Impact Resistance of Bendable Concrete Reinforced with Grids and Containing PVA Solution

Shrooq Abd Al Kareem
Department of Civil Engineering
College of Engineering
University of Baghdad
Baghdad, Iraq
s.shetan1901M@coeng.uobaghdad.edu.iq

Ikram Faraoun Ahmed
Department of Civil Engineering
College of Engineering
University of Baghdad
Baghdad, Iraq
ikram.faroun@coeng.uobaghdad.edu.iq

Abstract - The development of new building materials, able of absorbing more energy is an active research area. Engineering Cementitious Composite (ECC) is a class of super-elastic fiber-reinforced cement composites characterized by high ductility and tight crack width control. The use of bendable concrete produced from Portland Limestone Cement (PLC) may lead to an interest in new concrete mixes. Impact results of bendable concrete reinforced with steel mesh and polymer fibers will provide data for the use of this concrete in areas subject to impact loading. The experimental part consisted of compressive strength and impact resistance tests along with a result comparison with unreinforced concrete. Concrete samples, with dimensions of 100×100×100mm (cubes), and 500×500×50mm (slabs), were poured and were treated at ages of 28, 56, and 90 days. The compressive strength increased by 36.11%, 45.5%, and 52.4% respectively, whereas the impact resistance for samples reinforced with steel mesh and polypropylene fibers gave superior results to the conventional mixes.

Keywords - ECC concrete; impact resistance; polypropylene fiber

I. INTRODUCTION

In comparison with other building materials, concrete is more practical, durable, and economical [1]. Concrete is widely used as a building material due to its high durability, easy accessibility, and low cost [2] and is commonly used in almost every kind of construction [3]. Cracks are inevitable during the life of a concrete structure. Structures exposed to the external environment are more susceptible to cracking because they are affected by shrinkage or expansion in weight and drying in addition to other environmental conditions along with the overloading factor. These cracks affect the strength of the structures by weakening them and the mechanical properties and its durability are reduced as these cracks create a path for the penetration of harmful factors into the core of the structures [4]. Attempts have been made to reduce cracks and improve the tensile properties of concrete members by using traditionally reinforced steel bars and also through the application of restraining techniques. Although both methods provide more tensile strength to the concrete members, they do not increase the tensile strength of the concrete itself. In normal concrete and similar brittle materials, fine structural cracks develop even before loading due to drying shrinkage or other causes of volume changes. Upon loading, these micro cracks spread and open due to the stress concentration effect [5]. To give the concrete flexibility we have to modify the traditional material. This type of concrete is softer than conventional concrete and is known as the Engineered Cementitious Composite (ECC). Developed at the end of the twentieth century, the ECC demonstrates the unique properties of high strength concrete, including excellent stress-hardening properties, multiple cracking properties, and fiber bridging properties which in turn increase the ductility of a structure.

ECC, also called ultra-hard cementious composite, flexible concrete, or conflexpave, is a matrix-based composite material reinforced with short fibers with a maximum volume fraction of 2.0%. ECC blends are generally developed by adding Polyvinyl Alcohol (PVA) solutions, Polypropylene (PP), and Polyethylene (PE) fibers. The introduction of fibers aims to reduce the damage in the concrete structure that is exposed to seismic and impact loads [6]. ECC concrete, is an easy-to-form mortar-based composite reinforced with specially selected short polymer fibers. ECC acts more like ductile metal than brittle glass which leads to a wide variety of applications. The tensile stress capacity of ECC can reach 3-5%, which is much higher than the 0.01% of ordinary concrete. The compressive strength of ECC is similar to that of normal to high strength concrete. Ordinary concrete is brittle by nature while ECC is ductile. Due to this property, it has wide applications and future scopes in various fields [7]. The associated high fracture toughness and controlled slit width (typically less than 100µm) make ECC an ideal material for improving the serviceability and durability of infrastructures [8].

II. MATERIAL CHARACTERIZATION

A. Cement

The cement employed in the current research was Ordinary Portland Cement (OPC) and Portland Limestone Cement (IL). The IL was produced by LAFASTAGE and conforms to European Standard EN-197-1 & European Standard no 196-2-Type IL [9]. Tables I-IV show the properties and specifications of the two types of cement.
TABLE I. PHYSICAL TESTS OF IL ACCORDING TO EUROPEAN STANDARD EN-197-1 FOR GRADE (42.5)

| Test | Test result | Specification limits | Compliance |
|------|-------------|----------------------|------------|
| Finance (Blain) cm²/gm | 5105 | At least | Matching |
| Initial setting time (min) | 90 min | At least 45 min | Matching |
| | | | |
| Compressive strength (MPa) | | | |
| 2 days curing | 8 | At least (10-20) | Not matching |
| 28 days curing | 34 | At least 42.5 | Not matching |

TABLE II. CHEMICAL ANALYSIS OF IL ACCORDING TO EUROPEAN STANDARD EN 196-2

| Oxides and phases | Karasta test results (%) | Specification limits | Compliance |
|-------------------|--------------------------|----------------------|------------|
| CaO               | 62.22                    | -                    | -          |
| SiO₂              | 17.18                    | -                    | -          |
| Al₂O₃             | 4.19                     | -                    | -          |
| Fe₂O₃             | 2.91                     | -                    | -          |
| MgO               | 1.95                     | Not more than 5%     | Not matching |
| SO₃               | 2.44                     | Not more than 2.5%   | Not matching |
| LOI               | 6.21                     | Not more than 4%     | Not matching |
| Total             | 98.43                    | -                    | -          |
| Cl⁻               | 0.011                    | -                    | -          |
| C₃A               | 6.18                     | Less than 0.1%       | -          |
| LR                | 0.47                     | Not more than 1.5%   | -          |

TABLE III. CHEMICAL ANALYSIS OF OPC

| Oxide composition | Test results | Limits of IQS 45:1984 for OPC |
|-------------------|--------------|-------------------------------|
| CaO               | 62.32        | -                             |
| SiO₂              | 21.34        | -                             |
| Al₂O₃             | 4.93         | -                             |
| Fe₂O₃             | 5.43         | -                             |
| MgO               | 2.12         | < 5%                          |
| SO₃               | 2.35         | < 2.8%                        |
| LOI               | 1.72         | < 4%                          |
| LSF               | 0.86         | 0.66 – 1.02%                  |
| IR                | 0.83         | < 1.5%                        |
| Main Compounds (Bogue's equation) |
| C₃S               | 76.28        | -                             |
| C₃A               | 7.37         | -                             |
| C₄AF              | 6.72         | -                             |
| C₃AF              | 16.5         | -                             |

TABLE IV. PHYSICAL TESTS OF OPC

| Physical properties | Test results | Requirements of IQS No.5/2019 for OPC |
|---------------------|--------------|---------------------------------------|
| Specific surface area (Blaine method) m²/Kg | 376 | > 250 |
| Initial setting (h) | 2.45 | > 45 min |
| Final setting (h) | 4.20 | ≤ 10 |
| Soundness (autoclave method) % | 0.12 | < 0.8 |
| Compressional strength (MPa) at 2 days | 20 | ≥ 10 |
| Compressional strength (MPa) at 28 days | 37 | ≥ 42.5 |

C. Silica Fume

Silica Fume (SF) (condensed micro-silica) with an activity index of 121% conforming to ASTM C1240-15 [11] was used. The technical data for the SF are shown in Tables VII and VIII.

TABLE V. PHYSICAL AND CHEMICAL TESTS OF FINE AGGREGATES

| Property | Test result | I.Q.S.45:1984 limits |
|----------|-------------|----------------------|
| Specific gravity | 2.6 | - |
| Absorption % | 0.72 | - |
| Density (kg/m³) | 1580 | - |
| SO₃ | 0.2% | 0.50% (Max) |

TABLE VI. GRADING TESTS OF FINE AGGREGATES

| Sieve no. | Passing % | Limits of Iraqi specification no.45/1984 zone 2 |
|-----------|-----------|-----------------------------------------------|
| 10mm      | 100       | 100                                           |
| 4.75mm    | 93.3      | 100-90                                        |
| 2.36 mm   | 77.7      | 100-75                                        |
| 1.18 mm   | 66.6      | 90-55                                         |
| 600 µm    | 54.4      | 59-35                                         |
| 300 µm    | 26.3      | 30-8                                          |
| 150 µm    | 3.1       | 10-0                                          |

B. Sand

Ekhaider natural sand was employed as fine aggregates in this study. Its physical and chemical properties are shown in Table V. Sieve analysis shows that the sand lies in Zone 2 from the tests that were carried according to the requirements of [10] as shown in Table VI.

B. Sand

Ekhaider natural sand was employed as fine aggregates in this study. Its physical and chemical properties are shown in Table V. Sieve analysis shows that the sand lies in Zone 2 from the tests that were carried according to the requirements of [10] as shown in Table VI.

D. Superplasticizer

A third-generation superplasticizer (Sika Viscocrete -5930) was employed, which conforms to the specifications of ASTM C494 Types G and F [12]. Superplasticizers are employed to attain severe decrease of water, enhanced flowability, and optimal cohesion. The decrease in water-cement (w/c) ratio means that the cement paste permeability reduces noticeably, hence superplasticizers can be effectively employed to enhance the properties of concrete and prevent specific defects such as honeycombing.

E. Water

Tap water was used conforming [13]

F. Polypropylene Fibers

PP fibers absorb water and resist alkalis, chemicals, and chloride. Table IX shows the properties of PP fibers.
TABLE IX. PROPERTIES OF PP FIBERS

| Length | 12mm |
|-----------------|------|
| Diameter        | 0.032|
| Density Kg/m³   | 910  |
| Tensile properties | 600 - 700 |

G. Polyvinyl Alcohol (PVA) Solution

PVA is a water-soluble and biodegradable artificial polymer. PVA is an excellent adhesive with superior bonding strength and film forming and emulsifying properties. It has excellent adhesion to both hydrophilic and hydrophobic materials. The solution was prepared to employ closely 80g of PVC in 2lt of boiled water until it disappeared completely.

H. Reinforcement Grids

Two kinds of grid reinforcement were employed, steel and polymer with 12.7mm square opening size and 0.2mm diameter.

III. EXPERIMENTAL WORK

A. Mixtures

Two major categories of ECC mixtures have been designed and chosen. The first mixture was composed of OPC, sand, SF, PVA solution, and the optimum dosage of superplasticizer of about 1.3% which is within the acceptable range which is between 0.2 and 1.5% by weight of cement. The mix was reinforced with PP fibers. The second mixture was composed of the same components except that it was produced from IL cement. The mix designs are described in detail in Table X.

| Type      | Ref.  | ECC |
|-----------|-------|-----|
| Cement (kg/m³) | OPC   | 356  | 356 |
|           | IL    | 356  | 356 |
| Sand (kg/m³)  | Zone 2| 320  | 320 |
| SF (kg/m³)    | -     | 285  | 285 |
| VF (kg/m³)    | PPM   | -    | 18  |
| Water (kg/m³) | -     | 288  | 288 |
| S.F (kg/m³)   | 5930  | 4.6  | 4.6 |
| Acetate (kg/m³)| PVA  | -    | 3.55|

B. Molds Preparation

For compressive strength tests, 100×100×100mm cubes were used, and for the impact resistance test, 500×500×50mm molds were used.

IV. RESULTS AND DISCUSSION

A. Compressive Strength

The compressive strength test was conducted according to the British standard B.S.1881: part116 [14] by using 3 cubes specimens with dimensions of 100×100×100mm and with a testing machine of 2000KN capacity with loading rate of 2.5MPa/s, at a position perpendicular to the direction of casting (Figure 1-2). The compressive strength test was conducted at the ages of 28, 56, and 90 days.

It can be noted that the samples reinforced with PP fibers have better results than the reference mixtures. The increase in compressive strength was 36.11%, 45.5%, and 52.4% at 28, 56, and 90 days of water curing respectively. The difference between the two types of cement is the change in the chemical compounds of the cement. The interpretation of the compressive strength test results is divided into three stages:

At first, there is the addition of PP fibers. These fibers were combined with the cement paste and enhanced the ability of micro cracks to spread without breaking or pulling the fibers and therefore reduced the cracks in the concrete.
The second stage is the addition of small amounts of water-soluble polymers (PVA solution) that enhance the bonding strength and durability of cementing materials.

In the third stage, and keeping in mind the recent focus on the sustainable influence on unstable constructions, the environmentally friendly SF decreases carbon dioxide emissions by decreasing the amount of cement used. SF is a material with a volume twice smaller than cement, which can easily fill the voids between cement particles, and is also a highly active pozzolanic material that reacts easily with Ca(OH)₂ and water to form secondary CSH through a pozzolanic reaction whereby the generated CSH fills the capillary voids and a denser microstructure and high compressive strength can be achieved (Figure 2). Time-dependent deformation behavior of bendable concrete produced by IL cement was studied in [15]. Two types of IL cement were used and PP fibers and PVA solution were utilized. The best results obtained were for mixes containing PP fibers and PVA solution [15].

B. Impact Resistance

The device used to measure impact resistance contains three parts that can be described as follows:

- The main support part: It consists of an iron bracket that is strong enough to support the examination device during the examination and withstand the impact. It also contains another support on which the examination form is placed, which is of angle iron and is well fixed to prevent the movement of the form during the examination.

- The iron structure for dropping the block: It is a cylindrical tube with an inner diameter of 10.5cm. It is fixed with supports that prevent it from moving during the examination. This tube contains an opening of 1.5m height.

- The falling block: It is an iron ball, weighing 3.4kg with a diameter of 9.5cm. This mass is thrown from the height of 1.5m on the model several times.

The model is placed on the supporting iron structure, and then the iron block is dropped from the specified height of 1.5m on the model. The number of blows at which the first crack appears and the number of blows to cause failure were recorded. The average of three 50×50×5cm specimens was considered. The test was carried out at the ages of 28, 56, and 90 days according to ACI C-544 [16]. The results are shown in Table XI.

| Mix            | Reinforcement | 1st crack at day | Failure at day |
|----------------|---------------|------------------|----------------|
| Reference (OPC)| Plain         | 2                | 5              |
|                | Steel         | 6                | 9              |
|                | Polymer       | 5                | 7              |
| ECC OPC        | Plain         | 2                | 4              |
|                | Steel         | 6                | 8              |
|                | Polymer       | 5                | 7              |
| Reference (IL)| Plain         | 2                | 4              |
|                | Steel         | 5                | 7              |
|                | Polymer       | 5                | 7              |
| ECC IL         | Plain         | 2                | 4              |
|                | Steel         | 5                | 7              |
|                | Polymer       | 5                | 7              |

Dimensions: 50×50×5cm

According to the test results shown in Table XI and Figures 5 and 6, the samples reinforced with steel mesh and PP fibers have the greatest results with 67, 93, and 118 blows at 28, 56, and 90 days of water curing respectively, unlike the conventional mix which showed the lowest results. The mix reinforced with a plastic mesh had mid-values of 32, 50, and 67 blows respectively. The impact resistance test results interpretation is again divided into three stages:

At first, the addition of PP fibers: these fibers incorporated with the cement paste, enhanced the ability of micro cracks to spread without breaking or pulling the fibers and therefore the cracks in concrete were reduced.

The addition of small amounts of water-soluble polymers (PVA solution): enhances the bonding strength and durability of cementing materials.

The presence of steel mesh that has higher tensile strength: The bonding between concrete and reinforcing mesh plays a major role in impact resistance, as the number of blows required to cause first crack and failure increases. This can be attributed to the effect of the reinforcement mesh which helped absorb more impact energy efficiently (Figures 7-9). The behavior of superplasticized concrete slabs reinforced with different types of polymer grids and subjected to low velocity impact loading was studied extensively in [17]. The tested 500×500×50mm and 500×500×25mm slabs had either imported or local polymer grids. The adopted falling steel mass was 3.36kg in weight and 9.5cm in diameter and the falling height was 1.2m. Three mixes were used. Many properties were tested during this research, including compressive strength and impact resistance. The test results indicated that the presence of polymer grids as concrete reinforcement enhances significantly the mechanical properties of concrete. It increases the number of blows required to cause impact failure and delays first crack and final scabbing and spalling to take place [17].
The most notable outcomes of the current study:

- Compressive strength increased by 36.11%, 45.5%, and 90 days of water curing respectively.
- The fiber-reinforced slab and steel mesh showed superior performance in impact resistance compared to the traditional mixture with 32, 50, and 67 respectively.
- The cost of bendable concrete was reduced by using IL cement.
- Bendable concrete made with locally available materials and reinforcements can be widely used instead of conventional concrete at complex construction sites.
- It is possible to use locally manufactured IL cement in producing bendable concrete with acceptable mechanical properties reinforced with locally available grids.

V. CONCLUSIONS

According to the obtained experimental results, the following are the most notable outcomes of the current study:

- Compressive strength increased by 36.11%, 45.5%, and 52.4% over the traditional mixture at the age of 28, 56, and 90 days of water curing respectively.
- The fiber-reinforced slab and steel mesh showed superior performance in impact resistance compared to the traditional mixture and required 67, 93, and 118 blows at 28, 56, and 90 days respectively, while the slab reinforced with fiber and polymer mesh showed satisfactory results compared to the traditional mixture with 32, 50, and 67 respectively.
- The cost of bendable concrete was reduced by using IL cement.
- Bendable concrete made with locally available materials and reinforcements can be widely used instead of conventional concrete at complex construction sites.
- It is possible to use locally manufactured IL cement in producing bendable concrete with acceptable mechanical properties reinforced with locally available grids.

REFERENCES

[1] M. T. Lakhiar, S. Sohu, I. A. Bhatti, N. Bhatti, S. A. Abbasi, and M. Tarique, "Flexural Performance of Concrete Reinforced by Plastic Fibers," Engineering, Technology & Applied Science Research, vol. 8, no. 3, pp. 3041–3043, Jun. 2018, https://doi.org/10.48084/etasr.2084.

[2] M. T. Lakhiar, N. Mohamad, M. a. B. Shaikh, A. A. Vighio, A. A. Jhittal, and A. A. A. Samad, "Effect of River Indus Sand on Concrete Tensile Strength," Engineering, Technology & Applied Science Research, vol. 8, no. 2, pp. 2796–2798, Apr. 2018, https://doi.org/10.48084/etasr.1869.

[3] A. S. Buller, A. M. Buller, T. Ali, Z. A. Tunio, S. Shabbir, and M. A. Malik, "Experimental Characterization of Bacterial Concrete Against Mechanical and Durability Performance," Engineering, Technology & Applied Science Research, vol. 11, no. 1, pp. 6703–6707, Feb. 2021, https://doi.org/10.48084/etasr.3983.

[4] V. C. Li, "On Engineered Cementitious Composites (ECC) A Review of the Material and Its Applications," Journal of Advanced Concrete Technology, vol. 1, no. 3, pp. 215–230, Jun. 2011.

[5] P. Archana, A. N. Nayak, S. R. Nayak, H. Vaddar, and D. S. Magnur, “Study of Strength of Polypropylene Fiber Reinforced Concrete,” International Journal of Engineering Research & Technology, vol. 6, no. 6, May 2017.

[6] K. Ramasamy, S. Kandasamy, and K. Mani, "Influence of polymeric and non-polymeric fibers in hybrid engineered cementitious composites," Romanian Journal of Materials, vol. 48, no. 4, pp. 507–513, Jan. 2018.

[7] A. Chaudhary and A. K. Sharma, "Experimental Study on Flexural Behaviour of Engineering Cementitious Composite as Bendable Concrete," International Journal for Research in Applied Science and Engineering Technology, vol. 7, no. 6, pp. 1274–1278, Jun. 2019, https://doi.org/10.22214/ijart.2019.6219.

[8] V. C. Li, "Strategies for High Performance Fiber Reinforced Cementitious Composites Development," in Proceedings of International Workshop on Advances in Fiber Reinforced Concrete, Bergamo, Italy, Sep. 2004.

[9] Cement -Part 1: Composition, specifications and conformity criteria for common cements. CEN, 2011.

[10] ASTM C494 / C494M-15, Standard Specification for Chemical Admixtures for Concrete. West Conshohocken, PA: ASTM International, 2015.

[11] ASTM C1240 - 03a: Specification for Silica Fume Used in Cementitious Mixtures. West Conshohocken, PA: ASTM International, 2015.

[12] Iraqi Specification, No. 1703: Water used in concrete. Baghdad, Iraq, 1984.

[13] Testing concrete — Part 116: Method for determination of compressive strength of concrete cubes, in British Standard, BSI, 1983.

[14] "Testing concrete — Part 116: Method for determination of compressive strength of concrete cubes," in British Standard, BSI, 1983.

[15] "Time-dependent deformation behavior of bendable concrete produced by Portland limestone cement," M.S. thesis, University of Baghdad, Baghdad, Iraq, 2016.

[16] ACI Committee 544, "Design Considerations for Steel Fiber Reinforced Concrete," ACI, West Conshohocken, PA, USA, ACI 544.4R-88, 1988.

[17] I. F. A. Almulla, "Behaviour of concrete units containing Polymer grids," M.S. thesis, University of Baghdad, Baghdad, Iraq, 2002.