Journal of Technology Research (JTR)
Volume 3, Special Issue, (2025), pp 258-267, ISSN 3005-639X
The 7th Conference of Engineering Sciences and Technology
(CEST-2025)

Analysis of the Effect of Polyethylene Residues Recycling on Mechanical Performance and Collapse Behaviour in Concrete

Salhin Alaud [*1], Osama Aljrpe[1]
[1]Civil Engineering Department, Garaboulli Engineering Faculty, Elmergib University, Garaboulli, Libya.
*Corresponding author email: s.alaud@elmergib.edu.ly

Received: 27-09-2025 | Accepted: 20-11-2025 | Available online: 25-12-2025 | DOI:10.26629/jtr.2025. 27

ABSTRACT

This study aims to analyse the effect of adding crushing recycled High-Density Polyethylene (HDPE) residues to concrete mixtures as a partial substitute component for aggregates, with different volumetric ratios (0%, 10%, 20%, and 30%), as well as the introduction of HDPE fibres in a fixed volumetric ratio (1%) to help in flexural resistance, to evaluate the effect of these additives on the mechanical properties of concrete. Concrete samples were prepared according to these ratios and subjected to destructive and non-destructive tests, such as compressive strength, flexural, and impact load, in addition to examining collapse patterns after the test. Preliminary results showed that when 30% of HDPE was added may contribute to improved impact resistance, while leading to a decrease in compressive and bending resistance compared with the reference mixture, which can be compensated by using appropriate metal or chemical additives. Fibers have also helped to improve breakdown behaviour and reduce cracks. Visual analysis of collapses and the pattern of cracks also showed that the introduction of HDPE into concrete moves it from the traditional brittle state to the soft state, the higher its proportion in the mixture. In order to improve the sustainability of the materials used in construction and lessen environmental pollution brought on by plastic waste, the study suggests using the proportions of these materials that have been investigated in non-structural or light structural applications.

Keywords: Plastic concrete, HDPE, Mechanical performance, Failure behaviour.

تحليل تأثير إعادة تدوير بقايا البولي إيثيلين على الأداء الميكانيكي وسلوك الانهيار في الخرسانة

صالحين العود[1]، أسامة الجربي[2]
[1,2] قسم الهندسة المدنية، كلية الهندسة القره بوللي، جامعة المرقب، القره بوللي، ليبيا.

ملخـــــــص البحـــــــث

هذه الدراسة هي لتحليل تأثير إضافة حبيبات البولي إيثيلين عالي الكثافة **(HDPE)** المعاد تدويره إلى خلطات الخرسانة كمكون بديل جزئي للركام، بنسب حجمية مختلفة (0%، 10%، 20%، و30%)، وكذلك إدخال ألياف البولي إيثيلين نفسه بنسبة حجمية ثابتة (1%) لمساعدة الحبيبات في مقاومة الانحناء، وذلك بهدف تقييم تأثير هذه الإضافات على الخواص الميكانيكية للخرسانة. تم تحضير عينات خرسانية وفقًا لهذه النسب، وإخضاعها لاختبارات إتلافية وغير إتلافية مثل مقاومة الضغط، والانحناء، وقوة الصدم، بالإضافة إلى فحص

أنماط الانهيار بعد الاختبار. أظهرت النتائج الأولية أن دمج 30% من البولي إيثيلين قد يساهم في تحسين مقاومة الصدم، بينما يؤدي إلى انخفاض في مقاومة الضغط والانحناء، والتي يمكن تعويضها باستخدام إضافات معدنية أو كيميائية مناسبة. كما ساعدت الألياف أيضًا في تحسين سلوك الانهيار وتقليل الشقوق. أظهر التحليل البصري للانهيارات وأنماط الكسر أن إضافة البولي إيثيلين عالي الكثافة إلى الخرسانة ينقلها من حالتها الهشة التقليدية إلى حالتها اللينة كلما زادت نسبتها في الخليط. ولتحسين استدامة المواد المستخدمة في البناء والحد من التلوث البيئي الناجم عن النفايات البلاستيكية، تقترح الدراسة استخدام نسب هذه المواد التي خضعت للدراسة في التطبيقات غير الإنشائية أو الإنشائية الخفيفة.

الكلمات الدالة: الخرسانة البلاستيكية، البولي ايثيلين عالي الكثافة، الأداء الميكانيكي، سلوك الانهيار.

1. INTRODUCTION

With the ever-increasing amount of plastic waste generated by industrial and consumer activities, its management and recycling have become one of the major environmental challenges of the modern era. Polyethylene is one of the most widely used plastics in the world, used in the manufacture of containers, bags, pipes, and other products. Due to its slow decomposition in the environment, its accumulation significantly contributes to soil and aquatic pollution, necessitating the search for effective and sustainable solutions [1].

Among recent trends in sustainability is the use of recycled plastic waste in concrete production, either as partial replacement aggregates or in the form of fibers to enhance certain mechanical properties. Previous research has shown the potential of using plastic aggregates or fibers to improve impact resistance and reduce the self-weight of concrete, but this can lead to reduced strength and interfacial curing [2, 3].

Adding polyethylene to concrete in the form of granules or fibers is a promising method for enhancing mechanical properties, such as impact resistance, and reducing weight. Furthermore, differences in the physical form of the additive, whether granular or fiber, and the varying proportions added, can significantly affect the performance of the final material [4, 5]. Polyethylene has been used as an aggregate in concrete in various ways and forms, and numerous tests have been conducted to determine its effect on concrete properties, which in many cases resulted in a decrease. For example, when polyethylene was added as a coarse aggregate, the compressive strength decreased when an excessive replacement ratio was used in concrete [6]. Hence, the importance of studying the effect of these variables on the final properties of the composite material.

This study aims to evaluate the effect of adding granular of recycled polyethylene to concrete in different volumetric ratios (0%, 10%, 20%, 30%) as a partial substitute for aggregates, in addition to introducing fibers of the same material in a volume ratio of 1%. A set of laboratory tests will be conducted to determine the compressive strength, flexural strength, and impact resistance, in order to analyse the performance of the modified mixtures compared to conventional concrete. The study also seeks to determine the optimal proportion of polyethylene that It strikes a balance between mechanical performance and environmental impact reduction, enhancing the potential for the use of this material in sustainable construction projects.

2. MATERIALS USED

CEM I 42,5R regular Portland cement was utilized. Drinking water devoid of biological materials is used for the mixing process. Two types of aggregates were used in this study: marble granular, which is exported from Italy and has a specific weight of 2.63 and an absorption rate of 2.02%, and fine aggregate (sand), which is local and supplied from the city of Misrata with an absorption rate of 0.355%. Both of these aggregates fell within the bounds of the grain gradient curve in the Libyan specifications of fine aggregates (LNCSM49-2002) [7]. Sand made up 60% of the mixing rates for the two types of aggregates, while gravel aggregate made up 40%. The used polyethylene waste was supplied from collection and recycling sites. Part of it was ground into granules, which were then sieved and classified to sizes. The other part was manually cut into fibers with lengths ranging from 38-42 mm, widths from 2-3.5 mm, and thicknesses 1.8 mm. Figure 1 shows the granules and strips of the polyethylene used. A practical program of four concrete mixtures with varying percentages of polyethylene residues served as a basis for the study .

Fig 1. HDPE granules and fibres used in mixes.

Various percentages of aggregates were substituted with polyethylene aggregates based on their granular gradient, and material mixing ratios were employed in accordance with the volumetric equation of the mixes design. The following names were given to the mixtures: The polyethylene-free reference mixture is denoted by R0, whereas the other three mixtures CP10, CP20, and CP30 contain an alternative to natural aggregates in the form of 10%, 20%, and 30% polyethylene aggregate, respectively. The last three mixes also were supported by 1% percent polyethylene fibers. the natural aggregates were replaced partially with high-density polyethylene (HDPE) granules, based on the gradation of the natural aggregate particles. The mixing ratios for each of the aforementioned mixes are displayed in Table 1. The materials utilized underwent a number of mechanical, physical, and chemical tests.

Table 1. Types of mixtures and proportions of substances in the mixture kg/m^3.

Mix	Quantities				
	Cement	Water	Aggregate	HDPE aggregate	HDPE fiber
R0	350	183.7	1200.0	0.0	0.0
CP10	350	169.2	1079.2	31.7	28.3
CP20	350	168.6	960.0	57.3	28.3
CP30	350	167.7	840.0	85.9	28.3

3. METHODOLOGY

For the purpose of testing the compressive strength at day of seventh and twenty-eight**,** a total of 24 concrete cubes measuring 100 mm were made, six for each mix. 32 cylinders measuring 60 x 150 mm were made for the impact strength test, eight for each mix. For flexural strength testing at 28 days, 12 prisms measuring 100 x 100 x 500 mm were also made, three for each mixture.

A mechanical mixer was used to completely mix the ingredients dry. Water was then added, and mixing continued until the necessary workability was reached.

The fresh concrete was poured straight into the molds and compacted using a mechanical vibrator once the mixing procedure was finished and the slump test was performed on all new concrete mixes. For a full day, it was kept at the lab temperature (23±2°C) without any outside effects. The molds were taken out after a full day, the samples were numbered to help identify them, and they were submerged in water until the test was done.

Cubic Samples Three cubes are removed from each sample after a week of immersion in order to conduct a compressive test on them. The remaining samples are then removed, dried, and their densities are determined after twenty-eight days. These cubes are then subjected to the Ultrasonic Pulse Velocity (UPV) test. Following the completion of the compressive test, this procedure is repeated for all mixes. An Auto Test instrument from the global business ELE was used to conduct the compressive test. The load was applied to the cubic concrete samples at a rate of 140 kg/cm2 per minute until collapse, gradually and continuously. Prismatic samples The prisms were extracted 28 days after casting for flexural testing. Specimens were mounted on a center-point loading system, also from ELE, using an Auto Test machine. Loading was gradually applied to the prisms until failure at a load rate of 180 kg/min. This corresponds to a stress rate of approximately 0.02–0.10 MPa/s. Flexural strength results were recorded directly from the machine.

3.1 Cylindrical samples

After 28 days, the cylinders for every mix were taken out of the water curing process and dried in preparation for impact testing. A modified aggregate impact testing machine was employed to evaluate the impact of cylindrical concrete specimens. As seen in Figure 2, a steel ball with a diameter of 61 mm was positioned in the middle of the specimen, encircled by a die that applied the impact load vertically while preventing lateral movement. A weight weighing 13.5–14 kg as specified was dropped from 310 mm in height, and the number of blows needed until the first crack showed up, signifying failure, was counted.

To accurately measure the crack width, a high-resolution image of the surface cracks was captured using a Digi Micro Mobile (dnt) camera with 100×500 magnification and 12-megapixel resolution.

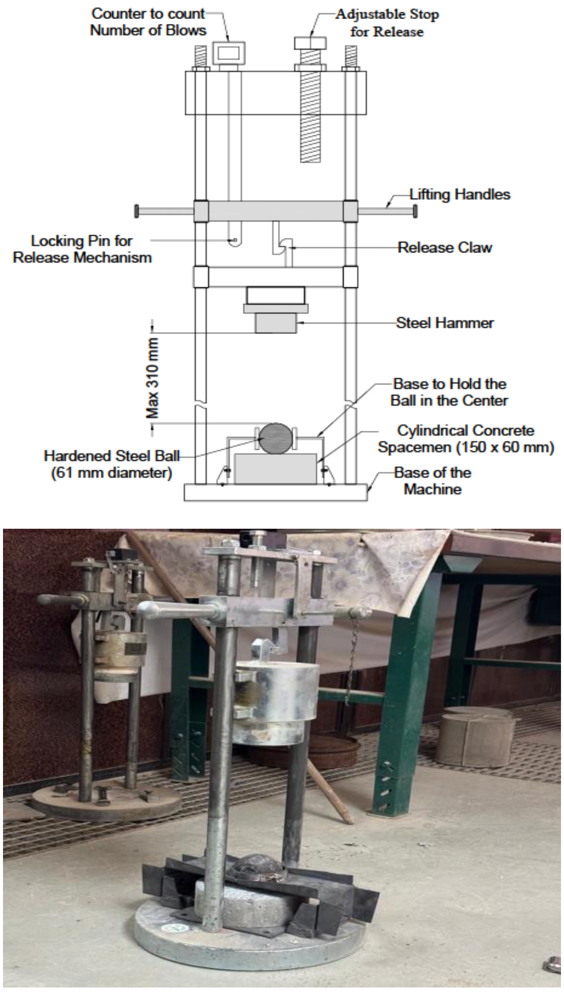

Fig 2. Modified Impact Device and Test Sample Preparation: section (upper) and photo (down).

4. RESULTS AND DISCUSSION

4.1 Analysis of Results

The slump test was performed for all mixtures immediately after mixing and the amount of water was controlled in order to obtain the same amount of the slump for all mixtures (70 mm). This step comes to compare the strength of the mixtures while excluding the factor of low strength due to the increase in the percentage of water in the mixture .

The hardened samples were tested after 7 and 28 days for compressive resistance and after 28 days for density calculation, UPV, bending and impact testing. Table 2 displays the test findings, which indicate that as the amount of polyethylene in the combination increases, the majority of the characteristics decrease. This is attributed to the fact that polyethylene is a light and non-porous material, which reduces the bonding between its components and the cement paste, and its presence leads to an increase in internal voids and poor load transfer within the concrete.

The density of hardened concrete is a fundamental property because it reflects the extent of the cohesion and hardness of the material after the hardening process is complete. The density of concrete and its resistance to bending and compression are directly correlated; the higher the density, the greater the concrete's strength [8]. As shown in Table 2, we can see that the density decreases with the increase in the amount of polyethylene substitution in the mixture, which is a natural result due to its lighter weight compared to natural aggregates.

The ultrasonic pulse velocity (UPV) test depends on the speed at which sound waves travel through the concrete material. The test was performed after calculating the density of the cubic samples. As the percentage of polyethylene increases, the UPV data in Table 2 also demonstrate a drop in velocity, suggesting a decline in the cohesiveness or quality of the internal matrix of concrete. However, the value of all the results in general indicates that the condition of the concrete is very good for all mixtures according to the classifications of many references.

Table 2. Results of various tests.

Concrete Mix	Density (kg/m^3)	Ultrasonic pules velocity, UPV (km/s)	Compressive strength (MPa)		Flexural strength (MPa)	Impact test (blows)
			7d	28 d		
R0	2309	4.38	27.97	33.14	3.92	2
CP10	2116	3.97	17.37	25.20	3.49	1
CP20	2076	3.93	17.01	22.18	3.45	2
CP30	1984	3.86	16.11	20.47	3.09	3

Compression testing of hardened concrete was conducted on 7-day and 28-day-old mixes. According to the results recorded in Table 2, a decrease in strength was evident with increasing polyethylene substitution ratio, both at the early stage (7 days) and after 28 days. This decrease is consistent with previous results of researchers when replacing HDPE granules or other plastic materials with aggregates in concrete [6, 9]. These results are attributed to the weak bond between the polyethylene granules and the cement paste, which causes them to slip and subsequently separate when compressive force is applied.

Flexural test yields the same result, even though polyethylene fibers were added to improve bending strength, however resistance decreases as the proportion of HDPE replacement in the mixture increases.

From the previous results of density, wave transmission velocity, compressive strength and flexural of all concrete, we find a decrease with the increase in the percentage of polyethylene replacement in the mixture. the percentage of reduction in the property compared to the reference mixture is recorded in Table 3.

Impact testing is an important dynamic test that determines the extent of the resistance of concrete to absorb shock. Impact resistance here is determined by the average number of impacts resulting from a free load falling on the center of the cylindrical specimen until the first visible crack appears on the specimen. From the impact results recorded in Table 2, we can see that with increasing HDPE, the shock absorption capacity is relatively improved, but the compressive strength and internal cohesion are weakened. The samples R0 and CP20 broke after two blows, indicating a semi-conventional behavior in terms of absorption capacity. The CP10 sample broke after a single blow, indicating sudden impairment in absorption and impact resistance. three blows required until the CP30 sample break, despite its weak compression and bending, indicating a relatively flexible or ductile behavior due to the properties of HDPE. In general, increasing HDPE improves the shock absorption capacity comparatively, but weakens compressive strength and internal cohesion.

4.2 Evaluating of collapse forms and crack patterns of compressive tests

Analysis and evaluating images and forms of collapses is to delve into the structure of the concrete mixture and compare it with other mixes. In this paragraph, the shapes of the collapsed specimens will be evaluated after the test.

Figure 3 illustrates the failure that occurs when the specimens undergo a compression test after seven days, and Figure 4 illustrates the collapse that occurs after twenty-eight days.

The failure changed from the typical brittle behavior of the reference concrete R0, which had good density and strength, to the concrete that

Table 3. Percentage of reduction in property with increase in HDPE compared to the reference mixture.

Concrete Mix	Density (kg/m^3)	Ultrasonic pules velocity, UPV (km/s)	Compressive strength (MPa)		Flexural strength (MPa)	Impact test (blows)
			7d	28 d		
R0	0%					
CP10	8%	9%	38%	24%	11%	8%
CP20	10%	10%	39%	33%	12%	10%
CP30	14%	12%	42%	38%	22%	14%

became "soft" and whose typical brittle behavior decreased when 30% HDPE was substituted.

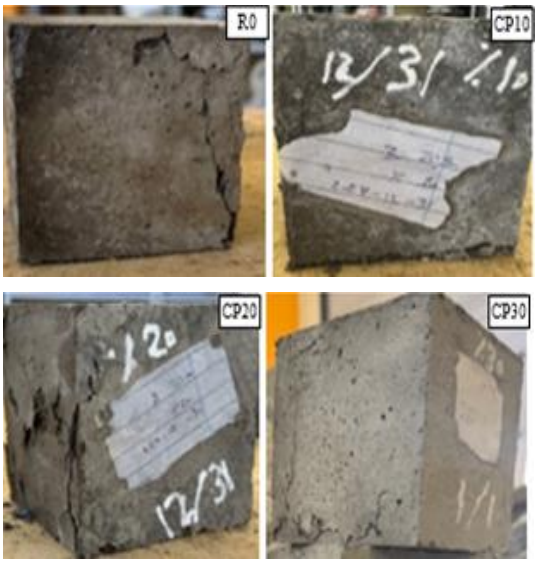

Fig 3. Collapse pattern of specimens (7-day compression test.

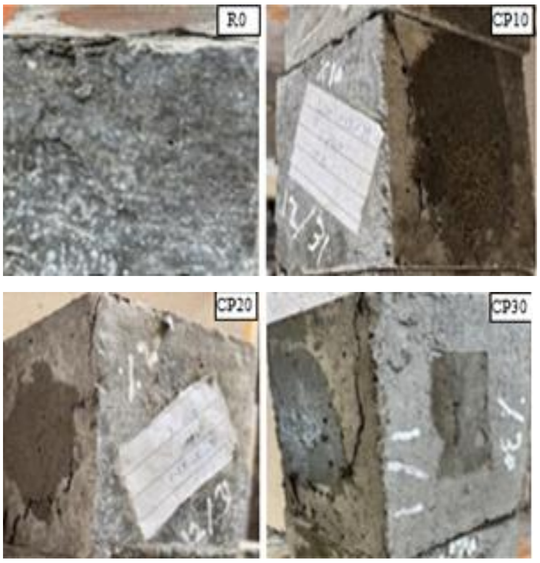

Fig 4. Collapse pattern of specimens (28-day compression test).

Failure Mode Analysis of Concrete Mixes Based on Time and Mix Type can be compared as a following:

Tests After 7 Days: Mix R0: A clear failure with sharp cracks at one cube corner indicates a typical compressive failure with a cohesive fracture pattern.

Mix CP10: Failure was noted with some splitting and semi-sharp edges. Despite being little weaker than the reference mix (R0), the strength was still within an acceptable range.

Mix CP20: Multiple cracks appeared with wider openings; however, the structural integrity was maintained. This indicates an early sign of weak interfacial bonding due to the addition of HDPE.

Mix CP30: Brittle shear failure was observed, characterized by irregular cracks and non-uniform crack patterns. This mix exhibited the most brittle behavior under loading conditions.

Tests After 28 Days: Mix R0: Strong and uniform failure occurred with relatively sharp cracks at the loading point. The strength increased significantly due to age and improved hydration.

Mix CP10: Similar failure mode to R0, but the cracks were finer and more widely distributed. This suggests improved ductility and a more gradual failure tendency compared to R0.

Mix CP20: Clear brittle fracture occurred with intersecting cracks and evidence of wide crack propagation. The weak adhesion of HDPE likely caused poor crack resistance and lower compressive strength.

Mix CP30: Gradual crushing failure was observed with smooth crack propagation, leaving behind brittle fracture surfaces. The distributed cracks led to non-uniform failure, resulting in a significant reduction in load-bearing capacity.

4.3 Evaluation of fracture patterns resulting from flexural and Impact strength testing

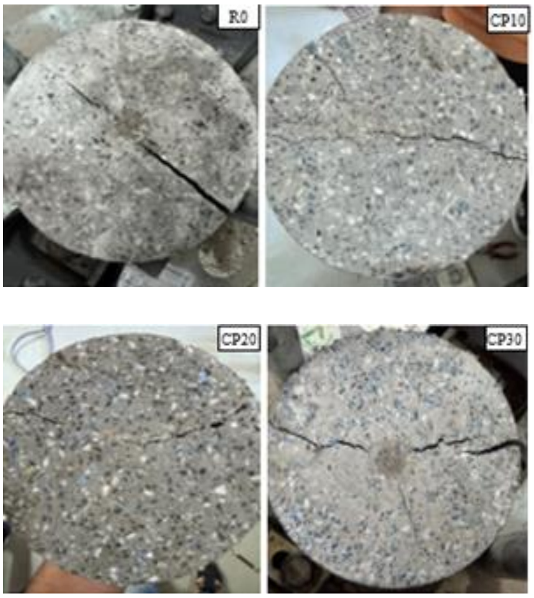

Fig 5. Failure pattern of specimens (flexural test at 28 days).

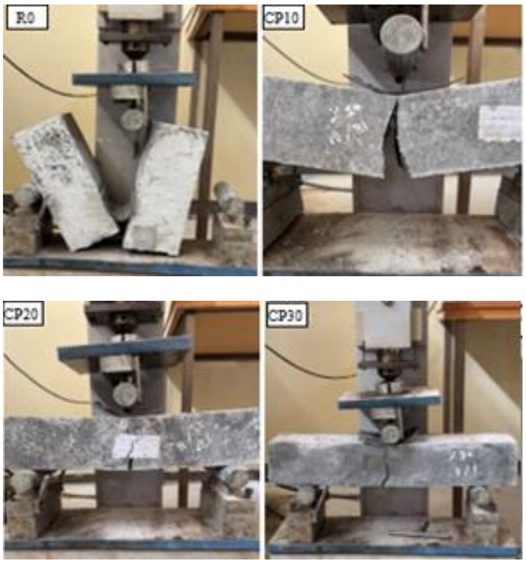

Fig 6. Failure pattern of specimens (Impact test at 28 days).

Flexural failure patterns testing for all mixes Figure 5 shows the resulting from. Analyzing these failures reveals a sharp linear fracture below the loading point at R0, and the specimen collapses completely, indicating typical brittle behavior. In samples CP10 and CP20, we observe less organized fractures, and the specimen has not fully separated along the lower surface. This is a result of the concrete's transition to ductile behavior and also due to the presence of HDPE fibers, that resist separation. In sample CP30, a diffuse and ductile fracture is observed, and the crack width is smaller, indicating a decrease in flexural toughness.

Despite the same fiber content in the CP mixes, the crack width decreases with increasing HDPE. This indicates that the addition of HDPE causes a gradual decrease in flexural strength, changing the failure mode from brittle to ductile/ductile as its percentage increases.

Impact cracking assessment of the specimen: The theoretical examination of the impact test expresses the crack width and nature of its formation. Figure 6 illustrates the crack patterns resulting from the impact test, resulting from the steel ball's transfer of the free load falling on it, as previously mentioned. From the figure, we notice that the crack pattern in specimen R0 is a sharp, direct radial crack (brittle behavior). In specimen CP10, a clearly distributed crack is located at the center. In specimen CP20, irregular cracks are superficially distributed. Meanwhile, in specimen CP30, there are wide surface cracks, with no obvious bursting. In general, increasing HDPE improves the impact absorption capacity relatively, but reduces the compressive strength and internal cohesion.

By performing a digital crack width analysis, it is found, as shown in Figure 6, that crack widths vary within the same specimen. Crack widths were measured using the aforementioned DNT camera in the widest regions of the crack. In specimen R0, the approximate average crack width is 0.97 mm, with a deep, sharp nature, indicating brittle failure. In specimen CP10, the approximate average is 0.34 mm, with narrower, less extensive cracks, indicating semi-brittle behavior. The approximate average for specimen CP20 is 1.11 mm, which is the highest in terms of average crack width, indicating the onset of a significant loss of internal bonding, a deterioration in cohesion, and an increase in ductility (semi-ductile). While the CP30 sample shows an average crack width of 0.954 mm, which are relatively distributed and wide cracks, representing ductile failure behavior.

In general, Crack morphology evolution: The failure pattern evolves from sharp, brittle cracks

R0

CP10

CP20

CP30

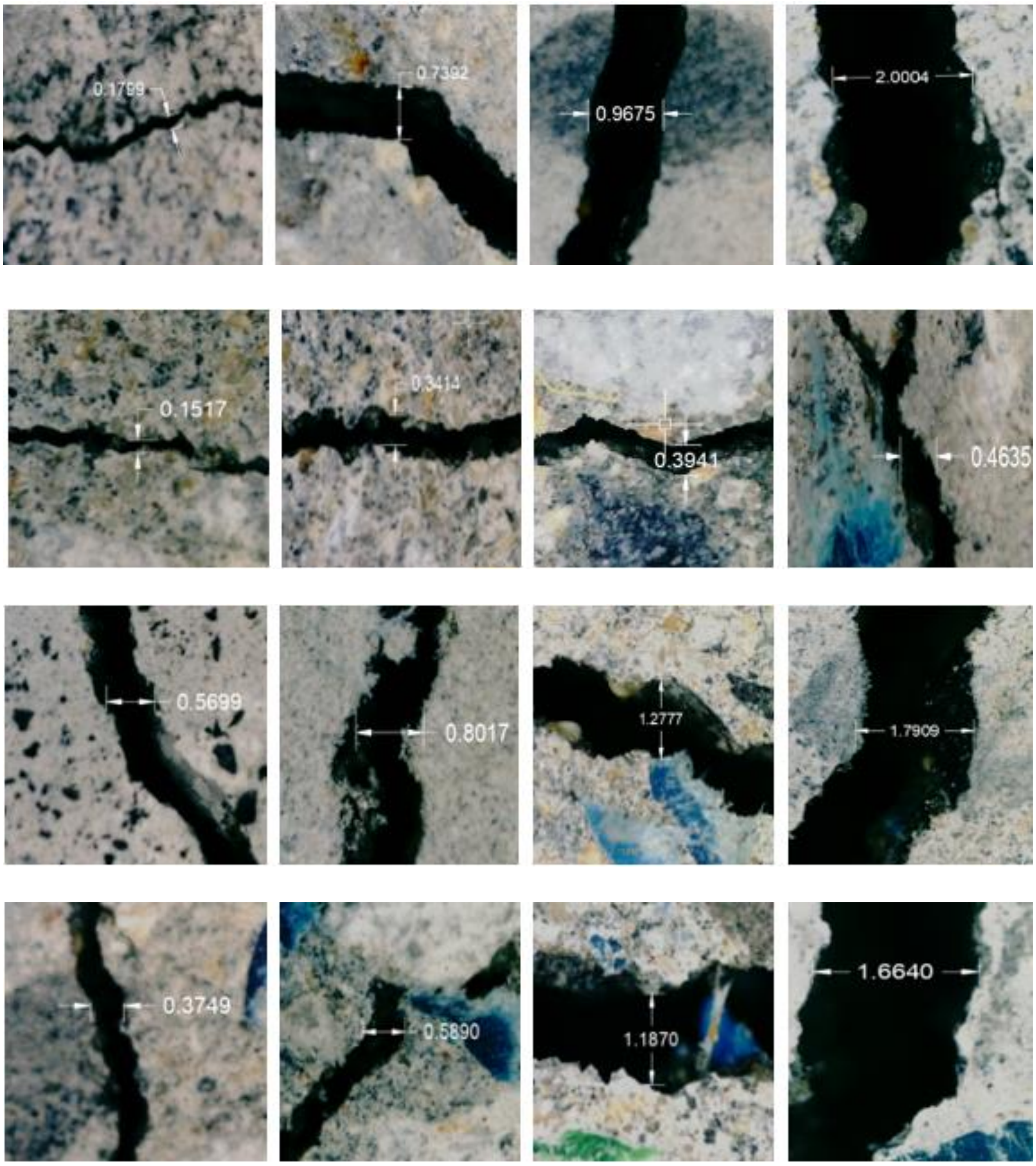

Fig 7. Crack with of specimens (Impact test at 28 days).

(in R0 and CP10) to branched, fine, network-forming cracks (in CP30), indicating an improvement in concrete behavior under dynamic impact conditions.

5. CONCLUSION

In the practical study, HDPE was partially substituted with aggregates in concrete at ratios of 10, 20, and 30%, and 1% fiber from the same polymer was added. The results were compared with a reference mixture that contained no additives. An analytical reading of the collapse forms, a summary of the test results on the samples, and a display of the ensuing cracks as follow:

1. Compressive and flexural strengths gradually decreased with increasing aggregate replacement with HDPE. The reference mix R0 showed the highest strength values, while CP30 recorded the lowest values.
2. In the impact resistance test, the CP30 mix showed the highest impact resistance (three blows), while the CP10 collapsed with one blow. Although CP30 was weaker in compression and flexural strength, its behavior under impact was more ductile and energy-absorbing.
3. CP10 recorded the narrowest average crack width reflecting semi-brittle behavior, while CP20 exhibited the widest cracks. CP30 was smaller.
4. In the failure morphology analysis, R0 showed a typical brittle failure with sharp cracks and sudden separation (brittle failure), while increasing the HDPE in the concrete mixes exhibited clear diagonal cracks, changes from semi-brittle failure to semi-ductile behavior.

This indicates that HDPE imparts superior ductility and dynamic endurance to concrete, despite its lower static strength.

In general, the weak interfacial bonding between the smooth, hydrophobic polymer surface and the surrounding cement matrix, which restricts stress transfer and results in higher internal voids and lower cohesion, is mechanistically responsible for the decrease in compressive and flexural strength with increasing HDPE content. Nevertheless, isolated zones of deformability are introduced by this same weak link and the inherent flexibility of HDPE particles, allowing strain redistribution under load. The polymer inclusions absorb and disperse some of the impact energy through elastic deformation and micro-sliding at the matrix–polymer contact rather than delivering stress suddenly. As a result, at increasing HDPE ratios, the failure mode changes from brittle fracture (in the reference mix) to ductile or pseudo-ductile behavior as crack propagation becomes slower and energy-intensive. As a result, dynamic toughness and impact resistance increase but static load-bearing capacity decreases, suggesting a change in the composite's mechanical response from strength-dominated to energy-absorption-dominated behavior.

Finally, the inclusion of HDPE in concrete reduces its traditional mechanical strength (compression and flexural strength) but improves its behavior under impact and makes collapse more ductile. This enhances the use of these admixtures in applications that require energy absorption and resistance to sudden collapse, such as barriers, factory floors, or structures subject to repeated impacts.

6. ACKNOWLEDGMENT

The researchers extend their sincere thanks to the Director of the Industrial Research Center in Tajoura, Engineer Ayman Al-Naas, Head of the Building Materials Department, and all the department's engineers for providing all the necessary resources to complete the practical aspects of this research.

REFERENCES

[1] Almeshal AM, Tayeh BA, Alabduljabbar H. Use of recycled plastic in concrete: A review. Constr Build Mater. 2020;247:118580.

[2] Ismail ZZ, Al-Hashmi EA. Use of waste plastic in concrete mixture as aggregate replacement. Waste Manag. 2008;28(11):2041–7.

[3] Rahmani E, Dehestani M, Beygi HM, Allahyari H, Nilbin M. On the mechanical properties of concrete containing waste plastic as aggregate. Constr Build Mater. 2013;47:1302–11.

[4] Mohanty AK, Misra M, Drzal LT. Natural fibers, biopolymers, and biocomposites. In: Mohanty AK, Misra M, Drzal LT, editors. CRC Press; 2005.

[5] Yang HS, Wolcott M, Kim HS, Kim S, Kim HJ. Properties of lignocellulose material-filled polypropylene bio-composites made from recycled materials. J Ind Eng Chem. 2004;10(3):377–83.

[6] Alaud S. Comparative study based on the utilization of polystyrene foam and high-density polyethylene in lightweight concrete. In: Fifth Conference on Engineering Sciences and Technology (CEST-2022); 2022; Jadu.

[7] Libyan National Center for Standardization and Metrology (LNCSM-49). Concrete aggregate from natural sources. Tripoli; 2002.

[8] Neville AM. Properties of Concrete. 5th ed. Pearson Education Limited; 2011.

[9] Alaud S. Effect of recycled PVC as a partial replacement of fine and coarse aggregate on some concrete properties. Asmarya J. 2021.