

Behavior of Polymer Modified Concrete Slabs under Impact

Dr. Abdulkader Ismail Al-Hadithi
Lecturer
College of Eng./Al-Anbar University

Dr. Bya'n S. Al-Nu'man
Assist. Proff.
College of Eng./ Al-Mustansiriya University

الخلاصة

يتضمن هذا البحث دراسة مقاومة الصدم للخرسانة المطورة بالبولىمر الـ Styrene Butadiene Rubber (SBR). لقد تمت إضافة مادة البولىمر كنسبة مئوية من وزن السمنت حيث تم استخدام ثلاث نسب من (البولىمر:سمنت) وهي 3%، 5% و 10% لانتاج سلسلتين من الخرسانة المطورة بالبولىمر إحداهما المستوى الاول متوسط مقاومة الانضغاط والأخرى المستوى الثانى ذات مقاومة انضغاط أعلى من الاولى، كما وتم انتاج خلطتين مرجعيتين لغرض المقارنة.

أظهرت النماذج المصنعة من الخرسانة المطورة بالبولىمر تحسناً في مقاومة الصدم سواء في فحص الصدم ذو السرعة المنخفضة أو العالية. لقد كان مقدار الزيادة في مقاومة الانضغاط عن الخرسانة المرجعية يتراوح ما بين (7.14% - 28.79%)، فيما كانت اعلى مقدار للزيادة في قيمة معايير الكسر قدرها (26.64%).

لقد أُستخدم أسلوب الاسقاط الحر المتكرر لكرة فولاذية تزن 1300 غم لفحص الصدم بالسرعة المنخفضة. لقد استخدم هذا الفحص بثلاث ارتفاعات وهي 2400 مم، 1200 ملم و 830 ملم. أما فيما يخص فحص مقاومة الصدم ذو السرعة العالية فقد تم استخدام أسلوب رمي اطلاقه بقطر (7.62 ملم) تطلق من بندقية نصف آلية من نوع كلاشنكوف تبعد عن الهدف (بلاطة خرسانية) بمسافة قدرها 15م.

لقد كان هنالك تحسناً ملحوظاً في فحص مقاومة الصدم بالسرعة الواطئة حيث كانت أعلى قيم لزيادة هذه المقاومة لغاية المقاومة القصوى للنماذج المصنعة من الخرسانة المطورة بالبولىمر هي (33.33%، 75% و 83.33%) للفحوصات بارتفاعات 2400 ملم، 1200 ملم و 830 ملم على التوالي. أما فيما يخص فحص مقاومة الصدم بالسرعة العالية فلقد تم تسجيل أعلى نقصان في مساحة التقشر عن نماذج الخرسانات المرجعية قدره (18.5% - 26.4%) لكل من الخرسانة المطورة بالبولىمر ذات المقاومة المتوسطة والعالية على التوالي، فيما كان أعلى نقصان في مساحة التشظي عن نماذج الخرسانات المرجعية قدره (11.42% - 35.6%) لكل من الخرسانة المطورة بالبولىمر ذات المقاومة المتوسطة والعالية على التوالي.

Abstract:

This research includes the study of improving impact resistance of concrete using styrene butadiene rubber (SBR) with different weight ratios of polymer to cement 3%, 5% and 10%. Two series of polymer modified concrete (PMC) were produced the first level I with moderate compressive strength and the other level II with higher compressive strength. Cubes, prisms and panels were made as follows:

Results showed an improvement in impact resistance of polymer modified concrete (PMC) over reference concrete in low-velocity and high-velocity impact properties. In conducting low-velocity impact tests, method of repeated falling mass was used: 1300gm steel ball falling freely from three heights 2400mm, 1200mm and 830mm. In high-velocity impact tests, shooting of 7.62mm bullets was applied to slab specimens from distance of 15m. The improvements were significant in low velocity impact resistance. The maximum increases were (33.33%, 75% and 83.33%) at ultimate failure for falling mass heights 2400mm, 1200mm and 830mm respectively.

In high-velocity impact strength tests, maximum reductions recorded in spalling area were (18.5% and 27%) for polymer modified concrete (level I) with moderate compressive strength and polymer modified concrete (level II) with higher compressive strength.

Maximum reductions recorded in scabbing area were (11.42% and 35.6%) for polymer modified concrete (level I) with moderate compressive strength and polymer modified concrete (level II) with higher compressive strength, respectively.

1. Introduction

The concept of polymer modification for cement mortar and concrete is not so new, as in 1923 the first patent of the concept had already been issued to Cresson⁽¹⁾. This patent refers to paving materials with natural rubber latexes, and cement was used as a filler. The first patent with the present concept of polymer modification was published by Lefebure⁽²⁾ in 1924. Since then, considerable research and development of polymer modification for cement, mortar and concrete have been conducted in various countries for 70 years or more. As a result, many effective polymer modification systems for cement mortar and concrete have been developed, and currently are used in various applications in the construction industry.

1.1. Polymer Portland Cement Concrete (PPCC)

ACI Manual of Concrete Practice Part 5-1990⁽³⁾ defines Polymer Portland Cement Concrete (PPCC) mixtures as normal Portland Cement Concrete to which a water soluble or emulsified polymer has been added during the mixing process. As the concrete cures, hardening of polymer also occurs, forming a continuous matrix of polymer throughout the concrete.

1.2. Polymer Modification for Mortar and Concrete

The use of polymer modification for cement mortar and concrete is not new. In 1923 using polymers “as an admixture” which consists of polymeric compounds to improve properties such as strength, modulus of elasticity, water proof, durability of cement mortar and concrete was a patent issued to “Cresson”⁽¹⁾, this patent refers to paving material with natural rubber latexes and cement was used as filler.

In Japan, polymer modified mortar is most widely used as a construction material for finishing and repairing works, but polymer modified concrete (PMC) is seldom used because of its poor cost – performance balance, however, the PMC is widely used for bridge deck overlays and patching work in U.S.A; for example 1.2 million m² of bridge decks are overlaid with polymer modified concrete (PMC)⁽⁴⁾.

To produce polymer-modified mortar and concrete, mostly polymers in dispersion (latex or emulsion) form are added to ordinary cement mortar and concrete during mixing. Polymer-modified mortar and concrete have considerable attraction because their process technology is very similar to that of ordinary cement mortar and concrete. The polymer dispersions widely used are styrene-butadiene rubber (SBR) latex, ethylene-vinyl acetate (EVA), and polyacrylic ester (PAE) emulsion in Japan and Europe, and the styrene-butadiene rubber latex, polyacrylic ester emulsion, and epoxy (EP) resin in the United States. Annual consumption of the polymer dispersions in Japan has exceeded 100,000 tons in recent years. In Japan and Europe, the epoxy resin is rarely used as a polymeric admixture because it is more expensive than latex or emulsion polymers. In Europe, Japan, and the United States, redispersible polymer powders are produced by spray-drying polymer dispersions such as ethylene-vinyl

acetate and vinyl acetate-vinyl carboxylate emulsions, and often employed for the same purpose as polymer dispersions.

1.3.Principles of Polymer Modification

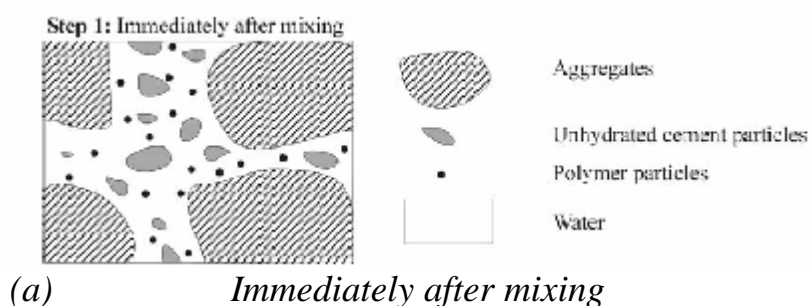
Although polymer-based admixtures in any form such as polymer latexes, water-soluble polymers and liquid polymers are used in cementitious composites such as mortar and concrete. It is very important that both cement hydration and polymer film formation (coalescence of polymer particles and the polymerization of resins) proceeds well to yield a monolithic matrix phase with network structure in which the cement hydrate phase and polymer phase interpenetrate. In polymer-modified mortar and concrete structures, aggregates are bound by such co-matrix phase, resulting in superior properties compared with conventional cementitious composite⁽⁵⁾.

Polymer latex modification of cement mortar and concrete is governed by both cement hydration and polymer film formation. The cement hydration process generally precedes the polymer film formation process by the coalescence of polymer particles in polymer latexes^(2,5). In due course both cement hydration and polymer film formation processes form a co-matrix phase. The co-matrix phase is generally formed according to the simplified model given by Ohama⁽²⁾, and integrated model by A. Beeldens, et al.⁽⁶⁾, shown in Fig(1).

Some chemical reactions happen between polymer and cement hydration that lead to improve the bond between cement hydrates and aggregates⁽²⁾.

Alaa' A. Laetif⁽⁷⁾ studied the effect of adding a polymer, which was an epoxy resin with hardener on the properties of the concrete. In this research (1/3) scale specimens consisted of cubes, cylinders, beams prisms and discs were prepared to investigate epoxy modification for the properties of concrete. It was found that the epoxy-modified concrete has higher mechanical properties, especially the splitting tensile strength. The extensibility of epoxy-modified concrete is largely increased with increasing polymer content.

The test results exhibit excellent improvement in durability properties of epoxy-modified concrete. In general, this study results indicate to that, the use of epoxy resin in concrete as an admixture improves many properties of Portland cement concrete.



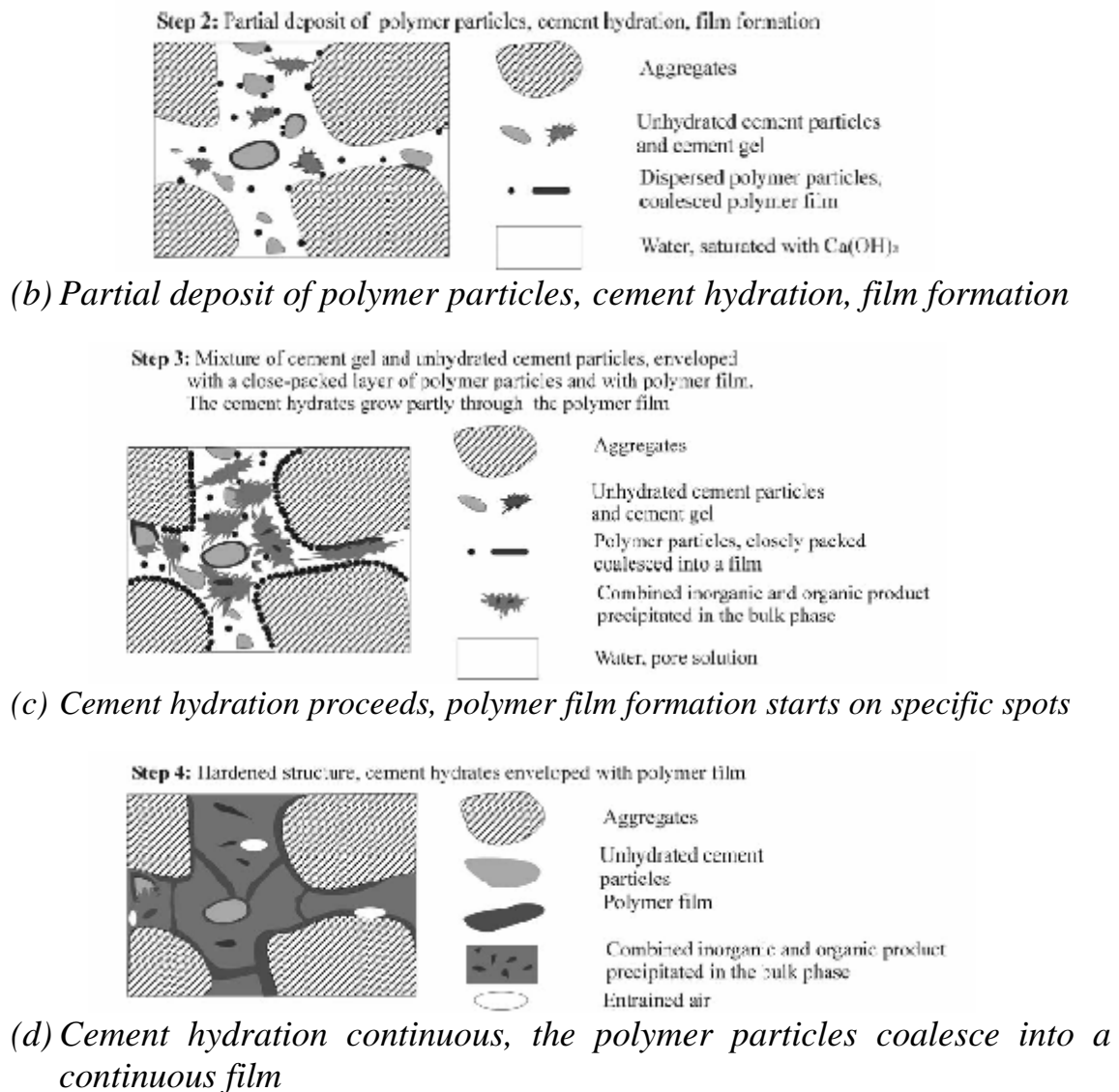


Fig.(1): Integrated model of structure formation ⁽²⁾.

1.4.Styrene Butadiene Rubber (SBR) Polymer Modified Concrete

SBR Polymer is the most widely used in concrete. Fig.(2), shows the chemical structure of Styrene butadiene Rubber latexes. Co-polymers of butidine with styrene (styrene-butadiene rubber (SBR)), are a group of large-volume synthetic rubbers⁽⁸⁾. High adhesion occurs between the polymer films that form and cement hydrates. This action gives less strain compared to ordinary concrete and improves the properties of concrete such as flexural and compressive strength and gives also a higher durability ⁽²⁾.

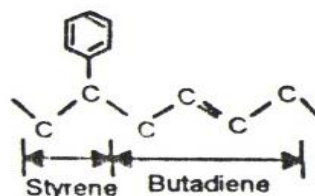


Fig.(2) Chemical structures of SBR polymer latexes ⁽⁸⁾

1.5.Impact in Polymer Concrete

J.Bhargava and A.Rehnstrom⁽⁹⁾ studied the dynamic impact of polymer cement concrete. Cylinders (100X200)mm were cast from plain and polymer cement concrete, some of the specimens were reinforced by polypropylene fibers also. The Hopkinson split bar method was used to find impact strength of specimens.

The dynamic strength of concrete obtained was 40-45% higher than the static strength. Polymer cement concrete showed 30-35% increase in dynamic strength over plain concrete. It was observed that for every concrete quality, there was an optimum stress transmission limit under dynamic loading.. If a specimen was subjected to higher amplitude pulses, there was no increase in transmitted stress, the excess energy being dissipated in fracturing.

Green⁽¹⁰⁾ suggested that the impact strength can be represented by the number of blows that concrete can withstand till there is no “no rebound” of the impacting device.

Qusai Kheder Hameed Al-Gasani⁽¹¹⁾ worked to improve impact and mechanical properties of concrete using SBR polymer with different weight ratios of polymer to cement. In this study steel fiber was also added to improve the properties of polymer modified concrete.

In conducting low-velocity impact tests, method of repeated falling mass was used: 1030gm steel ball falling freely from height of 2500mm. In high-velocity impact tests, shooting of 7.62mm bullets was applied on specimens 15m distance. Results of the study on properties of polymer modified concrete (PMC) show that:

- Clear improvement in all properties of polymer modified concrete (PMC) over reference concrete.
- Increase in compressive strength, splitting tensile and flexural strength is (15-30%), (13-40%) and (14-32%) respectively.
- Improvements is significant in low velocity impact resistance and it varies from 300% to 400% at ultimate failure and a mode failure shows a pronounced ductility.
- High-velocity impact strength decreases the projectile penetration depth to about (5-17%) and the scabbing area to about (15-35%).

Results of the study on properties of polymer modified concrete (PMC) including 1% by volume steel fibers show that:

- additional increase in all properties.
- Increase in compressive strength, splitting tensile strength and flexural strength is (18-38%), (52-85%) and (44-61%) respectively.
- Improvements are significant in low velocity impact resistance and it is 4375 % at ultimate failure and a mode failure show a pronounced ductility.
- High-velocity impact strength decreases the projectile penetration depth to about (28-39%) and the scabbing area to about (64-95%).

2. Materials and Test Methods

2.1. Cement

Sulphate resisting Portland cement from Al-Qa'em factory, conforming to Iraqi standard⁽¹²⁾, was used throughout the investigation. It was tested at National Center for Construction Laboratories and Researches.

2.2. Fine Aggregate

Natural sand from Al-Habaniya region in Al-Anbar Governorate was used in production of concrete specimens used in this study. Results of sieve analysis of this sand are shown in Table (1). It is shown that the sand confirms to Limits to the requirements of the Iraqi specification (IOS) No. 45-99⁽¹³⁾, zone (2).

Specific gravity and absorption of fine sand used were calculated according to ASTM - Designation: C 128-88⁽¹⁴⁾ and they were equal to 2.68 and 3% respectively. The sulfate content was equal to 0.35%.

2.3. Coarse Aggregate

Graded uncrushed coarse aggregate from Al-Jarayishi region in Al-Anbar Governorate was used for all concrete mixes in this study. The aggregates were conforming to the requirements of the Iraqi specification (IOS) No. 45-99⁽¹³⁾.

As shown in Table (2) which gives the sieve analysis results of that coarse aggregate. Specific gravity was equal to 2.79 and sulfate content was equal to 0.075%.

2.4. Mixing Water

Ordinary tap water was used in this work for all concrete mixes and curing of specimens.

2.5. Polymer

Styrene butadiene rubber (SBR) is used as polymer modifier in this study. Styrene butadiene, an elastomeric polymer, is the copolymerized product of two monomers, styrene and butadiene. Latex is typically included in concrete in the form of a colloidal suspension polymer in water. This polymer is usually a milky-white fluid. The Gulf International Chemicals Company, Oman, manufactured this polymer and the typical properties of SBR polymer is shown in Table (3). Other information is shown in Appendix (A). The polymer (SBR) was used as a ratio by weight of cement of 3%, 5% and 10%.

2.6. Plain Concrete Slab Specimens for Impact Resistance

For low and high velocity impact strength, square slabs of (500X500X50) mm were used. The moulds used for casting the slab specimens are shown in Plate(1).

2.7. Preparation of Concrete Specimens

A mechanical mixer of the capacity (0.07) m³ operated by electrical power was used. First of all aggregates and cement were added before adding polymer and dry mixing were continued until the dry mix became homogenous, then the polymer was added until all particles are fully coated with polymer and finally water were added

and mixing continues until uniform mix is obtained. This procedure is similar to the method used by Ohama⁽⁴⁾.

2.8. Mix Proportions

Two groups of mixes were used in this research. Table (4) shows the mix proportions of materials used in this work.

2.9. Casting, Compacting and Curing

The moulds were lightly coated with mineral oil before use, according to ASTM C192-88⁽¹⁵⁾, concrete casting was carried out in three layers. Each layer was compacted by using a vibrating table until no air bubbles emerged from the surface of concrete and the concrete is levelled off smoothly to the top of moulds. Then the specimens were kept in the laboratory for about (24) hrs. After that the specimens remoulded carefully and for two days immersed in water for polymer concrete specimens, whereas the control specimens immersed in water for (14) days. For the beam specimens the vibrating was done internally using immersing vibrator.

2.10. Compressive Strength Test

Compressive strength was determined using (100X100X100) mm cubes according to B.S.1881 part 116⁽¹⁶⁾. ELE machine with a capacity of (1000) kN was used for that test. The average compressive strength of three cubes was recorded.

2.11. Flexural Strength Test

(100X100X500)mm Concrete Prisms were prepared according to ASTM C192-88⁽¹⁵⁾. Two point load test was carried out according to ASTM C78-94⁽¹⁷⁾ using ELE (50)kN capacity machine. Average modulus of rupture of two prisms was obtained.

2.12. Impact Tests

2.12.1. Low Velocity Impact Test

Twenty four, 91-day age (500X500X50) mm slab specimens were tested under low velocity impact load. The impact was conducted using 1300gm steel ball dropping freely from heights 2.4m, 1.2m and 0.83m. The test rig used for low velocity impact test is shown in Plate(2). Specimens were placed in their position in the testing frame with the finished face up. The guiding pipe is then placed in a position. The mass was then dropped repeatedly and the number of blows required to cause first crack was recorded. The number of blows required for failure (no rebound) was also recorded.

2.12.2. High Velocity Impact Test

Slabs with the same dimensions of low velocity impact specimens were used in this test. Eight slab specimens were tested at 91 days of age. The slabs were fixed in vertical position carefully to avoid movement. Centres of the slabs were indicated by soft pen. Slabs were tested under high velocity impact using 7.62mm bullets. The specifications of armor piercing bullet are given in Table(5).

Table (1): Sieve Analysis Results of the Sand Used.

Sieve Size	Accumulated percentage passing	Limits of Iraqi Specifications No. 45:1999 ⁽¹³⁾ Zone 2
4.75mm	100	90-100
2.36mm	96.3	75-100
1.18mm	77.6	55-90
600micron	50	35-59
300micron	32	8-30
150micron	12.5	0-10

Table (2): Sieve Analysis Results of the Gravel Used.

Sieve Size	Accumulated percentage of passing %	Limits of Iraqi Specifications No. 45:1999 ⁽¹³⁾
14.0	100	100
10.0	94.75	85-100
5.0	9.25	0-25
2.36	0	0-5

Table (3): Typical Properties of Styrene Butadiene Rubber(SBR) Polymer.

No	Properties	Description
1	Appearance	White emulsion
2	Specific Gravity	1.03 ± 0.02 @ 25°C
3	PH Value	9±2
4	Freeze/Thaw Resistance	Excellent
5	Chloride Content	Nil
6	Flammability	Non-flammable
7	Compatibility	Can be used with all types of portland cement

*Properties are obtained from the product catalogue⁽¹⁸⁾

Table (4): Mix Proportions of Materials Used in this Work for Making One Cubic Meter of Concrete.**a-Concrete Level I with Moderate Compressive Strength.**

Symbol	Cement (kg)	Gravel (kg)	Sand (kg)	Water Liter	Polymer (liter)			W/C %	(P+W)/C %	Slump (mm)
					Mixture of polymer	Liquid Polymer (33%)	Water (66.67%)			
RM*	340	1385	515	183.92	-	-	-	0.54	-	70
PM3	332.8	1355.8	504.2	169	10	3.32	6.67	0.50	0.54	80
PM5	330.8	1347.6	501.16	162	16.54	5.52	11.02	0.49	0.54	100
PM10	326	1327.6	493.76	143.4	32.6	10.8	21.6	0.44	0.54	125

b-Concrete Level II with Higher Compressive Strength.

Symbol	Cement (kg)	Gravel (kg)	Sand (kg)	Water Liter	Polymer(liter)			W/C %	(P+W)/C %	Slump (mm)
					Mixture of polymer	Liquid Polymer (33%)	Water (66.67%)			
RH*	550	985	656.8	214.5	-	-	-	0.39	-	75
PH3	538	963.6	642.6	191.39	16.15	6.12	11.124	0.36	0.39	95
PH5	525.1	940.67	627.2	178.5	26.26	9.57	17.5	0.34	0.39	142
PH10	512.2	917.32	611.72	148.56	51.22	18.9	34.14	0.29	0.39	155

*Water curing (14)days, whereas all the other mixes were (2) days water curing.

For symbols the letters which were used mean as below:

R: Reference

M: Moderate compressive strength

P: Polymer

Number (like 3): Polymer content as a percentage by weight of cement content

H: Higher compressive strength

Table (5): Specifications of Armor Piercing Bullets⁽¹¹⁾.

<u>Bullets Dia.</u> (mm)	<u>Muzzle Velocity</u> (m/sec)	<u>Pressure</u> (kg/cm ²)	<u>Mass</u> (gm)
7.62	714-756	2800	7.47-7.87

3. Results and Discussion:

3.1. Behavior of Concrete Slabs under Low Velocity Impact:

Low velocity tests results are performed in terms of the number of blows required to cause ultimate failure. These tests were applied to square slabs of dimensions (500X500X50)mm subjected to repeated impact blows by falling mass (steel ball) of 1300 gm dropped from three heights (2.4)m, (1.2)m and (0.83)m at (91)day age. The effect of (P:C) ratio on the impact resistance of concrete slabs are showed in Table (6).

From Table (6), Fig.(3), Fig.(4) and Fig.(5) it can be seen that the addition of polymer leads to increase in the impact resistance when compared with the references mixes. This may be attributed to the role of polymer itself in increasing impact resistance^(19,20), and consequently the impact energy absorption capacity.

The comparisons among impact resistances in different heights for polymer modified concretes with moderate compressive strength and polymer modified concretes with higher compressive strength are shown in Figs.(5) and (6). From Fig.(3) and Fig.(5) it can be seen that, polymer modified concrete level I with moderate compressive strength has a maximum impact resistance equal to (5 blows to ultimate failure) for concrete mix with (P:C) ratio equal to (5%) at (2.4m) height of falling mass, (7 blows to ultimate failure) for concrete mix with (P:C) ratio equal to (5%) at (1.2m) height of falling mass and (11 blows to ultimate failure) for concrete mix with (P:C) ratio equal to (5%) at (0.83m) height of falling mass .

From Figs.(4) and (6) it can be seen that, polymer modified concrete level II with higher compressive strength has a maximum impact resistance equal to (5 blows

to ultimate failure) for both concrete mixes with (P:C) ratio equal to (3%) and (5%) at (2.4m) height of falling mass, (9 blows to ultimate failure) for concrete mix with (P:C) ratio equal to (10%) at (1.2m) height of falling mass and (13 blows to ultimate failure) for concrete mix with (P:C) ratio equal to (5%) at (0.83m) height of falling mass .

From the Figures mentioned above it can be seen that the impact resistance represented by number of blows until failure decreases with the increasing in falling mass height. That might be due to an increase in strike force with an increase in the falling mass height, and that means an increase in the absorbed energy by concrete slab body in each strike, and that leads to distribution of the total impact energy on the fewer number of blows until failure.

From Table (6) and Fig.(7), it can be seen that the increase in (P:C) ratio leads to an increase in impact resistance. For polymer modified concrete level II with higher compressive strength the maximum percentages of increase in impact resistance over reference mix are equal to (44.44%) , (50%) and (25)% for mixes PH5 , PH10 and (both PH3 and PH5) for falling mass heights (0.83m), (1.2m) and (2.4m) respectively.

For polymer modified concrete level I with moderate compressive strength the maximum percentages of increasing in impact resistance over reference mix are equal to (83.33%) for mixes (PM3 and PM5) at (0.83m) falling mass height, (75%) for (PM5) mix at falling mass equal to (1.2)m in high and (33.33)% for (PM5) mix at falling mass height equal to (2.4)m. This means that the role of polymer in impact resistance is more pronounced at moderate strength.

3.2. Relationship between Impact Resistance and Compressive Strength:

Figs.(8) and (9) show the relationships between Impact resistance and compressive strength for polymer modified mixes used in this research. It can be seen from these figs. that, the increase in compressive strength leads to an increase in impact resistance and this increase depends on the (P:C) ratio.

From best fitting of curves in GRAPHER software several empirical formula are suggested for relationships between impact resistance and compressive strength at (91)day age for polymer modified concrete.

For (2.4)m height of falling mass the empirical formula is:

$$I . R . = 0 . 111008 \times f_{cu} \dots\dots\dots(1)$$

Coefficient of determination (R^2)=0.98

For (1.2)m height of falling mass the empirical formula is:

$$I . R . = 0 . 172788 \times f_{cu} \dots\dots\dots(2)$$

Coefficient of determination (R^2)=0.97

For (0.83)m height of falling mass the empirical formula is:

$$I . R . = 0 . 239654 \times f_{cu} \dots\dots\dots(3)$$

Coefficient of determination (R^2)=0.97

where :

$I . R .$ = Impact resistance (Number of Blows)

f_{cu} = Compressive strength at (91) day age in (Mpa)

3.3. Relationship between Impact Resistance and Flexural Strength:

The relationships between impact resistance and flexural strength for polymer modified concrete are shown in Fig.(9). From this Figure it can be seen that the increase in flexural strength leads to an increase in impact resistance. From best fitting of curves in GRAPHER Software several empirical formula are suggested for relationships to connect impact resistance at (91)day age and flexural strength at (28)day age for polymer modified concrete as given below:

For (2.4)m height of falling mass the empirical formula is:

$$I.R. = 1.06402 \times f_r \dots\dots\dots(4)$$

Coefficient of determination (R^2)=0.98

For (1.2)m height of falling mass the empirical formula is:

$$I.R. = 1.67902 \times f_r \dots\dots\dots(5)$$

Coefficient of determination (R^2)=0.98

For (0.83)m height of falling mass the empirical formula is:

$$I.R. = 2.30234 \times f_r \dots\dots\dots(6)$$

Coefficient of determination (R^2)=0.96

where :

$I.R.$ = Impact resistance at (91) day age (Number of Blows).

f_r =Flexural strength at (28) day age in (Mpa).

Relationships above lead to the fact that, the increase in strength properties due to the addition of SBR polymer leads to an increase in impact resistance. An increase in strength properties is due to modification of concrete by SBR polymer and that leads to building strong microstructure due to continuous three-dimensional network of polymer molecules throughout concrete which increases the binder system due to good characteristics of SBR polymer as mentioned before in the preceding chapters.

3.4. Mode of Failure under Low Velocity Impact:

Plates (2),(3) and (5) show the failure of top face of slabs specimens for three heights of falling mass, which were tested in this research. From these plates it can be seen that, for all slabs used in low velocity impact tests, the crack starts from the point of contact between the slab and the falling mass (center of slab) and propagates in length across of specimens dimensions until fractured into separate pieces (ultimate failure).

It is obvious from these plates that, the lines of failure at lowest height of falling mass which is equal to (0.83) m are not straight in direction, whereas the lines of failure for slabs subjected to falling mass from heights equal to (1.2 and 2.4) m are straight.

For impact test in which the height of falling mass equals (2.4) m, most of the slabs reach the ultimate failure without the occurrence of the first crack, except PM5 and PH3 mixes. For low velocity impact tests with falling mass failure of unmodified concrete was more brittle than that latex of modified concrete slabs. The slabs made of

references mixes reach the first crack and ultimate failure at number of blows less than that of the slabs made of polymer modified concrete.

3.5. Behaviour of Concrete Slabs under High Velocity Impact:

High velocity impact test was done on (500X500X50)mm slabs by shooting bullets of (7.62)mm caliber having a striking velocity of (720 m/sec) from a (15)m distance. Table(7) shows the results obtained from that test. Figs (12), (13) and (14) illustrate the relationship between (P:C) ratio for slabs made of polymer modified concrete with moderate compressive concrete and higher compressive strength and spalling and scabbing. From the Table and Figs. mentioned above, it can be seen that, polymer modified concrete level II with higher compressive strength slabs in general give reduction in spalling area compared with reference mix, whereas for polymer modified concrete level I with moderate compressive strength slabs the reduction was recorded only in specimens with highest (P:C) ratio (10%). From the same Table and Figures it can be seen also that, the addition of polymer leads to decreasing the scabbing area when compared with reference mixes for both polymer modified concrete level I with moderate compressive strength and polymer modified concrete level II with higher compressive strength.

In general, areas of spalling of polymer modified concrete level I with moderate compressive strength slabs are less than those of polymer modified concrete level II with higher compressive strength, whereas the area of scabbing of polymer modified concrete level I with moderate compressive strength slabs is greater than that of polymer modified concrete level II with higher compressive strength. Generally, the spalling area at front face is less than the scabbing area at back face for all concrete slabs, this behaviour is attributed to the reflection of compressive wave from the front face to tensile wave in the back face of concrete specimens. It can be seen also that, the area of scabbing decreases with the an increase in damping for concrete specimens containing polymer and also due to the increase in bond strength and tensile strength of concrete slabs with an increase in (P:C) ratio⁽⁴⁴⁾.

From Plate (6), it can be seen that the number of cracks, and the length of cracks decrease with the increase in (P:C) ratio. This behaviour might be due to an increase in strength and bond action of the polymer structure within at the distance from the center of contact zone when the intensity of energy decreases. For polymer modified concrete level I with moderate compressive strength slabs there are cracks on the back face for all slabs, whereas there are cracks on the front space for slabs made of RM and PM3 mixes only. For polymer modified concrete level II with higher compressive strength only reference mix (RH) has a crack on the both sides, whereas the concrete slabs modified by the addition of polymer do not have any crack on any side.

All slabs were perforated in this test.

Table(6):Number of Blows that Caused First Crack and Ultimate Failure and the Percentages Increase about References Mixes.

Mix	RM	PM3	PM5	PM10	RH	PH3	PH5	PH10
No. of blows at first crack for (2.4m) falling mass height	3	4	4	4	4	5	4	4
No. of blows at (2.4m) falling mass height	3	4	5	4	4	5	5	4
(%)Increasing in No.of blows over References mix.	0	33.33	66.67	33.33	0	25	25	0
No. of blows at first crack for (1.2m) falling mass height	3	5	5	5	6	6	6	8
No. of blows at (1.2m) falling mass height	4	6	7	6	6	8	7	9
(%)Increasing in No.of blows over References mix.	0	50	75	50	0	33.33	16.67	50
(%)Increasing in No.of blows over (2.4m)	33.33	50	40	50	50	60	40	125
No. of blows at first crack for (0.83m) falling mass height	5	6	9	5	8	9	12	9
No. of blows at (0.83m) falling mass height	6	7	11	7	9	10	13	10
(%)Increasing in No.of blows over References mix.	0	16.67	83.33	16.67	0	11.11	44.44	11.11
(%)Increasing in No.of blows over (2.4m)	100	75	120	75	125	100	160	150

Table (7): Results of High-Velocity Impact Resistance of Tested Slabs at Age of (91) Days

Mix.	(P:C)%	Condition of the Front Face	Condition of the Back Face
RM	0	Spalling area (113.1)cm ² + 3 long hair cracks.	Scabbing area (56.74)cm ² + 2 long hair cracks + one short hair crack .
PM3	3	Spalling area (110)cm ² + 3 long hair cracks.	Scabbing area (79.1)cm ² + 3 long hair cracks.
PM5	5	Spalling area (92.2)cm ² + no hair cracks.	Scabbing area (61.3)cm ² + 2 long hair cracks.
PM10	10	Spalling area (112.6)cm ² + no hair cracks.	Scabbing area (50.3)cm ² + 2 long hair cracks.
RH	0	Spalling area (106.9)cm ² + 2 long hair cracks.	Scabbing area (74.7)cm ² + 2 long hair cracks + one short hair crack .
PH3	3	Spalling area (95)cm ² + no hair cracks.	Scabbing area (70.9)cm ² + no hair cracks.
PH5	5	Spalling area (91)cm ² + no hair cracks.	Scabbing area (66.5)cm ² + no hair cracks.
PH10	10	Spalling area (78)cm ² + no hair cracks.	Scabbing area (48.1)cm ² + no hair cracks.

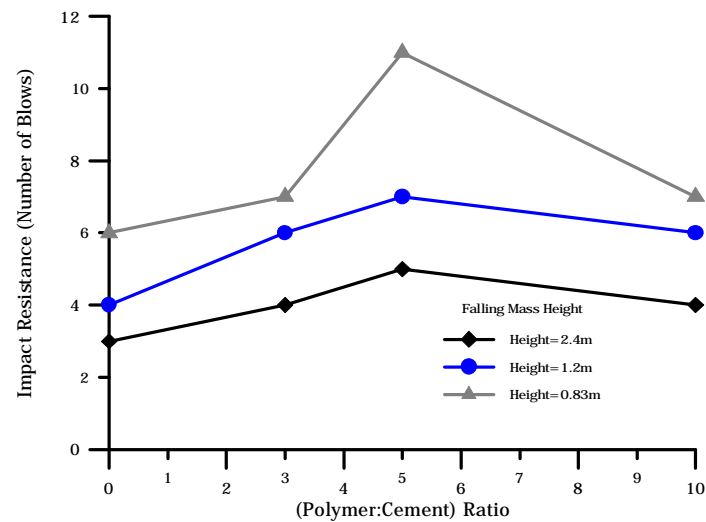


Fig.(3): Relationship between (P:C) Ratio and Impact Resistance at 91 day for Concrete Mixes with Moderate Compressive Strength.

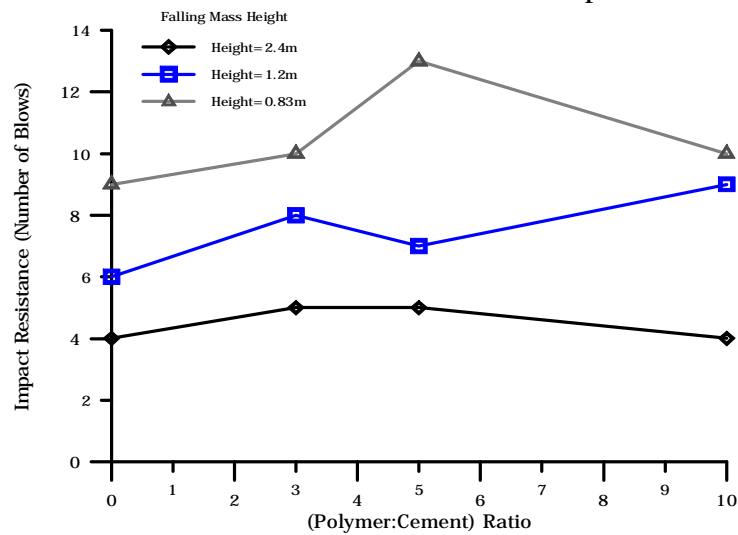


Fig.(4): Relationship between (P:C) Ratio and Impact Resistance at 91 day for Concrete Mixes with Higher Compressive Strength.

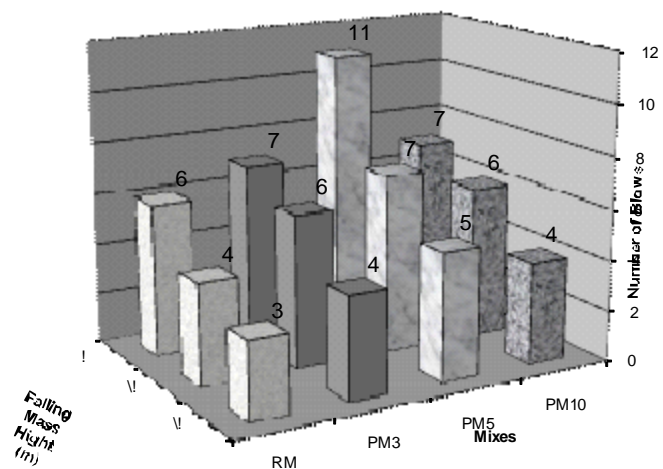


Fig.(5): Comparison of Impact Resistance between Concrete Mixes with Moderate Compressive Strength at 91 day.

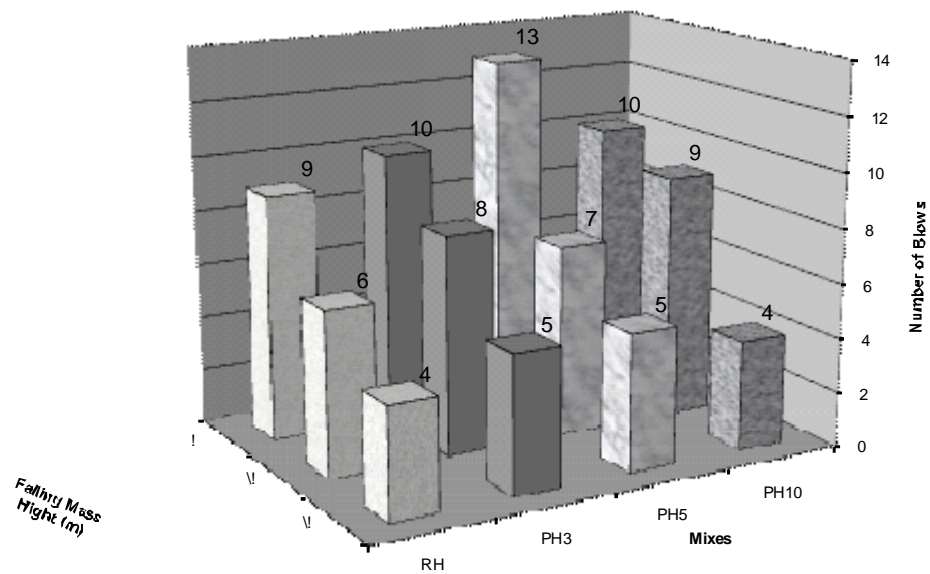


Fig.(6):Comparison of Impact Resistance between Concrete Mixes with Higher Compressive Strength at 91 day.

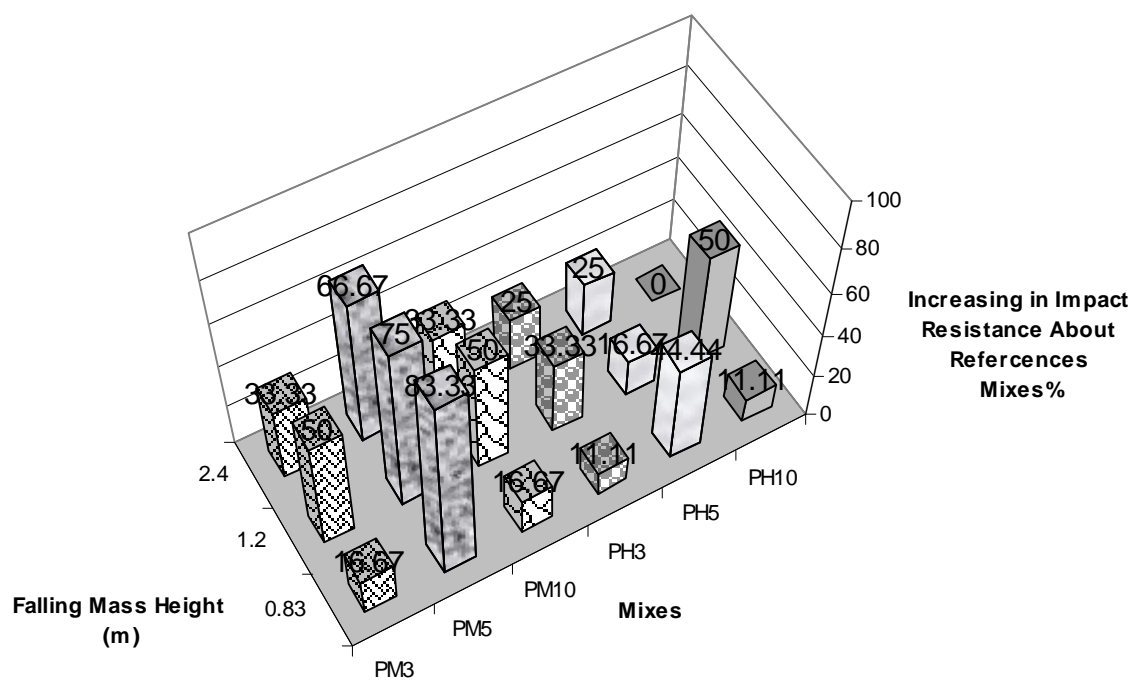


Fig.(6-5):Comparison of an Increasing of Impact Resistance about References Mixes for All Mixes at 91 day.

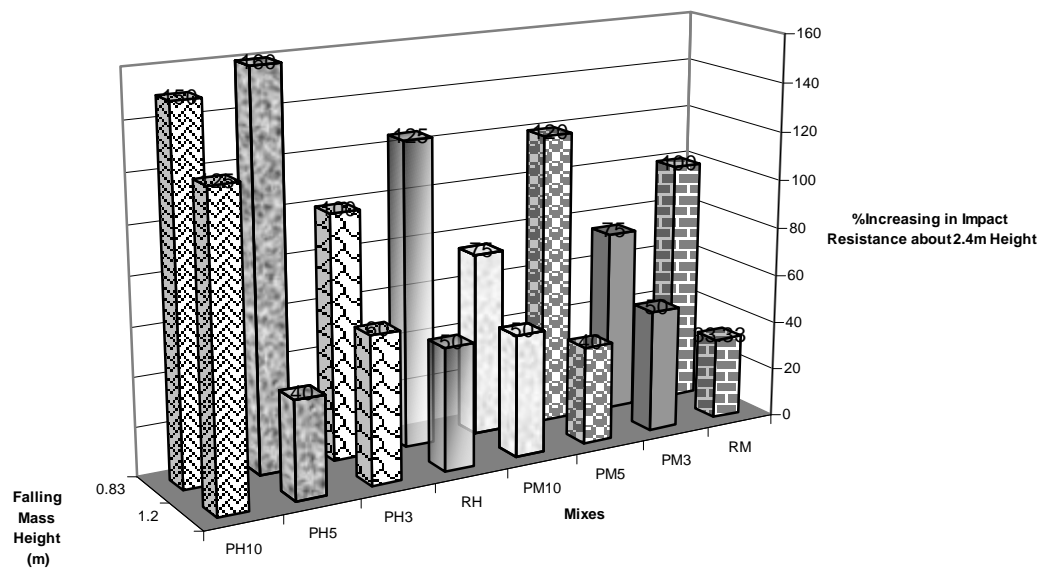


Fig.(7):Comparison of an Increasing of Impact Resistance about (2.4m) Falling Mass Resistance for All Mixes at 91 day.

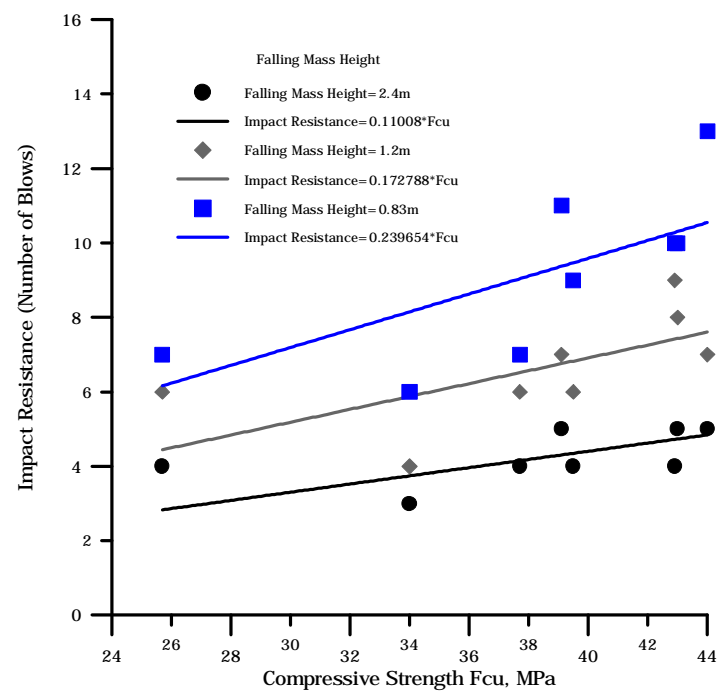


Fig.(8):Relationships between Compressive strength and Impact Resistance at 91 day age for all Concrete Slabs.

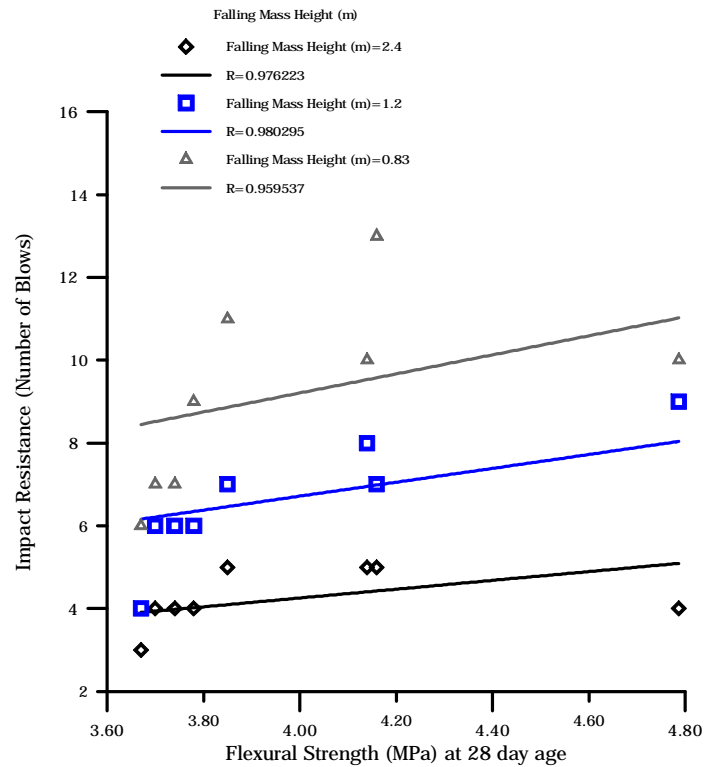


Fig.(9):Relationships between Flexural at 28 day strength and Impact Resistance at 91 day for all Concrete Slabs.

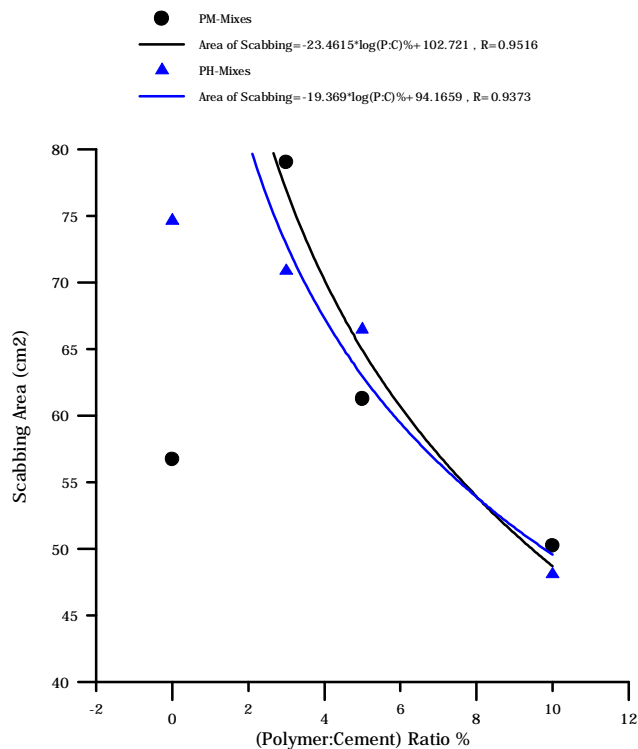


Fig.(10):Relationships between (P:C) ratio and Scabbing Area at High Velocity Impact Test for all Concrete Slabs at 91 day.

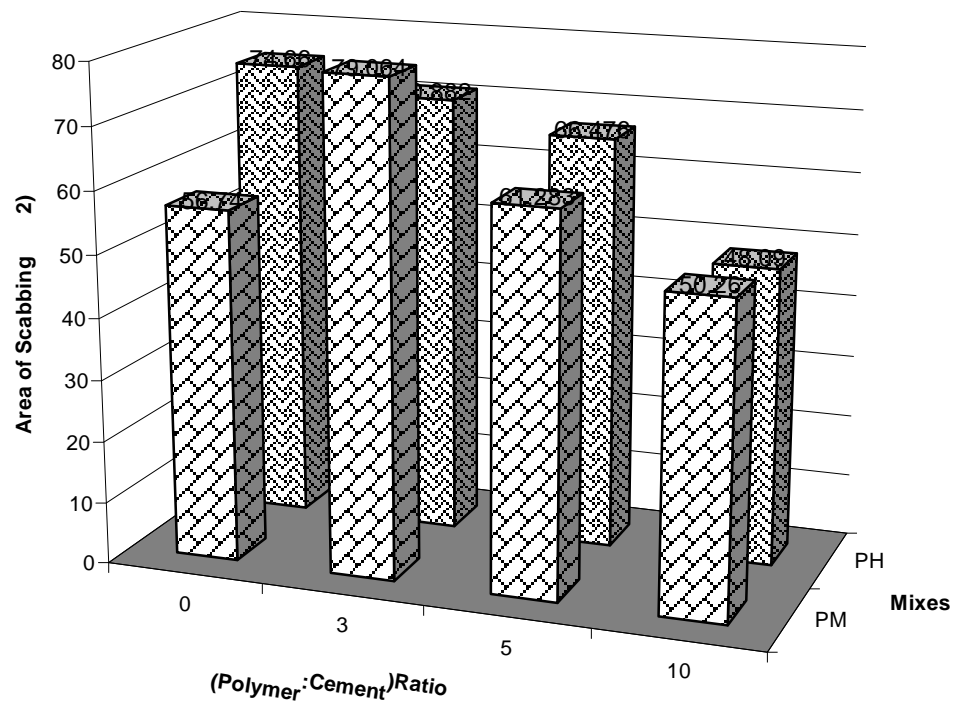


Fig.(11):Comparison of Area of Scabbing for different (P:C)Ratio at High Velocity Impact Test for All Concrete Slabs at 91 day.

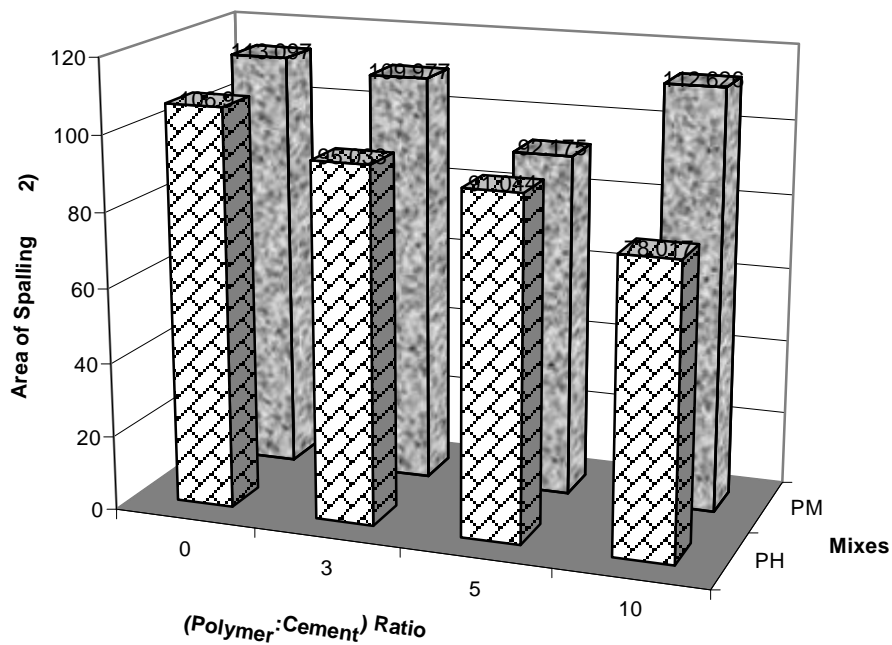


Fig.(12):Comparison of Area of Spalling for different (P:C)Ratio at High Velocity Impact Test for All Concrete Slabs at 91 day.

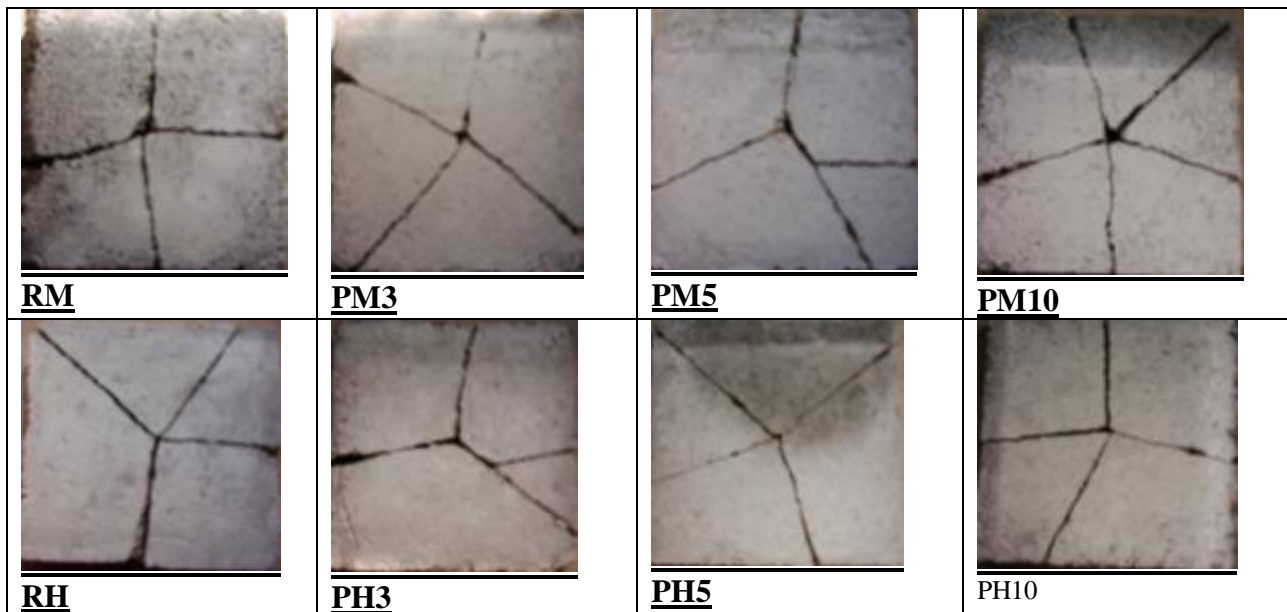
Behavior of Polymer Modified Concrete Slabs under Impact

- Low velocity impact resistance of polymer modified concrete slabs with moderate compressive strength is greater than that of reference mix concrete slabs and the maximum increase in that resistance is:
 - 33.33% for PM3 and PM10 at 2.4 m falling mass height.
 - 75% for PM5 at 1.2 m falling mass height.
 - 83.33% for PM5 at 0.83 m falling mass height.
- Low velocity impact resistance of polymer modified concrete slabs with moderate compressive strength is greater than that of reference mix concrete slabs and the maximum increasing in that resistance were:
 - 25% for PH3 and PH5 at 2.4 m falling mass height.
 - 50% for PH10 at 1.2 m falling mass height.
 - 44.44% for PH5 at 0.83 m falling mass height.
- For the different heights of falling mass the low-velocity impact resistance of the lowest height (0.83m) is greater than that of the other heights.
- The addition of SBR polymer leads to decreasing in area of spalling. The maximum reductions in spalling area are equal to (18.5%) for polymer modified concrete level I with moderate compressive strength and equal to (26.4%) for polymer modified concrete level II with higher compressive strength, compared to respective reference concretes.

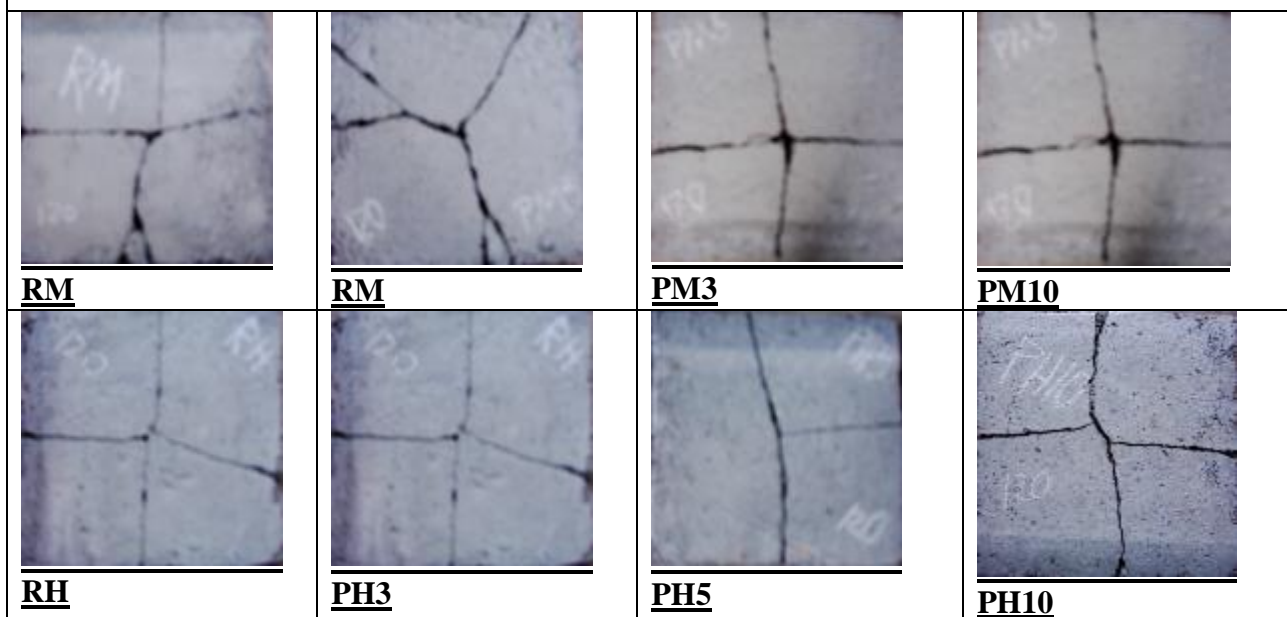
In general, the addition of SBR polymer leads to decreasing in area of scabbing. The maximum reduction in scabbing area is equal to (35.6%) for polymer modified concrete level I with moderate compressive strength and equal to (11.42%) for polymer modified concrete level II with higher compressive strength, compared to respective reference concretes.



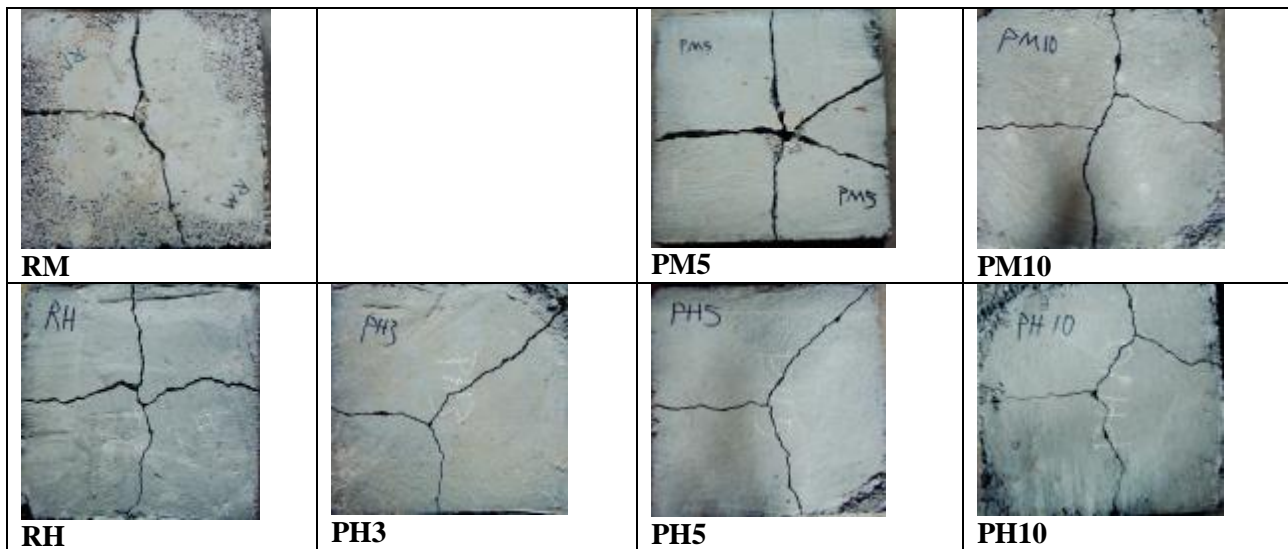
**Plate(1):a-Test rig Used for Low Velocity Impact Test
b-Frame Used for Supporting Impact Slabs**



Plate(2): The Mode of Ultimate Failure at Top Face of Slabs under (2.4)m Falling Mass Low Velocity Impact Test.



Plate(3): The Mode of Ultimate Failure at Top Face of Slabs under (1.2)m Falling Mass Low Velocity Impact Test.



Plate(4): The Mode of Ultimate Failure at Top Face of Slabs under (0.83)m Falling Mass Low Velocity Impact Test.



Plate(5): The Mode of Failure of Slabs under High Velocity Impact

4-References

- 1-Cresson, L., "Improved manufacture of rubber road-facing , rubber- flooring rubber-tiling or other rubber lining". British Patent 191, 474,12Jan.I923.Cited (Ohama, Y., "Polymer-based Admixtures ". Cement and Concrete Composites J. 1998, 20 ,pp.189-212.
- 2-Ohama, Y., "Polymer-Based Admixtures." Cement and Concrete Composites J., 1998, 20,pp. 189-212.
- 3-ACI Committee 548 , " Guide for the Use of Polymers in Concrete", ACI Manual Of Concrete Practice Part 5-1990 . (ACI 548.1R-86), American Concrete Institute, Detroit, ACI Publication, 1990.
- 4-Omaha, Y. , "Recent Progress in Concrete-Polymer Composites". Advn. Cem. Bas. Mat. , Elsevier Scince Ltd., New York ,1997,pp.31-40.
- 5-Fukuchi,T. and Ohama,Y., "Manufacturing High-Strength Concrete". Int. Symposium, SP-58, ACI, Detriot, 1978:215-224.
- 6-Beeldens, A. ; Germert,D. V. ; Ohama,Y. and Czarnecki, L. ; "From Microstructure to Macrostructure: an Integrated Model of Structure Formation in Polymer Modified Concrete", 4th Asia Symposium of Polymers in Concrete, Korea, May 1-3, 2003. (Internet report).
- 7-Letif, Alaa' A., "A Study on The Properties of Polymer-Modified Concrete". M.Sc. thesis. Civil Eng. University of Basrah. Dec. 1998.
- 8-McCrum , N.G., Buckley .C.P. and BucknaIi.C.B.. "Principles of Polymer Engineering ".Oxford University Press . 2^{Ed}. 1997.pp. 447.
- 9-Bhargava, J. and Rehnstrom, A., "Dynamic of Polymer-Cement Concrete". International Symposium, SP-58, ACI, Detroit, 1978, pp:313-327.
- 10-Green, H., "Proc. of the Institution of Civil Engineering ".vol.28, No.6797, 1964, pp:383-396. Cited (Letif, Alaa' A., "A Study on The Properties of Polymer-Modified Concrete". M.Sc. thesis.Civil Eng.University of Basrah. Dec. 1998).
- 11-Al-Gassani, Qusai K. H., "Impact Resistance of Plain and Steel Fiber Reinforced Polymer Modified Concrete". M.Sc. thesis. Civil Engineering Dept., Eng. College. Al-Mustansiriya University, April , 2004.
- 12-المواصفات العراقية / 5 ، " السمنت البورتلاندي " ، الجهاز المركزي للتقييس و السيطرة النوعية، بغداد 1999 ، صفحة 8 .
- 13-المواصفة القياسية العراقية رقم 45 ، " ركام المصادر الطبيعية المستعمل في الخرسانة والبناء "، الجهاز المركزي للتقييس والسيطرة النوعية، مجلس التخطيط ، بغداد ، 1999 .
- 14-ASTM, C128-88, "Standard Test Method for Specific Gravity and Absorption of Fine Aggregate", Annual Book of ASTM Standard, Mortar", Philadelphia, Vol.04-02, 1989, pp:68-71.

- 15-ASTM C-192. “ Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory, 1988.
- 16-British Standard Institute BSI, B.S.1881: Part 116:1983, “Method for Determination of Compressive Strength of Concrete Cubes”.
- 17-ASTM C78-1994, “Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading”, Annual Book of ASTM Standards, American Society for Testing and Materials. Philadelphia, Pennsylvania, Vol.04.02 1994.
- 18-GIC Manual “Gulf International Chemicals SAOG”, www.gicomman.com, June 2002.
- 19-Shirai, A. and Ohama, Y., “Improvement in Flexural Behaviour and Impact Resistance of Ferrocements by Use of Polymers”, Journal of Ferrocement, Vol.20, No. 3, July, 1999, pp:275-264. Cited (Al-Gassani, Qusai K. H., “Impact Resistance of Plain and Steel Fiber Reinforced Polymer Modified Concrete”. M.Sc. thesis. Civil Engineering Dept., Eng. College. Al-Mustansiriya University, April , 2004.)
- 20-Ohama, Y. and Sugahara, T., “Impact Resistance of Steel Fiber-Reinforced Polymer Concrete”, the Twenty Fourth Japan Congress on Materials Research. The Society of Material Science, Japan, 1981, pp:254-257., Cited (Al-Gassani, Qusai K. H., “Impact Resistance of Plain and Steel Fiber Reinforced Polymer Modified Concrete”. M.Sc. thesis. Civil Engineering Dept., Eng. College. Al-Mustansiriya University, April , 2004.).