Sieve Size (mm)	Accumulated Percentage Passing (%)	Limit of Iraqi Specification No. 45/1984
12.5	100	100
9.5	99	85-100
4.75	20.3	10- 30
2.36	4.1	0- 10
1.18	0	0- 5

Specific gravity=2.71

3.1.4 Water

Ordinary drinking water was used in all mixes.

3.1.5 Polymers

Styrene butadiene rubber was used in this work of which the chemical composition is shown in Table (5). The polymer (SBR) was used as a ratio by weight of cement of 4%, 8% and 12%.

Table (5) Chemical Composition of Styrene Butadiene Rubber (SBR)

Infra-Red (I.R) Test	pH%	Humidity	Solid Particles Content %
Styrene butadiene rubber with small percentage of admixtures	8.2	42.4	57.42

* The test was done in Ibn-Rushud industrial company.

3.1.6 Steel Fibers

Higher tensile steel fibers crimped type were used with volume fraction of (1%). Table (6) shows the properties of the used steel fibers.

Table (6) Properties of Steel Fibers

Type	Property	Specification
Crimped	Density.	7860 kg/m^3
	Ultimate strength	1500 MPa
	Modulus of elasticity	2*10^5 MPa
	Poisson's ratio	0.28
	Length	50 mm
	Diameter	0.5mm
	Aspect ratio	100

3.2 Mix Proportions

Table (7) shows the mix proportions of materials used in this work.

Table (7) Mix Proportions of Materials

Symbol	Proportion Cement:Sand:Gravel	Polymer-Cement Ratio %	Steel Fiber Content (Vol.%)	W/C Ratio	Curing Conditions
0		0	0	.4	*
1		4	0	.35	**
2		8	0	.35	**
3		12	0	.35	**
0F	1:1.3:2.5	0	1	.4	*
1F		4	1	.37	**
2F		8	1	.37	**
3F		12	1	.37	**

* Water Curing (27) days .
** Water curing (6) days and Air curing (21) days. (2)
Note: W/C Ratio including polymer water.

3.3 Concrete Mixing Procedure

A mechanical mixer of (0.1m^3) capacity was used. The interior surface of the mixer was cleaned and moistened before placing the materials. Aggregates were added before adding the cement.

After adding the cement, the materials were well mixed for about (1.5) minutes to attain uniform mix. The required quantity of tap water was then added, finally the (SBR) polymer should be added to the homogonous mix and mixing should be continued until all particles are fully coated with (polymer-cement past) matrix. Moreover the total mix should have a uniform or a homogenous color. **Ohama** (16) adopted this procedure under the title "Modification with liquid polymers".

For mixes that contain steel fibers; the same procedure was used and the steel fibers were added after adding the (SBR), then the mixing was continued until the concrete becomes homogenous in consistency.

3.4 Casting, Compaction and Curing

The molds were lightly coated with mineral oil before using; concrete casting was carried out in three layers. Each layer was compacted by using a vibrating table for (15-30) seconds until no air bubbles emerged from the surface of concrete, and concrete is leveled off smoothly to the top of the molds. Then the specimens were kept covered with polyethylene sheet in the laboratory for (24) hrs, after that the specimens remolded carefully and marked. Specimens without polymer immersed in water until the age of test, while ***Folic*** and ***Randonjanin*** (2) method was used for curing the polymer modified concrete specimens by curing for (6) days in water and kept in air until test. The ages of test were (28) and (90) days for control, properties and impact tests.

3.5 High Velocity Impact Test

In this research, it is decided to study the possibility of improving the impact resistance of concrete by using polymers and both polymers and steel fibers with concrete.

Two group of circular slab specimens (500 mm) in diameter and (50 mm) thickness for each were tested under high velocity impact using 7.62 mm bullets. They were 16 specimens. The specifications of armor piercing bullet are given in Table (8).

Table (8) Specification of Armor Piercing Bullets

Bullets Dia. (mm)	Muzzle Velocity (m/sec)	Pressure (kg/cm^2)	Mass (gm)
7.62	714-756	2800	7.47-7.87
9.00	380-410	7047	7.32-7.87
12.7	810-825	3100	47.4-49.0

A special stand and circular support were designed and fabricated to be suitable for holding the specimens fabricated to withstand the impact (kinetic) energy of bullet in a stable fixed manner. The rig used in this test is shown in Plate (1).

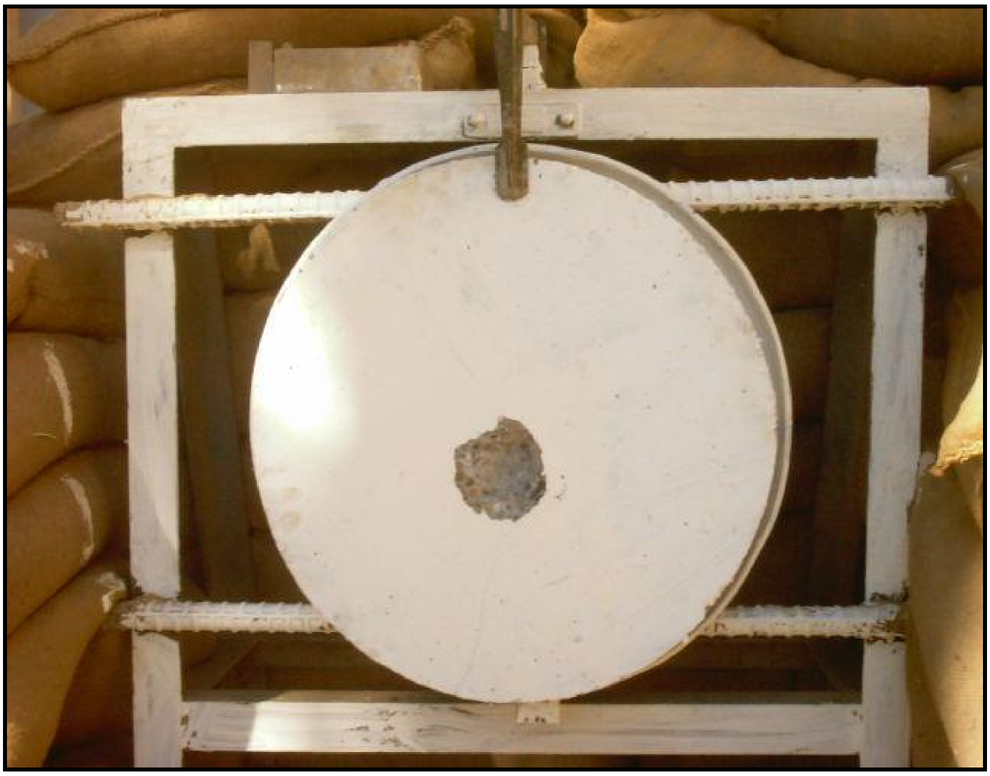


Plate (1) Test Rig Used for High Velocity Impact Test

After curing time of (90 days) the specimens were white painted , fixed in their positions and fitted carefully to avoid any movement. The machine gun was directed to the specimen center and each specimen was subjected to a single hit with horizontal shooting 15m distant . After shooting the penetration was measured using a graduated steel bar, and the general condition of the specimen after test was observed and photographed.

Companion specimens for mechanical properties were made. 100 mm cubes for compressive strength, 100 mm diameter 200mm height splitting tensile strength, (100×100×400 mm) prisms for flexural strength (modulus of rupture) were companionly used

4. Behavior of Concrete Specimens under High Velocity Impact

This test was done on disc concrete specimens (500 mm) in diameter and (50 mm) thickness by shooting bullets of (7.62 mm) caliber having a striking velocity of (720 m/sec.) from a distance of (15 m).

The results obtained from this test are presented in Table (9) and plotted in Figs (1), (2), and (3). These figures illustrate the relationship between the P/C ratio for concrete specimens, with and without steel fibers, with spalling, scabbing and penetration depth respectively.

From Table (9) and Fig (3), it can be seen that the results for polymer concrete specimens in general gave reduction in spalling area compared with reference mix.

Also from the same table and figures, it can be seen that the addition of steel fibers leads to additional reduction in spalling area, where the spalling area is less when compared with concrete specimens without steel fibers. this additional reduction in spalling areas might be due to the ability of steel fibers to absorb the high amount of energy because of its high tensile strength.

From Plate (2), it can be seen that the number of cracks, and also the length of cracks decrease with the increase in P/C ratio. This behavior might be due to the increase in strength and bond action of polymer at a distance from the center of contact zone when the intensity of energy decrease. Also it can be seen that the addition of steel fibers prevents the appearance of any crack, and this behavior might be due to the high ability of steel fibers to bond the matrix and absorbed high amount of energy.

From Table (9) and Fig (3) it can be seen that the area of scabbing is more than the area of spalling for all concrete mixes, this behavior is attributed to the reflection of compression wave from the front face to tensile wave in the back face of concrete specimens. Also it can be seen that the area of scabbing decreases with the increase in P/C ratio, which might be due to the increase in damping for concrete specimens containing polymer and also due to the increase in bond strength and tensile strength of concrete specimens with increase in P/C ratio .The reductions in scabbing area were (14.73 %) and (34.58 %) for concrete specimens with P/C ratios (8 %) and (12 %) respectively.

From Plate (2), it can be seen the high reduction in the number and type of cracks for concrete specimens with polymer compared with reference specimens, where the reference specimens have four long wide cracks, and this type of damage may illustrate the less area of scabbing compared with concrete specimens with (4 %) P/C ratio, where the impact energy scattered at fracture of specimen leads to increase the area of scabbing in reference specimens.

From the same Table and Fig (2), it can be seen that the area of scabbing decreases with the addition of steel fibers. This might be due to the presence of steel fibers which increases the ductility and leads to absorb high amount of energy. Also it can be seen that area of scabbing decreases with the increase in P/C ratio, this decrease might be due to the participation of polymer with steel fibers to improve the strength properties and increase ductility and absorption to impact wave. The reductions in scabbing area from the reference concrete were (64%) and (95.18%) for concrete specimens with steel fibers and with P/C ratio (8%) and (12%) respectively. From plate2, it can be seen that there is no crack in the back face of specimens, (this behavior was explained previously).

From Table (9) and Fig (3), it can be seen that there is a decrease in penetration depth with an increase in P/C ratio. This might be due to the increase in P/C ratio which leads to a decrease in W/C ratio and an increase in the strength properties and ductility of specimens. The reductions in penetration depth were (5.55%), (8.33%), and (16.67%) for concrete specimens with P/C ratios (4%), (8%), and (12%) respectively. Also, it can be seen that there is significant decrease in penetration depth with the addition of steel fibers and an increase in P/C ratio. This decrease might be due to the ability of steel fibers to strengthen the matrix and increase the bond between the steel fibers and matrix with an increase in P/C ratio. The reductions in penetration depth were (25%), (27.77%), (30.56%), and (38.89%) for steel fibers reinforced specimens with P/C ratios (0%), (4%), (8%), and (12%) respectively. From Plate (2), it can be seen that the addition of steel fibers leads to prevent more number of fragments to fly from the back face of concrete specimens which leads to more safety for users of buildings exposed to impact by projectiles or explosive loads.

Figures (4) to (9) show the relationship between compressive strength, splitting tensile strength , flexural strength and penetration depth for all concrete specimens without and with steel fibers at (90) days respectively. It can be seen that the increase in strength properties leads to a decrease in penetration depth, and this decrease in penetration depth might be due to the addition of polymer and steel fibers which leads to an increase in the strength properties and energy absorption then to a decrease in the penetration depth.

90 day concrete compressive strengths were ranged (48-64) MPa ,splitting tensile strength (4.2-7.8) ,and flexural strength (5-8) MPa corresponding to (36-30)mm penetration depth ,and (27-22) mm with fibers.

Tab 9 Results of High-Velocity Impact Resistance of Tested Specimens at Age of (90) Days

Symbol	P/C Ratio (%)	S.F (%Vol.)	Condition of the front face	Condition of the back face	Penetration depth(mm)
0	0	0	Spalling area(82.25cm^2)+Two long hair cracks	Scabbing area(204.65cm^2)+Four long wide cracks	36
1	4	0	Spalling area(67.5cm^2)+One long hair crack	Scabbing area(245.63cm^2)+One long hair crack	34
2	8	0	Spalling area(71.15cm^2)+One small hair crack	Scabbing area(174.5cm^2)+One long hair crack	33
3	12	0	Spalling area(53.13cm^2)+No crack	Scabbing area(133.87cm^2)+One long hair crack	30
0F	0	1	Spalling area(51.56cm^2)+No crack	Scabbing area(114.75cm^2)+No crack	27
1F	4	1	Spalling area(53.75cm^2)+No crack	Scabbing area(86.87cm^2)+No crack	26
2F	8	1	Spalling area(50.87cm^2)+No crack	Scabbing area(73.62cm^2)+No crack	25
3F	12	1	Spalling area(54.3cm^2)+No crack	Scabbing area(9.85cm^2)+No crack	22

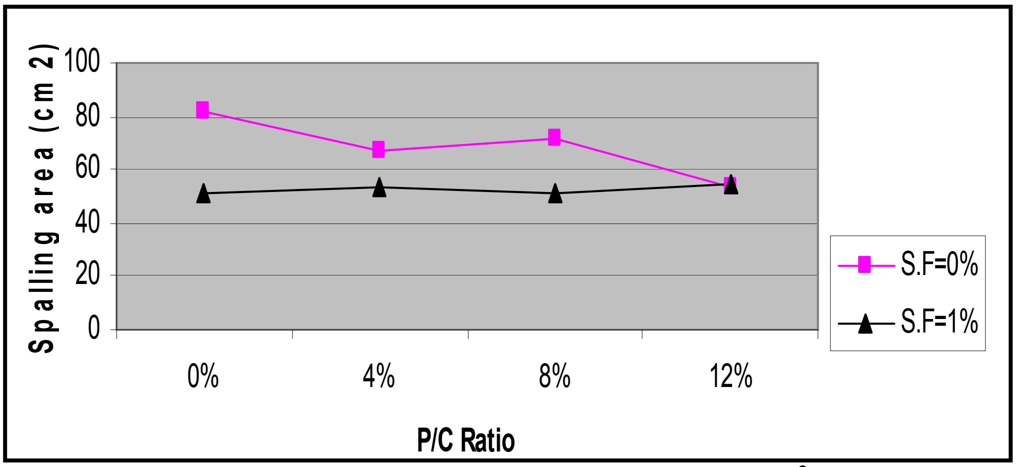


Fig. (١) Relationship between P/C Ratio and Spalling Area (cm^2)

for Concrete Slabs with and without Steel Fibers at (90) Days

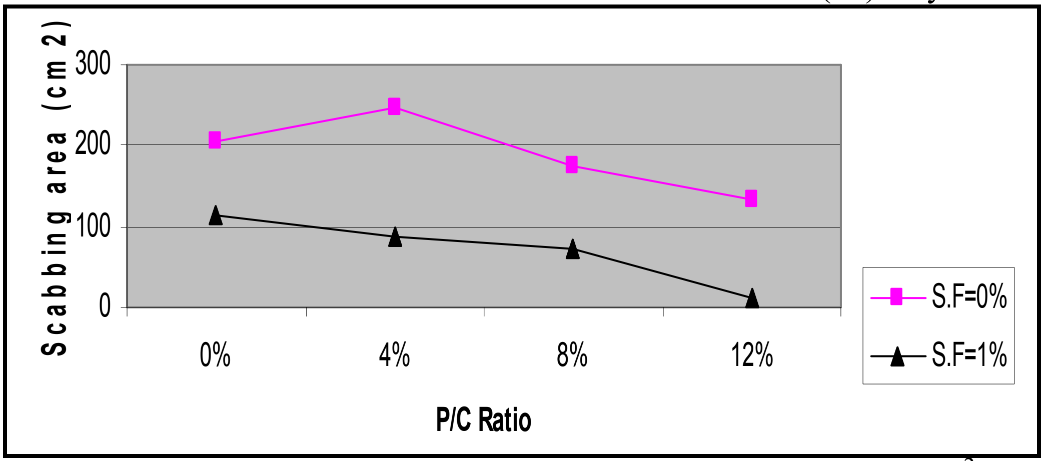


Fig. (2) Relationship between P/C Ratio and Scabbing Area (cm^2)
for Concrete Slabs with and without Steel Fibers at (90) Days

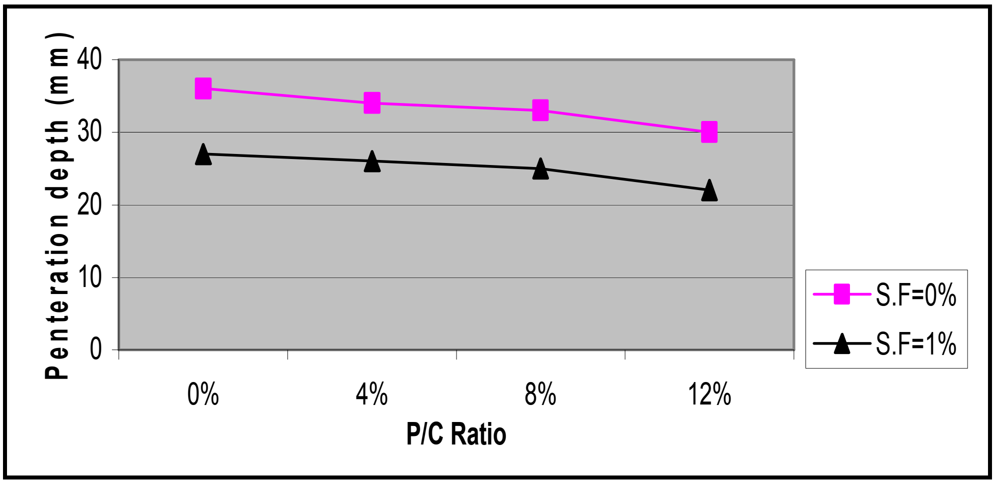


Fig. (3) Relationship between P/C Ratio and Penetration Depth (mm)
for Concrete Slabs with and without Steel Fibers at (90) Days

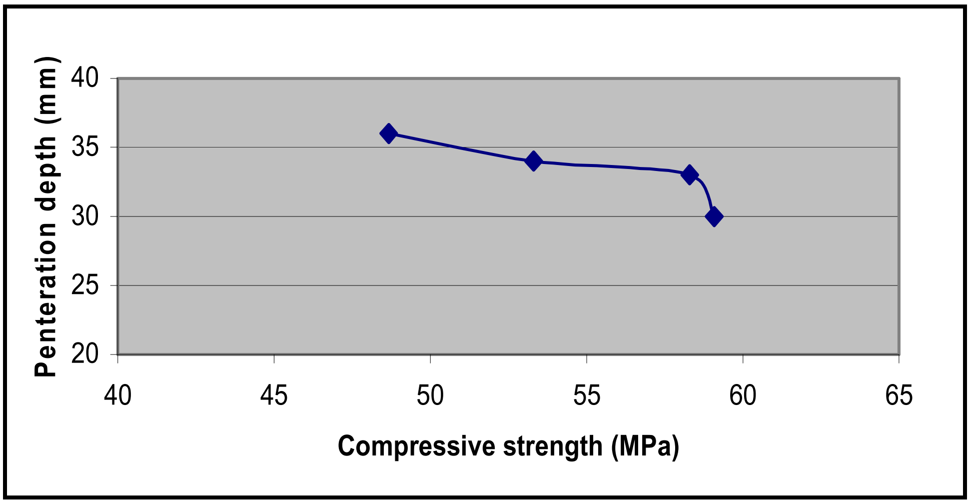


Fig. (4) Relationship between Compressive Strength and Penetration Depth (mm) for Concrete Specimens without Steel Fibers at (90) Days

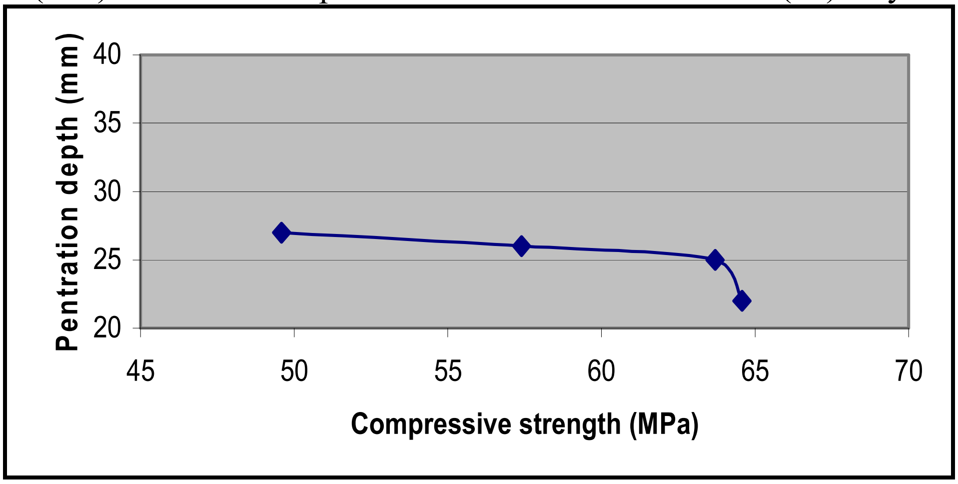


Fig. (5) Relationship between Compressive Strength and Penetration Depth (mm) for Concrete Specimens with (1%) by Volume Steel Fibers at (90) Days

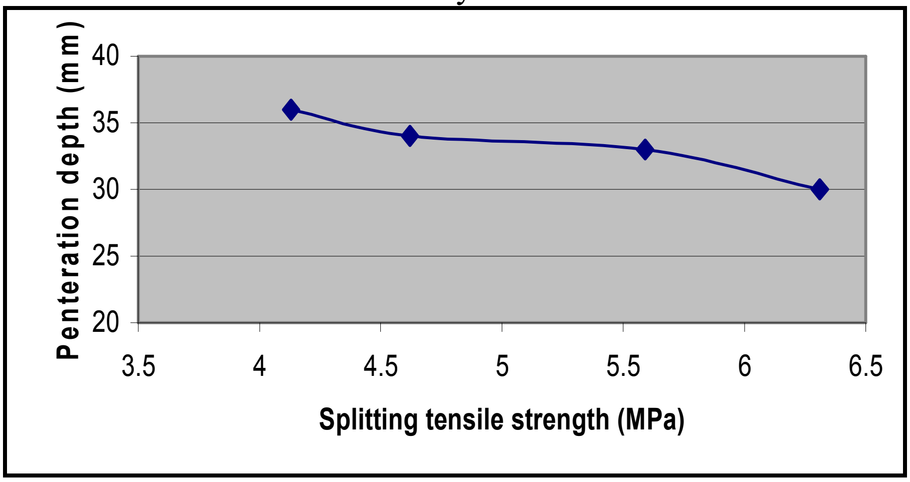


Fig. (6) Relationship between Splitting Tensile Strength and Penetration Depth (mm) for Concrete Specimens without Steel Fibers at (90) Days

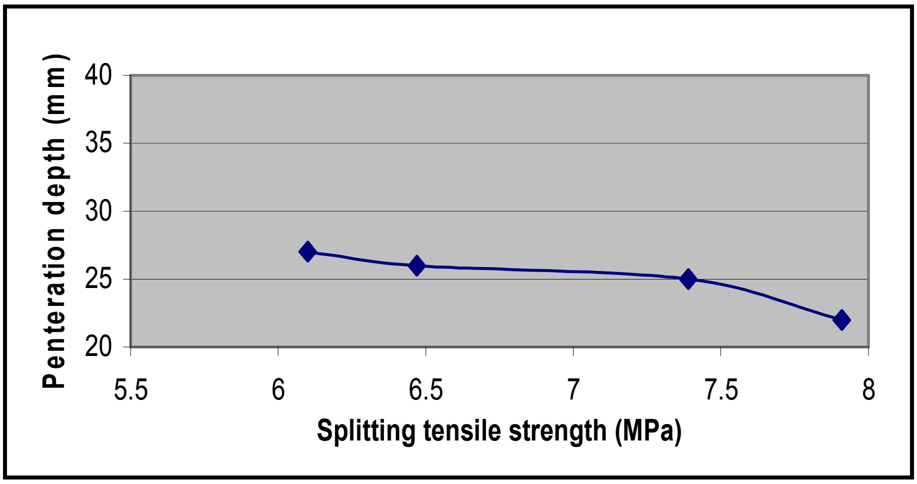


Fig. (7) Relationship between Splitting Tensile Strength and Penetration Depth (mm) for Concrete Specimens with (1%) by Volume Steel Fibers at (90) Days

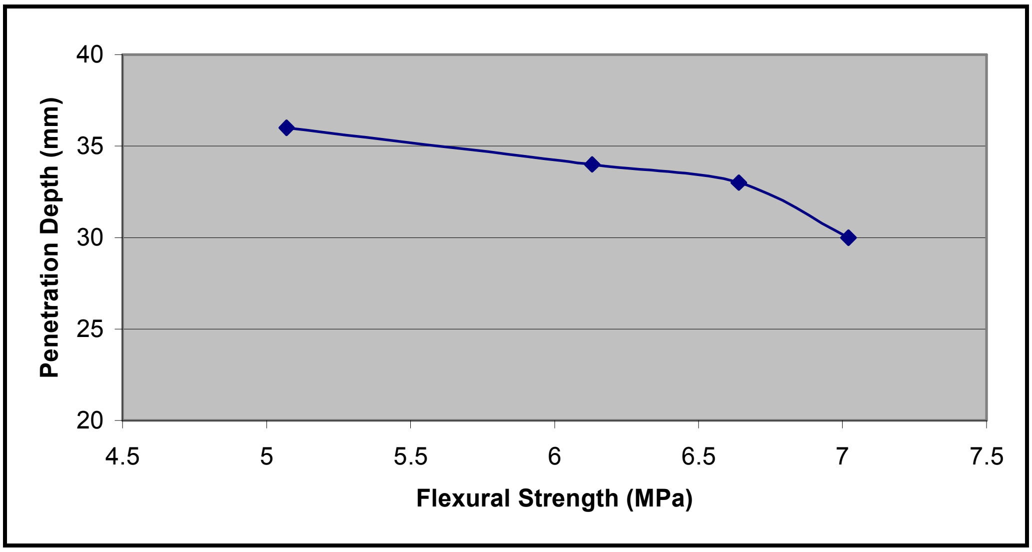


Fig. (8) Relationship between Flexural Strength and Penetration Depth (mm) for Concrete Specimens without Steel Fibers at (90) Days

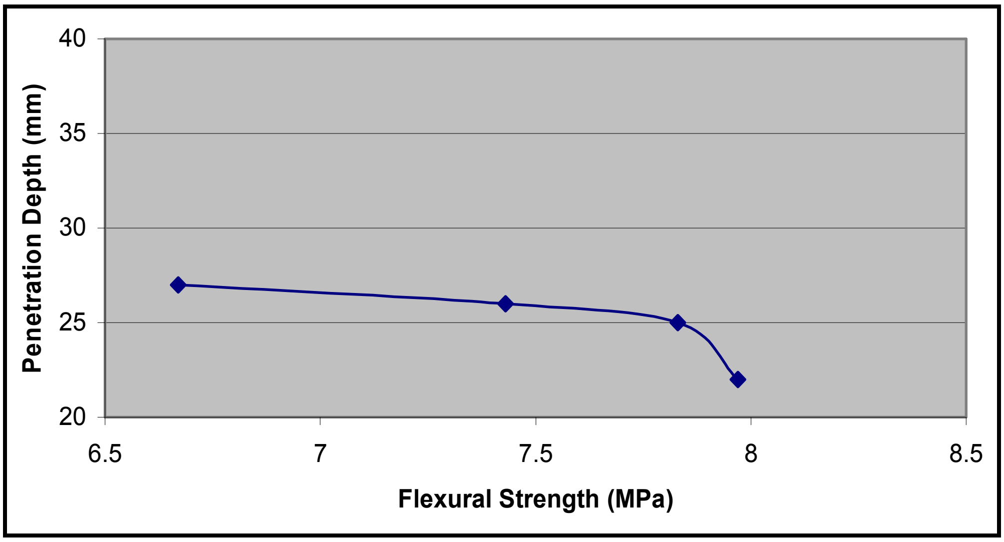
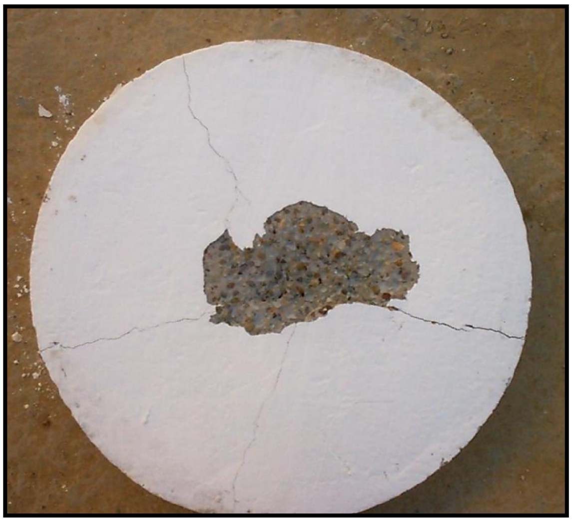
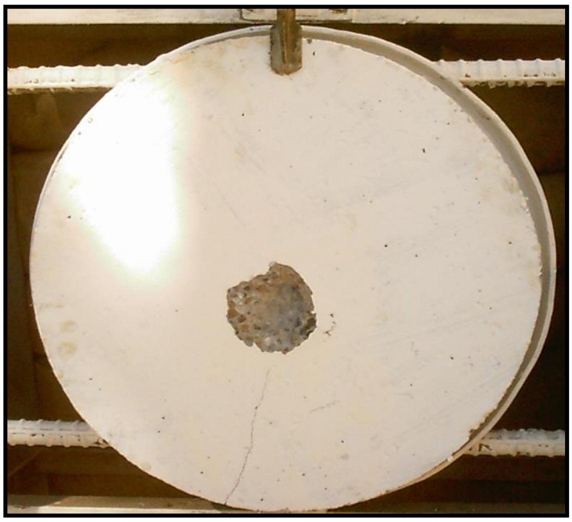


Fig. (9) Relationship between Flexural Strength and Penetration Depth (mm) for Concrete Specimens with (1%) by Volume Steel Fibers at (90) Days

(0)
Front Face



(0)
Back Face



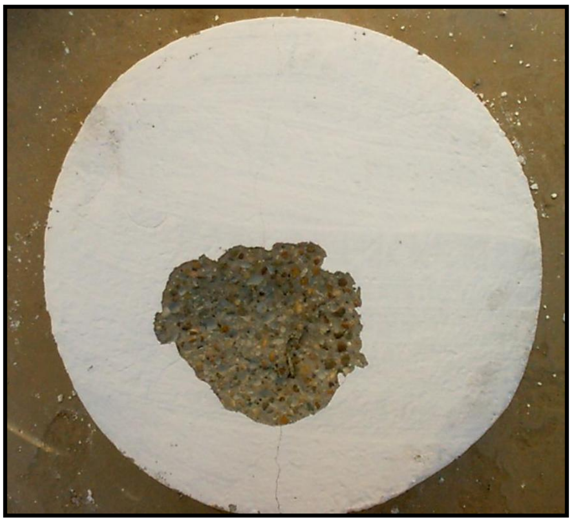
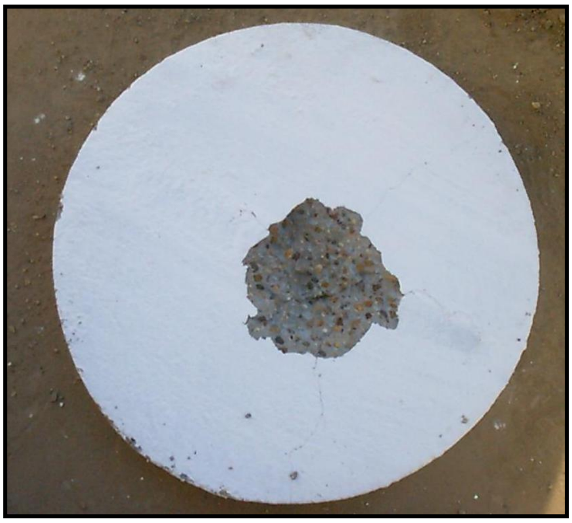
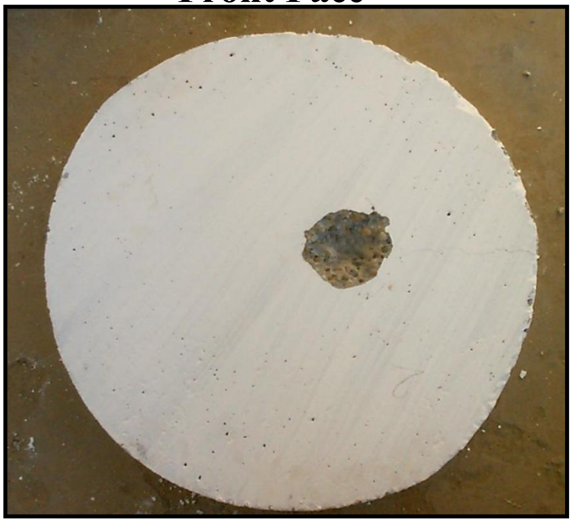


Plate (2) The Mode of Failure of Slabs Specimens under High Velocity Impact



(2)
Front Face

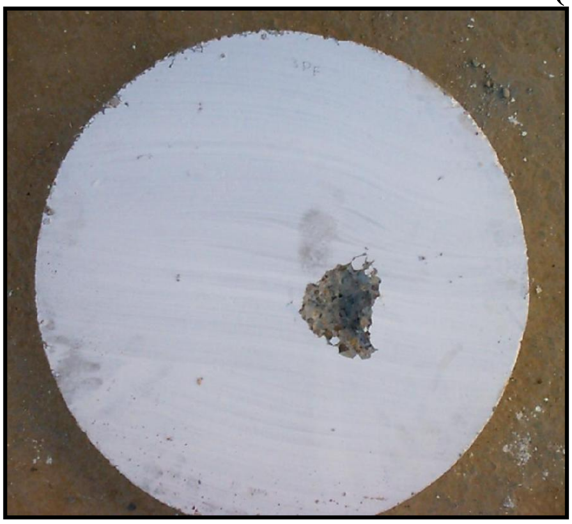
(2)
Back Face



(3)
Front Face

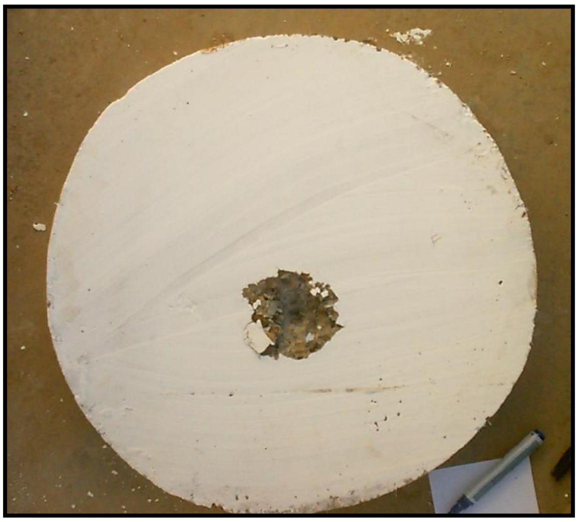
(3)
Back Face

Plate (2) Continued



(0F)
Front Face

(0F)
Back Face



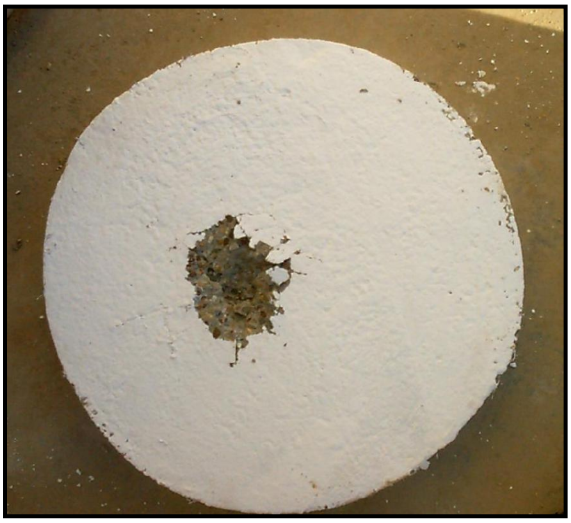
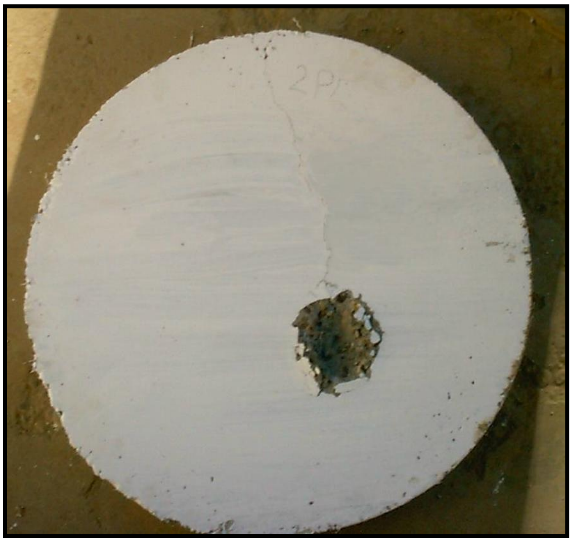


Plate (2) Continued

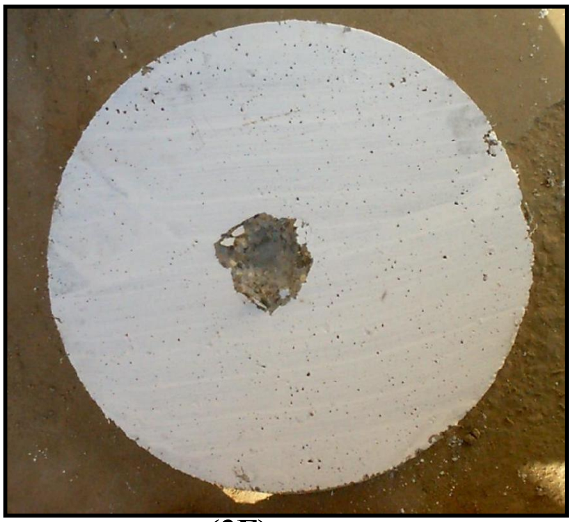
(1F)
Front Face

(1F)
Back Face



(2F)
Front Face

(2F)
Back Face



(3F)
Front Face

(3F)
Back Face

5. Conclusions

Features of high-velocity impact resistance for polymer modified concrete can be stated as follows:

1. Reduction in spalling area compared with reference concrete.
2. Addition of 1% by volume steel fibers resulted in further reduction in spalling area.
3. Addition of steel fibers resulted in prevention of the appearance of cracks.
4. Scabbing area was decreased in comparison with reference concrete, ranged between 14.7% and 34.6% corresponding to 8% and 12% P/C ratios, respectively. Addition of steel fibers of 1% by volume caused significant further decrease. The corresponding reductions over reference concrete were 64% and 95%, respectively.
5. Penetration depths of projectiles were decreased in polymer modified concrete over reference concrete. The decreases were 5.6%, 8.3% and 16.7% for P/C ratios 4%, 8% and 12% respectively. The addition of steel fibers caused significant further decrease. The corresponding reductions over reference concrete were 27.8%, 30.6% and 38.9% respectively.
6. Addition of steel fibers caused significant reduction in the number of fragmentations flying out of the back face of specimens.

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