Migration Letters

Volume: 20, No: S12(2023), pp. 375-393

ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)

www.migrationletters.com

Compressive Strength and Impact Behavior of Pet Fiber Reinforced Self-Compacting Lightweight Concrete Using Expanded Polystyrene Beads As Coarse Aggregate

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Abstract

The behavior of self-compacting lightweight concrete (SCLWC) slabs was explored in this study. These slabs were made with waste materials acquired from the surrounding area, such as expanded polystyrene beads (EPS) and polyethylene terephthalate (PET). It can be found in large quantities in a variety of countries as municipal waste material due to the fact that it is produced every day. the Self Compacting Concrete (R mix) made of EPS content as an alternative of coarse aggregate and Six SCLWC mixtures made of EPS content as an alternative of coarse aggregate with a different Volumetric ratio of PET content (0, 0.25, 0.5, 0.75, 1.0, and 1.25%), a. An aspect ratio of 28 was applied when the PET fibers from waste plastic, which were originally made from bottles of soft drink, were incorporated into SCLWC. Additionally, the flexural behavior of SCLWC slaps was looked into as part of this investigation. The slaps were created using the same waste materials but were reinforced with one of three distinct types of bars (4, 6, or 10) and were labeled as belonging to Group A, Group B, or Group C, respectively.

The addition of PET did not result much increase in the compressive strengths of SCLWC specimens, as determined by the results of an examination of the mechanical characteristics of those specimens. The low-velocity impact test was carried out using the method of repeated falling mass, and a steel ball weighing 1400g was employed in the experiment. The ball dropped freely from a height of 2400 mm onto concrete panels measuring 500 mm by 500 mm by 50 mm and featuring a mesh made of discarded plastic fiber. According to the results that were acquired in the past, the number of strikes that generated the initial fracture as well as the last crack (failure) was determined. When compared with the reference mix, the mixes that contained plastic fibers exhibited superior increases in their respective mechanical properties.

Keywords: *self-compacting lightweight concrete (SCLWC), expanded polystyrene beads (EPS), polyethylene terephthalate (PET).*

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1. Introduction

Many concrete structures have the potential to be affected by dynamic loads that can be caused by the impact of a ballistic tornado, a produced missile, impulsive loads caused by air bursts or wind gusts, as well as earthquakes and machine vibrations. These types of loads can cause damage to the concrete. Reinforcing fragile materials with fibers has been a practice that dates back to prehistoric times. Bricks that had been baked in the sun were sometimes given a reinforcement of straw, and masonry mortar and plaster were sometimes given a reinforcement of horsehair.[1]

Concrete is considered a brittle material as it has low tensile strength and failure strain. It is hard to stop the creation and growth of cracks that have occurred within the material, and the material is susceptible to cracking under tensile load or dynamic load. In order to address these issues and to extend the amount of time that concrete may remain in service, a material known as concrete with fiber reinforcement has been developed. This type of concrete incorporates fibers in order to improve the material's mechanical qualities. [2]

In recent years, there has been growth in the manufacturing of concrete, which has resulted in the development of new forms of environmentally friendly concrete. These particular kinds of concrete are highly suggested for use in the building of secure and long-lasting constructions that are able to withstand a variety of loads. One example of this kind of concrete is classified as self-compacting concrete, or SCC for short. SCC has the capacity to decrease voids, increase durability, and decrease bleeding thanks to the augmentation of adhesion provided by fiber. In addition, because it can be compacted under its own weight, SCC can be regarded as an economical material that can cut down on both the cost and the amount of time required for vibration.[3]

It is hard to prevent the creation and growth of cracks that have occurred within the material, and the material is susceptible to cracking under tensile load or dynamic load. Fiber-reinforced concrete, when fibers are introduced for better mechanical properties, was created to answer these disadvantages and to lengthen the service duration of concrete [4]. Fiber-reinforced concrete has also been developed to increase the service duration of concrete. Fiber concrete, often known as fiber-reinforced concrete, is a composite material. It capitalizes on both the strong compressive strength of concrete and a powerful tensile force of fibers in order to achieve its desired effect. In addition to this, it improves the ductility, toughness, and impact strength of the concrete, as well as the adhesion peeling off, pulling out, bridging, and load transferring of the fibers in the concrete, which leads to an increase in the energy absorption capacity of the concrete [5].

Plastic waste fibers, when added to SCC, provide a number of benefits, including the delay of micro fractures and an enhancement in the material's tensile behavior in relation to the fiber content. The accumulation of discarded plastic items poses a significant danger to the natural world. The most common sort of waste plastic is called polyethylene terephthalate (PET), and it is the primary component of bottles that contain soft drinks and mineral water that are thrown away after use. The vast majority of PET materials are discarded solely in landfills, despite the fact that more than 0.3 million units are consumed annually.Therefore, it is worthwhile to investigate the possibility of improving SCC's ductility as well as its resistance to impact load and its capacity to absorb energy. The employment of these fibers that have been recycled from used plastic could potentially contribute to the enhancement of SCC qualities and lessen the hazard that waste disposal poses to the environment. Because increasing the quantity of fibers by more than 2% causes fiber agglomeration, segregation, and non-homogeneity within the mixture, which in turn leads to the formation of weak concrete with high porosity, adding fibers to concrete is not a novel notion.[6] In comparison to the strength possible in polypropylene-fiber-reinforced concrete, the potential for strength in nylon fiber reinforced concrete was explored.In comparison to those of polypropylene fiber concrete, the compressive and splitting tensile strengths, as well as the modulus of rupture (MOR), of the nylon fiber concrete were enhanced by 6.3%, 6.7%, and 4.3%, respectively. In terms of its impact resistance, the nylon fiber concrete outperformed its polypropylene counterpart in terms of the first-crack and failure strengths, as well as the percentage increase in the post-first-crack blows. [7]

Poly(vinyl butyral), also known as PVB, is used as the only aggregate in a research project [8] that aims to build a novel cementitious composite that is reinforced with poly(vinyl alcohol), also known as PVA fiber. PVB possesses a wide variety of unique engineering aggregate qualities. The Charpy impact test is used to evaluate a material's capacity to absorb the energy of an impact. When compared with standard concrete and traditional lightweight concrete, the results demonstrate that the PVB composite material has a higher capacity for impact energy absorption but a lower density [9].

Investigate what happens when recycled fibers (RP) made from industrial or post-consumer recycled plastic waste are used as reinforcing fibers in concrete, as suggested by Alhozaimy [10]. Investigations were conducted into the RP fiber concrete's permeability as well as its plastic shrinkage cracking and mechanical qualities. According to the findings, the plastic shrinkage cracking in plain concrete with RP fibers at a volume fraction of 1 to 2% was practically identical to the plastic shrinkage cracking in plain concrete without RP fibers at 0%, while at a volume fraction of 3 to 4%, there were no plastic shrinkage cracks seen.

Yadav [11] looks into how the incorporation of plastics in concrete affects the mechanical characteristics of concrete and how those properties alter. In addition to the mechanical qualities of the produced concrete, the thermal parameters of the concrete are also investigated.According to the findings of this study, the production of lightweight concrete can be attributed to the utilization of plastic aggregates. The addition of plastics causes a reduction in both the compressive and tensile strengths of concrete. The most significant modification brought about by the utilization of plastics is a decrease in the thermal conductivity of concrete. This modification is brought about by the utilization of plastics in concrete.

Ismail utilized a total of thirty kilograms of scrap plastic in the form of fabriform shapes [12]. Concrete preparation and curing procedures according to standard practice Test Specimens were used in the et al study as a partial substitute for sand by 0%, 10%, 15%, and 20% of the total weight of 800 kg of concrete mixtures. The findings demonstrated that the spread of microscopic cracks could be stopped by including waste plastic in the form of fabriform forms in the concrete mixtures. This study proves that utilizing discarded plastic as a sand-substitution aggregate in concrete is a good way to minimize the cost of materials and tackle some of the solid waste concerns caused by plastics. The National Institute of Standards and Technology (NIST) carried out the research.

2. Experimental Program:

2-1 Materials

The materials that used in the present work are:

2-1-1 Cement

Ordinary Portland Cement (OPC) ASTM Type I is used. The cement is complied to Iraqi specification no.5/ 1999 [13]

2-1-2 Coarse Aggregate

In this investigation, a maximum size was 10 mm used. the gravel has been thoroughly cleaned and rinsed with tap water. In Table 2-1-2 the physical properties and grading of the coarse aggregate according to the Iraqi standard specification (I.Q.S.) No.45/ 1984 [14].

Table 2-1-2: The Gradient and Physical Properties of Used Coarse Aggregate

Sieve Size(mm)	Passing %	Iraqi Standard (IQs) No.45/1984
14	100	100
10	86	85-100
5	7	0-25
2.36	2.5	0-5
Sulphate content (SO3 %)	0.04%	≤ 0.1
Specific gravity	2.65	-
Absorption (%)	0.6%	-
Maximum particle size	10 mm	-

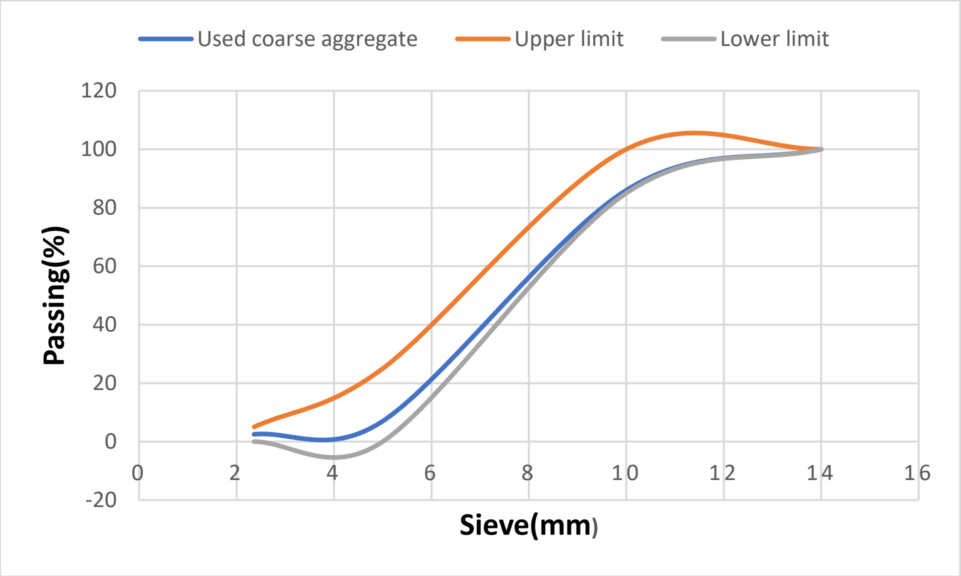


Figure 2-1-2: Coarse Aggregate Sieve Analysis

2-1-3 Fine Aggregate

the Anbar governorate, was chosen as the source of natural sand for the study's fine aggregate. Table 3-2 the grading and physical characteristics of the fine aggregates meet the requirements of Iraqi standard specification (I.Q.S.) No. 45/ 1984 [14].

Table 2-1-3: Physical and Chemical Properties of Fine Aggregate (Sand)

Sieve Size(mm)	Passing %	Iraqi Standard (IQs) No.45/1984
10	100	100
4.75	90	90-100
2.36	84	75-100
1.18	52	55-90
0.6	42	35-59
0.3	17	8-30
0.15	4	0-10

Physical Properties	Test Result	Limits of Iraqi Standards
Specific gravity	2.7	-
Sulphate content (SO3 %)	0.35%	0.5 % (max)
Absorption (%)	0.8%	-

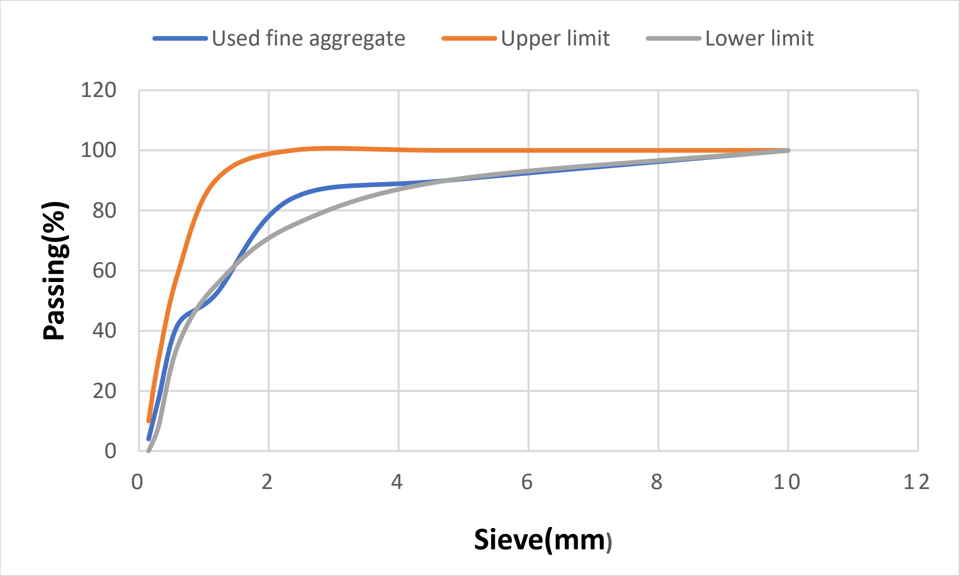


Figure 2-1-3: Fine Aggregate (Sand) Sieve Analysis

2-1-4 Water

All specimens were poured using tap water, which was also utilized for the curing procedure.

2-1-5 Superplasticizer (SP)

In the study's modified mixes, a superplasticizer by the brand name Sika ViscoCrete 5930 was used. It complies with ASTM C494 type G's standards for superplasticizer [15].

2-1-6 Silica Fume (SF)

the use of silica fume (SF) with a specific gravity of 2.2 and conforming to ASTM C1240-15 [16].

2-1-7 Expanded Polystyrene Beads (EPS)

We used spherical, essentially one-size EPS beads that are commercially available. According to the grading, most beads are no larger than 10 mm. The EPS utilized in this investigation is white, 38 with a 100% loss on ignition, a softness point between 80 and 100 °C, and water absorption by immersion after 28 days of 1 to 3% volume (see Figure 111). Table 111 displays the EPS grades and some of its physical

Table 2-1-7: Sieve Analysis and Physical Properties for Expanded Polystyrene Beads (EPS)

Sieve Size	Passing %	ASTM C330
12.5mm	100	100
9.5mm	91	80-100
4.75mm	6.5	5-40
2.36mm	1.5	0-20

Physical Properties		
Specific gravity	0.009	.
Water absorption	0	.
Maximum particle size (mm)	10	.

2-1-8 Polyethylene Terephthalate (PET)

The fibers were obtained by cutting PET, gathered directly from disposed packing straps in sites. The thickness of PET was 0.3 mm. The aspect ratio of fibers (28) was adopted in this work. The Dimensions and physical properties PET fibers are given in Table 2-1-8.

Figure 2-1-8: PET Used in Experiment Work

Table 2-1-8: Dimensions and Physical Properties of PET

Length (mm)	Width (mm)	Thickness (mm)	Aspect Ratio	Density (kg/m3)	Water absorption	Young Modulus (MPa)
30	3	0.3	28	1100	0	1700

2-1-9 Steel Reinforcement Bars

All tested beams were reinforced by steel reinforcement bars with different diameters (Ø4, Ø6, and Ø10) mm the properties of steel reinforcement according to ASTM A615/A615M-18e1 [17].

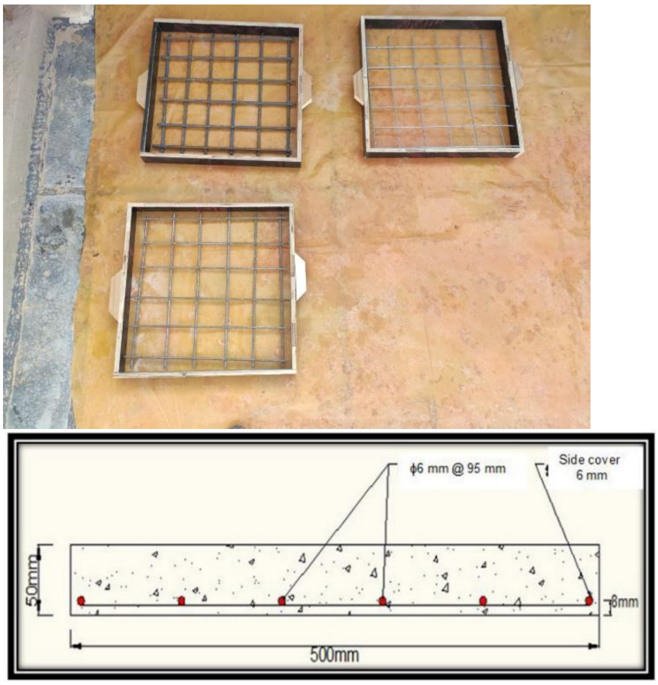


Figure 2-1-9: Reinforcement Slap

2-1-10 Wooden Mold

Six molds were made from the plywood, which consists of four sides and bed. The interior dimensions of all molds are (500) mm length, (500) mm width and (50) mm height.

2-2 Mixing, Casting and Curing Procedure

In this investigation, the following procedures were used to prepare SCC containing PET fibers:

1.The coarse aggregate and a small quantity of water were added to the pan mixer.

2.During the rotation of the mixer, PET fibers were introduced progressively and continuously to prevent concreting and uneven distribution.

3.After one minute, half of the cementitious components (cement and micro silica) and half of the fine aggregate were added to the mixture. One minute is spent continuing the mixture.

4.Following the addition of half of the water and superplasticizer, the mixture is mixed for two minutes until a uniform consistency is achieved.

5.Cement, mrico silica, coarse and fine aggregate, water, and superplasticizer were added to the mixer. In this phase, the blending continues for an additional three minutes.

Casting Before the day of casting, all molds were brushed with lubricant and reinforced against impacts.After being cast, the specimens were covered and stored at 22 2 °C. After 24 hours, the specimens were demolded and stored for 28 days in a curing vessel. The curing water temperature of the concrete specimens was 22 degrees Celsius. Using ASTM C192/C192M [18], the curing procedure for these specimens was determined.

According to Table 2-2, the percentages of PET in concrete mixtures were 0.25, 0.5, 0.75, 1.0, and 1.25 percent. The selection of the PET content for each concrete was primarily based on previous studies that determined the minimum and maximum PET content for concrete. Silica fume was applied to stem the flow of blood. Consequently, the w/cm ratio was reduced to 0.4. In addition, superplasticizer Sika ViscoCrete 5930 was added to all mixtures to make them more practical.

Table 2-2: Concrete Mixtures Proportion Ratios

Mix Code	R	E	E0.25	E0.5	E0.75	E1	E1.25	SG
Cement (kg/m3)	400	400	400	400	400	400	400	3.15
Silica Fume (kg/m3)	100	100	100	100	100	100	100	2.2
Superplasticizer (kg/m3)	10	10	10	10	10	10	10	1.08
Water (kg/m3)	180	180	180	180	180	180	180	1
Fine aggregate (kg/m3)	850	850	862.62	859.22	855.83	852.44	849.05	2.65
Coarse aggregate (kg/m3)	850	0	0	0	0	0	0	2.68
Expanded polystyrene (EPS) (kg/m3)	0	2.86	2.79	2.78	2.77	2.76	2.74	0.009
Fiber	0	0	2.75	5.5	8.25	11	13.75	1.1

2-2 RESULTS AND DISCUSSION

2-2-1 Compressive Strength Test

The compressive strengths of all mixtures are summarized in Table 2-2-1. The table depicts the compressive strengths at 7, 28, and 90 days after curing. The reported compressive strength values are the mean of three specimens fabricated from each mixture.

Table 2-2-1: Compressive strength test results of all mixtures

Mix Code	Compressive strength		
	7 day	28 day	90 day
R	60	75	80
E	18	19	22
EP-0.25	19.5	20	21
EP-0.50	20.5	21	23
EP-0.75	22	23	25.25
EP-1.00	23	24.5	26.5
EP-1.25	21.5	22	23.25

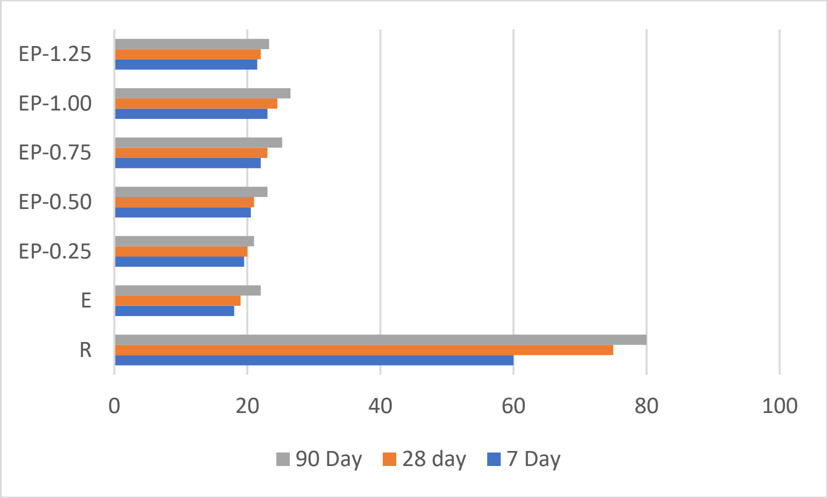


Figure 2-2-1: Compressive strength test results of all mixtures

As seen in Compressive Strength (MPa) Mix Code 7-day 28-day 90-day, Figure 2-2-1 demonstrates that the use of PET does increase the compressive strength of lightweight concrete up to 1% of PET content, while increasing PET content has a diminishing effect on compressive strength. Based on a comparison of the effects of increasing PET content, the compressive strength increased with the addition of 0.25, 0.5, 0.75, 1.0, and 1.25 percent PET, except for the 1.25 percent PET mixture. This decrease is a result of the bonding between the mixture's constituents (EPS, fibers, and cement paste), which reduces the mixture's need for water due to the non-absorbent nature of EPS and the uniform surface of EPS, which reduces its interlocking with cement paste [19]. In addition, the progressive increase in compressive strength values with increasing plastic waste fiber proportions can be attributed to the binding force between the plastic waste surface and cement [20][21].

2-2-2 Low Velocity Impact Test

Twenty-one specimens of 56-day-old (500 500 50) mm slabs were tested with a low velocity impact force. The impact was created by a 1,400-gram steel projectile falling unrestrained from 2.4-meter heights. The specimens were positioned in the testing apparatus with the completed side facing up. The falling mass was then repeatedly lowered, and the number of impacts necessary to induce the first crack was recorded. Also recorded was the number of strikes required for failure (no recoil).

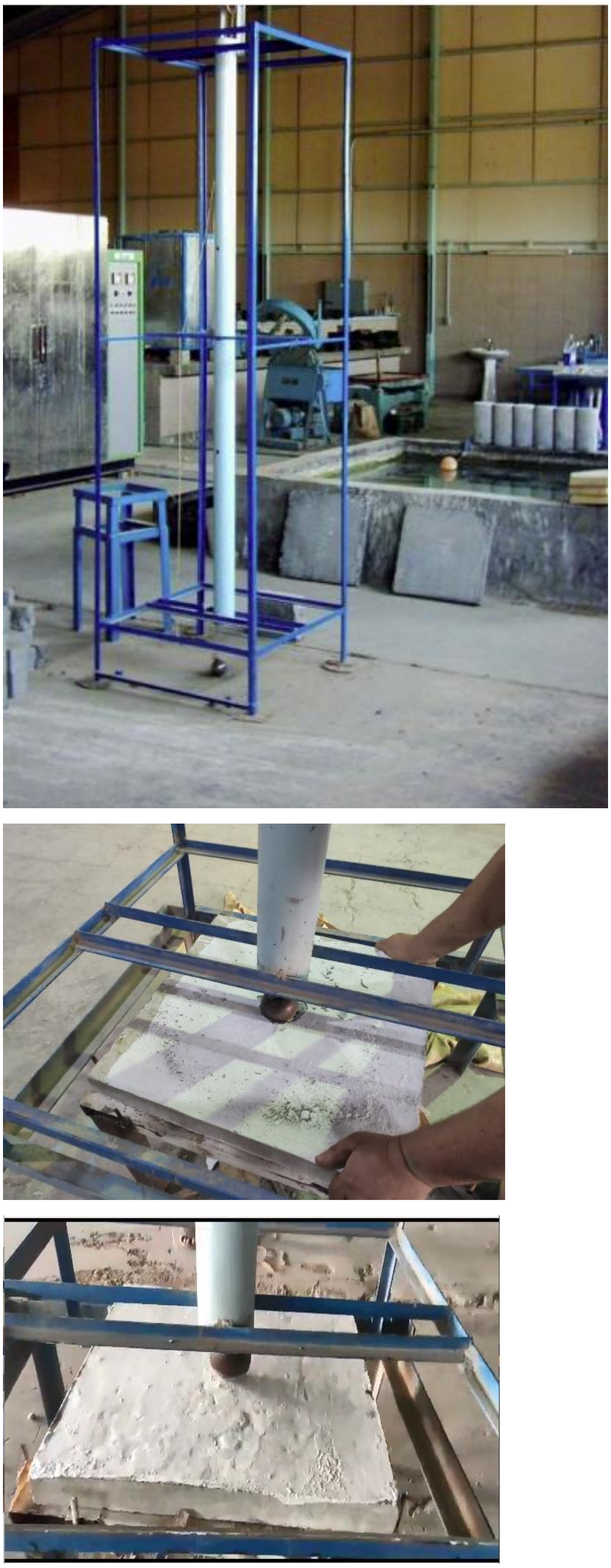


Figure 2-2-2: Impact Test setup

At 56 days of age, 500 mm 500 mm 50 mm square slabs were subjected to repetitive impact blows by falling mass (1400 g) lowered from three heights (2.4 m). All mixtures containing waste plastic exhibit a significant improvement in low-velocity impact resistance compared to the reference mix. Figure 4 illustrates the effect of adding PET as a percentage by volume of the concrete at the time of its first fracture and failure. It can be seen that the impact resistance increased as the ratio of refuse plastic to concrete increased. The cracks begin at the slab's center (where the bulk is descending) and extend in all directions along lines perpendicular to its edges. At a percentage of (1.25%) of refuse fiber added to concrete, the specimen displays a decent resistance to fracture due to the fiber distribution throughout the concrete. This indicates an increase in tension stress, ductility, energy absorption, and adhesion strength.This test is conducted to determine the number of strikes necessary to cause the first fracture and eventual failure. Figures (2-2-2) depict the increase in impact resistance at first fracture and ultimate failure for all concrete mixtures at age (56) days.[22]

Table 2-2-1: Low Velocity Impact Test results of all mixtures

Group	Mix	Rein.Slap	PET %	NO. of first cause		Energy Absorption (N.m)	
				First crack	Ultimate failure	First crack	Ultimate failure
A	R-A	4@90	0	2	39	66	1287
	E-A		0	6	45	198	1485
	EP0.25-A		0.25	6	44	198	1452
	EP0.5-A		0.5	8	44	264	1452
	EP0.75-A		0.75	8	51	264	1683
	EP1-A		1	10	59	330	1947
	EP1.25-A		1.25	11	69	363	2277
B	R-B	6@90	0	3	40	99	1320
	E-B		0	7	51	231	1683
	EP0.25-B		0.25	8	50	264	1650
	EP0.5-B		0.5	8	55	264	1815
	EP0.75-B		0.75	9	58	297	1914
	EP1-B		1	11	62	363	2046
	EP1.25-B		1.25	11	68	363	2244
C	R-C	10@90	0	3	41	99	1353
	E-C		0	7	50	231	1650
	EP0.25-C		0.25	6	52	198	1716
	EP0.5-C		0.5	9	55	297	1815
	EP0.75-C		0.75	8	54	264	1782

	EP1-C		1	10	61	330	2013
	EP1.25-C		1.25	12	71	396	2343

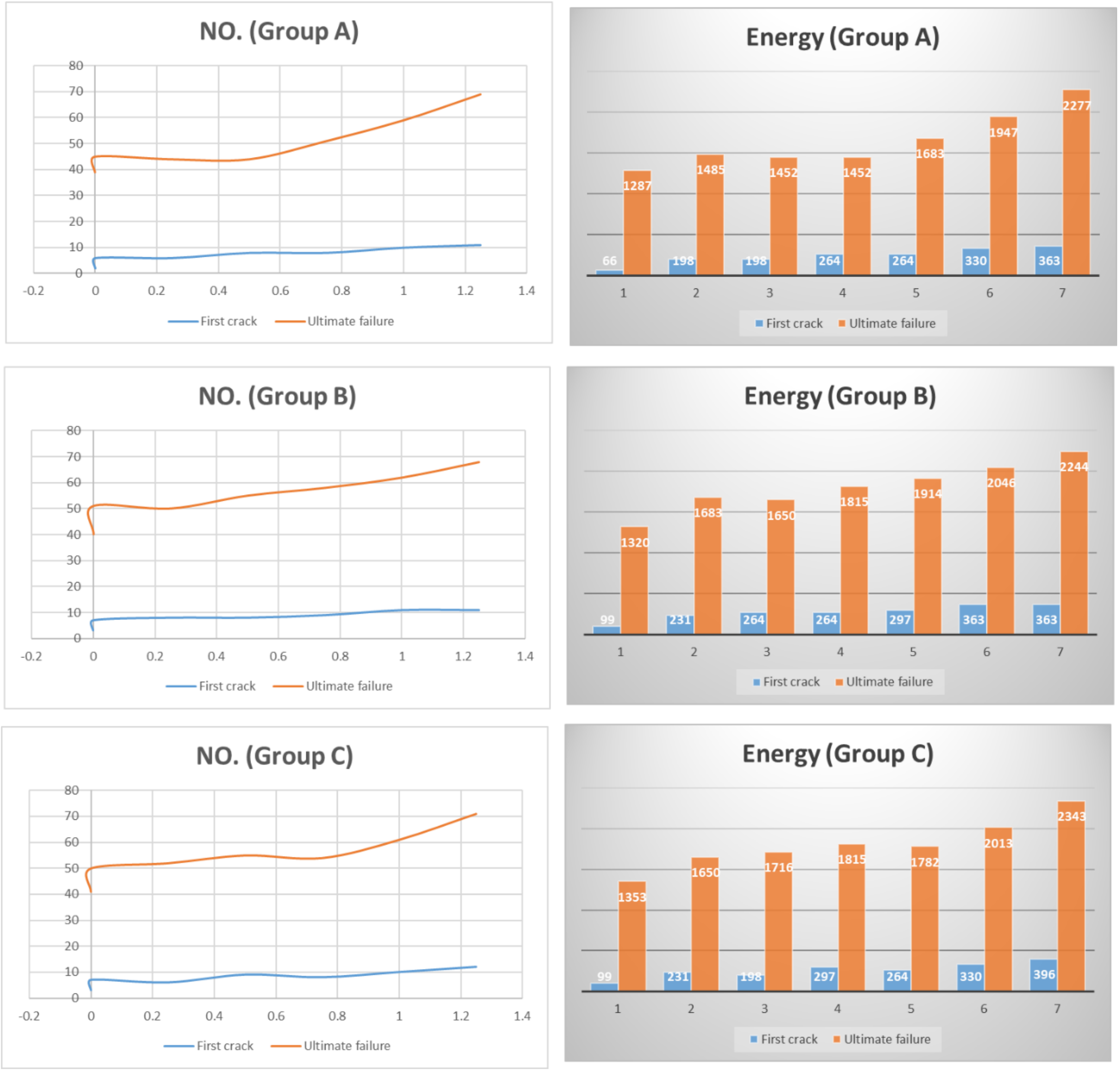


Figure 2-2-2: Low Velocity Impact Test results for all group

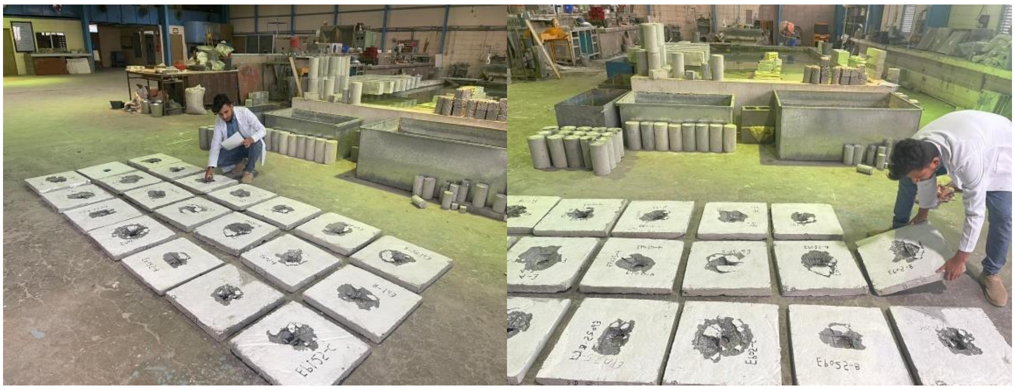
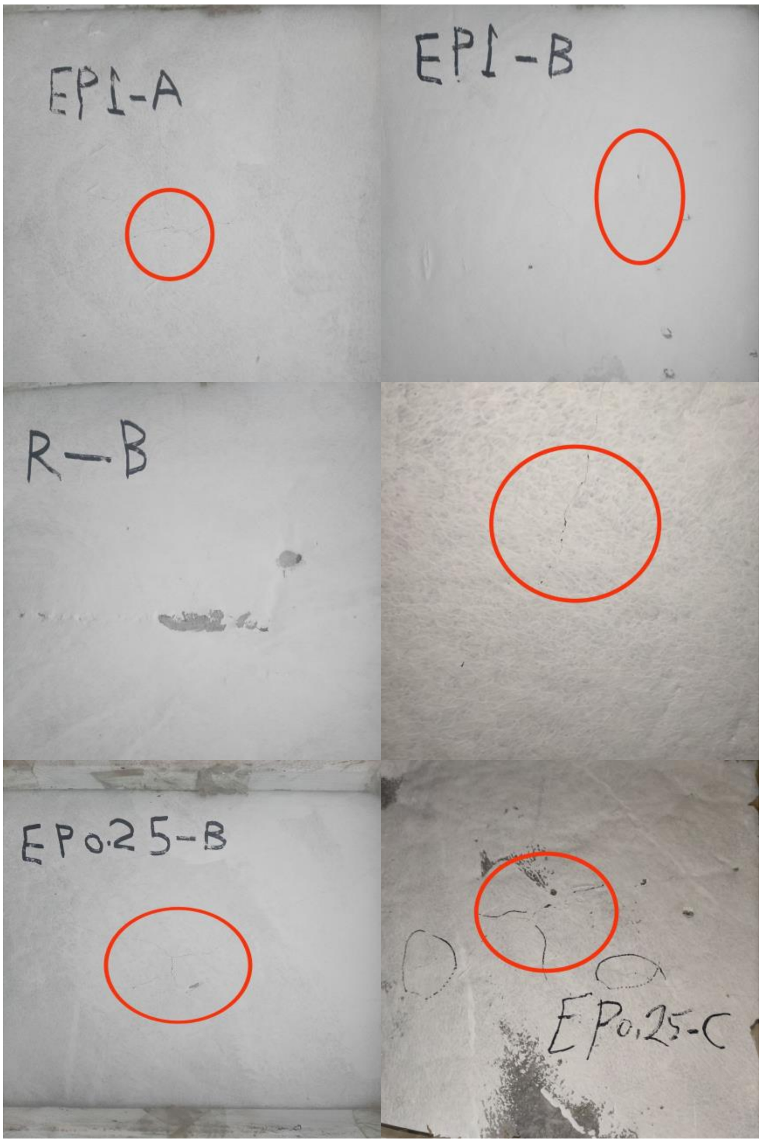
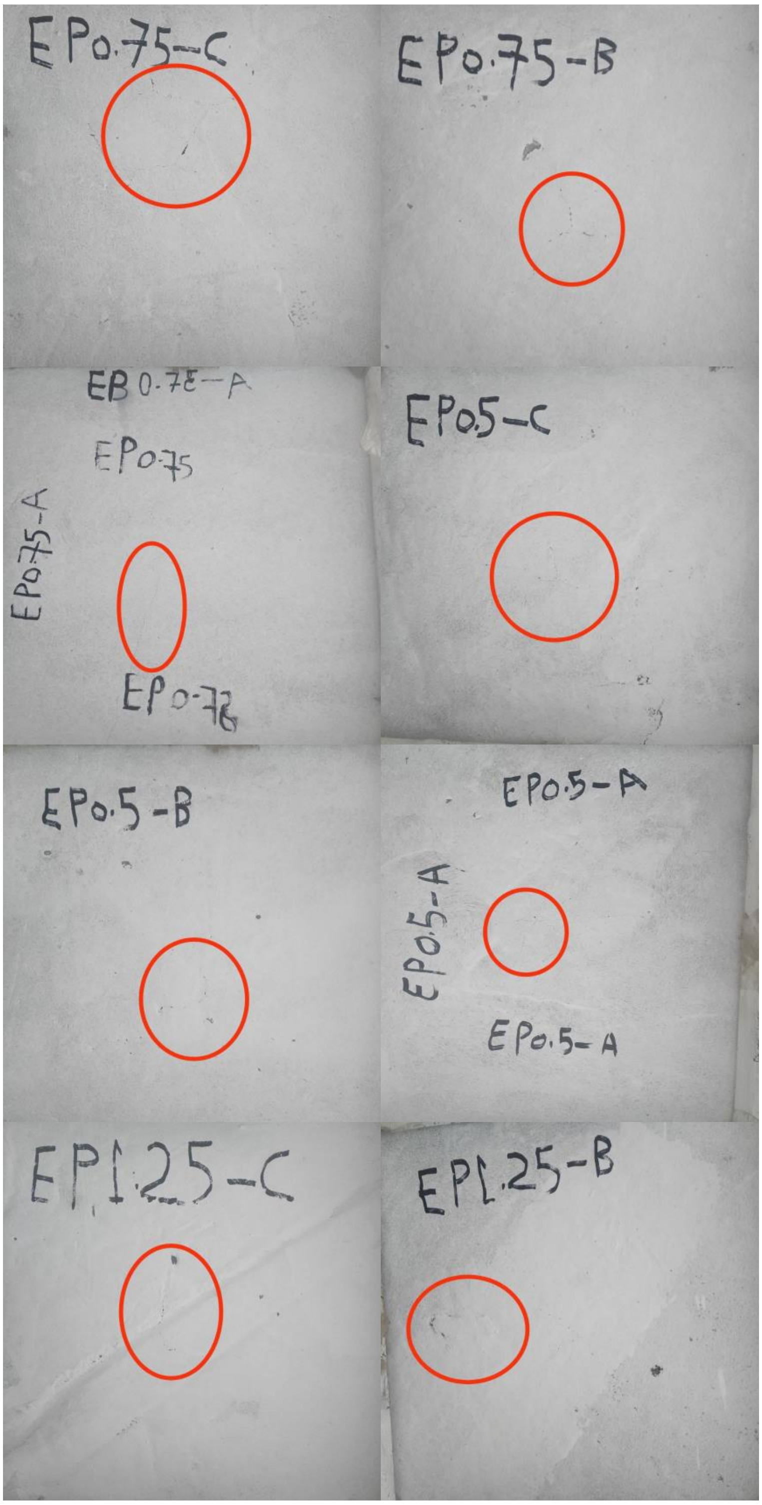


Figure 2-2-3: Test Samples




EP0.75-C
EP0.75-B
EB0.7E-A
EP0.75
EP0.75-A
EP0.76
EP0.5-C
EP0.5-B
EP0.5-A
EP0.5-A
EP0.5-A
EP1.25-C
EP1.25-B

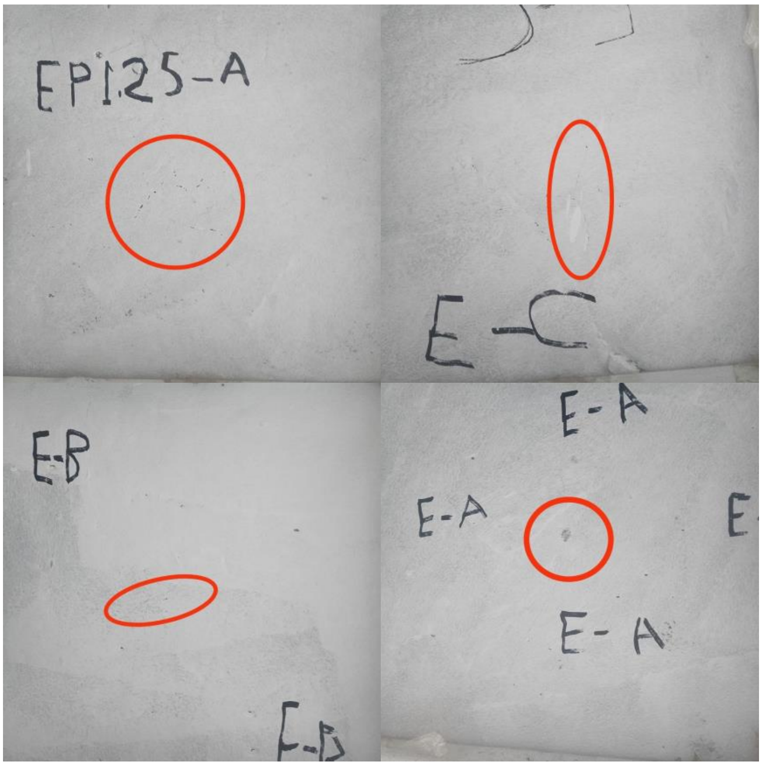
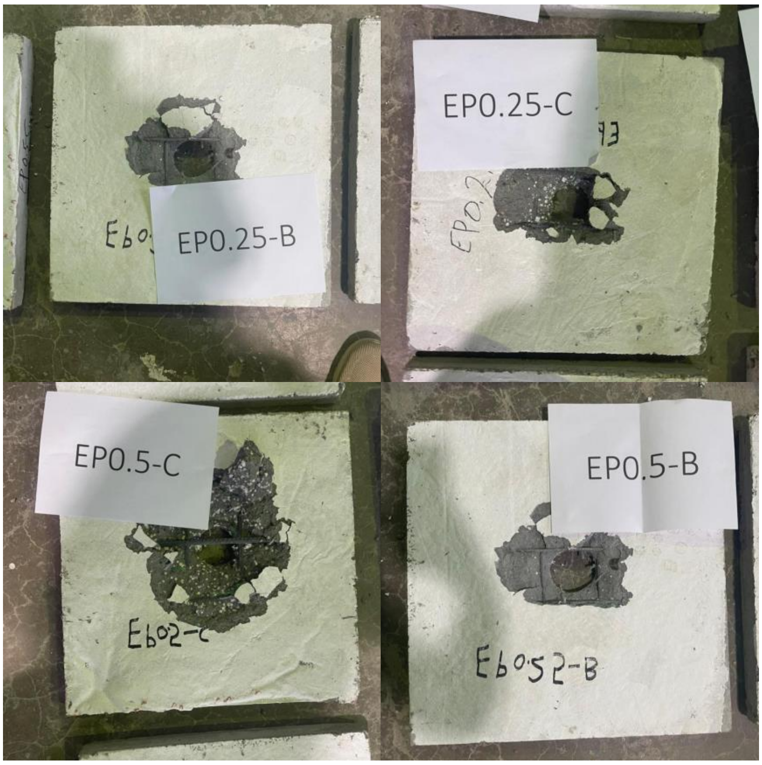
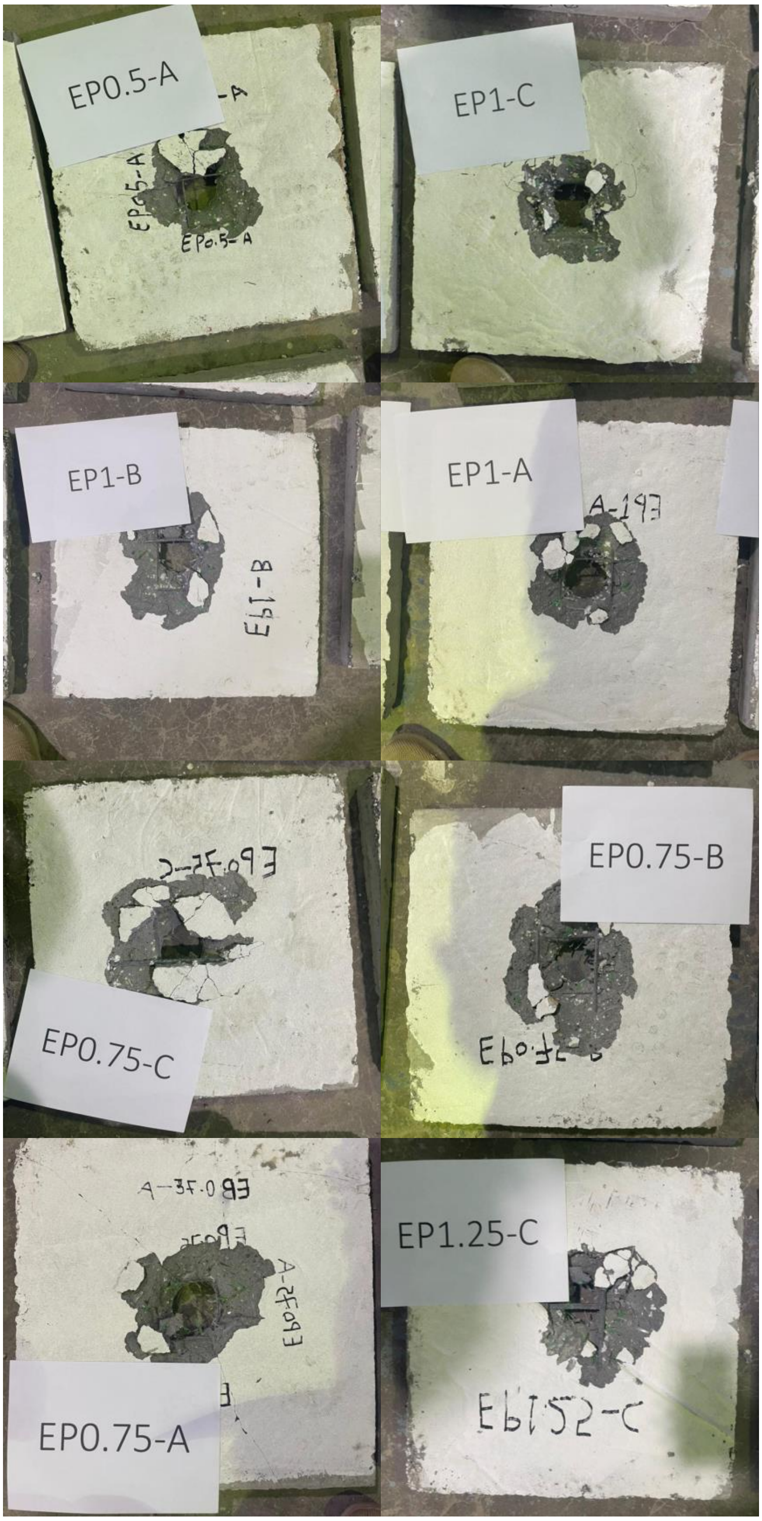


Figure 2-2-4: Low Velocity Impact Test First Crack




EP0.5-A
EP1-C
EP1-B
EP1-A
EP0.75-C
EP0.75-B
EP0.75-A
EP1.25-C

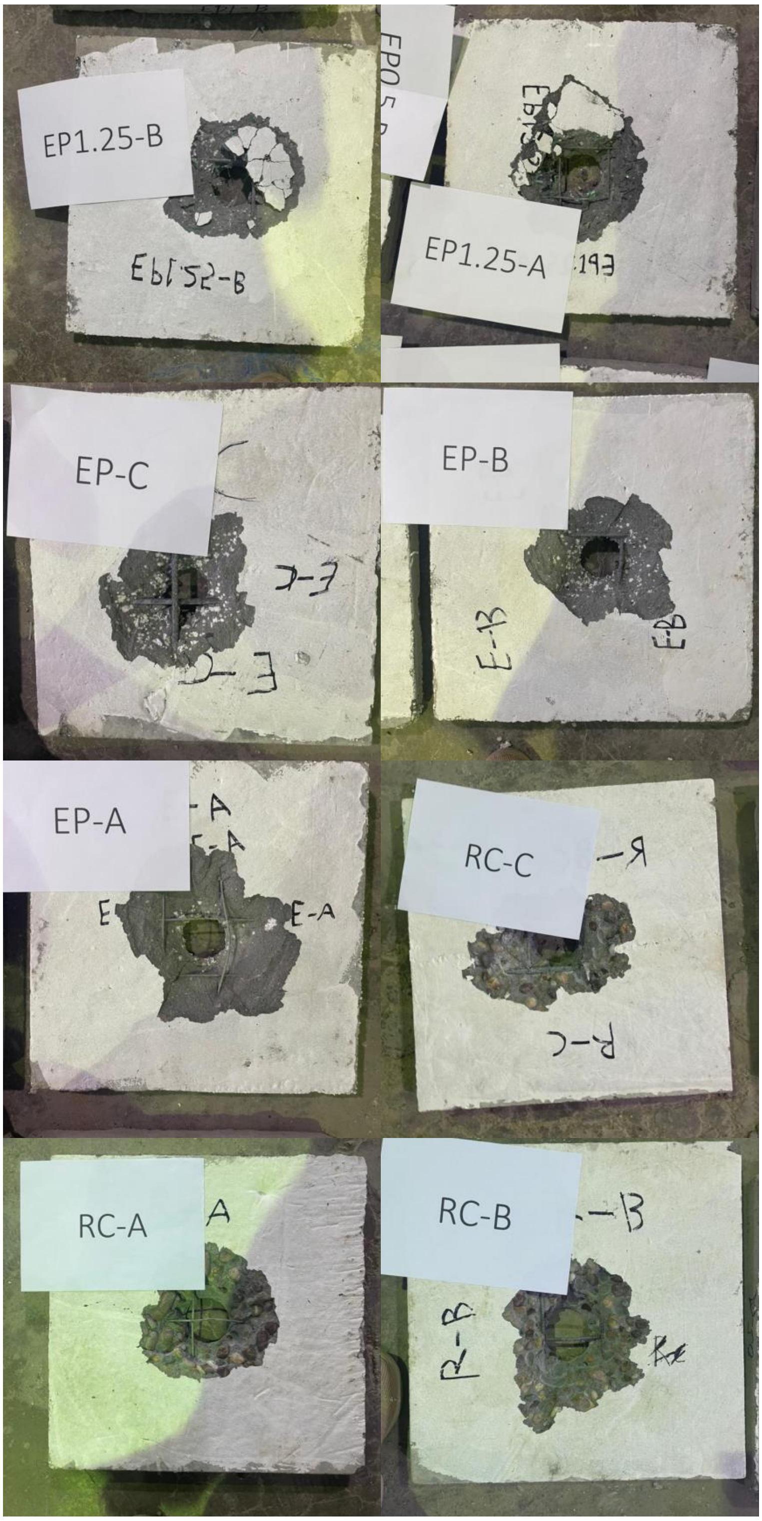


Figure 2-2-2: Low Velocity Impact Test Failure

CONCLUSION

New technology is self-compacting lightweight fiber-reinforced concrete (SCLWC). This study investigated the effect of varying amounts of polyethylene terephthalate (PET) in addition to the complete substitution of coarse aggregate with EPS. This investigation utilized five SCLWC formulations (0.25, 0.5, 0.75, 1.0, and 1.25% PET content) in addition to control concrete (R mix) and lightweight concrete (EP mix) composed of EPS content as a replacement for coarse aggregate. The inclusion of EPS decreased the density (weight) of the concrete mixtures because EPS has a tendency to form more aggregates and make the mixture more wet. Therefore, concrete formulations were modified to compensate for the increased workability caused by the incorporation of PET. The following are the findings of the study:

1. The increased PET content decreased the workability as a result of clustering that occurred during the blending phase. therefore Self-compacting lightweight concrete made with EPS as the coarse aggregate and variable quantities of PET revealed that the density of SCLWC decreased as PET content in concrete formulations increased. Nonetheless, a higher water absorption capacity was observed in these composites due to air entrapment and the formation of air cavities, which allow water to permeate the concrete matrix more readily.

2. The density of self-compacting lightweight concrete with expanded polystyrene foam (EPS) as coarse aggregate and varying quantities of polyethylene terephthalate (PET) decreased as PET content in concrete formulations increased. Air entrapment and the formation of air cavities allow water to penetrate the concrete matrix more readily, resulting in a higher water absorption capacity in these mixtures. Consequently, air cavities have increased.

3. The mechanical property investigation of the SCLWC specimens revealed that the addition of PET did not significantly increase the compressive strengths.

4. In order to obtain the optimum strength and durability benefits of SCLWC, they must be cured for longer than 28 days (56 and 90 days) if the construction and service schedule permits.

5. It is suggested that, in the design of SCLWC compositions with prescribed PET and EPS contents, the workability, stability of fresh concrete, and hardened properties of SCLWC concrete be improved.

6. Significantly enhanced low velocity impact resistance of SCLWC mixtures modified with PET in comparison to the reference mixture. In comparison to the reference mixture, an increase in PET content increases the number of strikes at both the initial fracture and failure.

7. Based on the results of this study, the optimal percentage of PET fibers in SCC could be 1%. To prevent a further decrease in workability, enhance SCC properties, and increase impact resistance, the addition of PET fibers at a concentration between moderate and high (1.25%) may be acceptable.

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