Time Dependent Behavior of Engineered Cementitious Composite Concrete Produced from Portland Limestone Cement

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Abstract. Conventional concretes are nearly unbendable, and just 0.1 percent of strain potential makes them incredibly brittle and stiff. This absence of bendability is a significant cause of strain failure and has been a guiding force in the production of an elegant substance, bendable concrete, also known as engineered cement composites, abbreviated as ECC. This type of concrete is capable of displaying dramatically increased flexibility. ECC is reinforced with micromechanical polymer fibers. ECC usually uses a 2 percent volume of small, disconnected fibers. Thus, bendable concrete deforms but without breaking any further than conventional concrete. This research aims to involve this type of concrete, bendable concrete, that will give solutions for concrete deficiencies. Two types of Portland Limestone Cement were used, Karasta (CK) and Tasluja (CT). Four mixes were adopted, polypropylene fibers (PP) and polyvinyl alcohol solution (PVA) were conducted to prepare the mixes. The tests were carried out at the age of 28 days of water curing. Best results were presented for mixes containing PP fibers and PVA solution than those without fibers for drying shrinkage and creep tests.

Keywords: Limestone cement; drying shrinkage; creep; bendable concrete.

1. Introduction
A measure of tensile deformation is ductility (strain). Attempts to achieve tensile ductility of concrete material are demonstrated in the early attempts by [1] and later [2]; they showed that high tensile ductility could be obtained hundreds of times that of traditional concrete with continuous aligned fibers. Bendable concrete is a strain-hardening and multiple ultra-ductile concrete and multiple-cracking attitude in flexure and tension. ECC’s tensile strain capability, compared to 0.01 percent for standard concrete, will exceed 3-5 percent. In recent full-scale structural applications, the damage resistance and essential tight crack width performance of ECC have been considered desirable by structural designers [3].

There are various forms of cement used in industry, with ordinary portland cement being the primary one and often used. One method to reduce the use of cement clinkers and CO\textsubscript{2} emissions is to supplement them with sufficient environmentally and economically sustainable materials. Limestone is one of these products. Cement in compliance with the EN 197-1 standard with a particular weight percent of limestone is named Portland-limestone cement (PLC) [4].
2. Time-dependent deformation of bendable concrete

2.1 Drying shrinkage
The drying shrinkage outcomes from the removal of capillary water mostly from hardened cement mixture, resulting in concrete contraction and crack formation. A new type of ECC with low-drying shrinkage characteristics has been studied by [5] and compared with conventional ECC. Experimental results indicate that the estimated drying shrinkage strain at 28 days is just $(109 \times 10^{-6})$ to $(242 \times 10^{-6})$ for low shrinkage engineered cementitious composite, but the shrinkage strain at 28 days is almost $(1200 \times 10^{-6})$ for conventional ECC, which is almost 7 times greater than the shrinkage of the low shrinkage matrix composite. Xinqi et al. [6] analyzed the shrinkage properties of bendable concrete. In order to examine the effect of fiber material and super-plasticizer (SP) on the overall drying shrinkage value of ECC mixes. The conclusions of the tests show that, in most situations, the fiber quality has no influence on the overall drying shrinkage effect of bendable concrete, and SP could reduce it slightly. The effect of sand/binder ratio, water/binder ratio, shrinkage reducing agent content, PVA fiber, and fly ash content on the drying shrinkage has been studied by [7] in order to minimize the drying shrinkage strain of standard ECC and decrease the shrinkage variations between concrete and PVA fibers. The results indicate that ECC's drying shrinkage strain decreased with the increasing sand/binder ratio, shrinkage reducing agent, and fly ash content, and increases with the water to binder ratio increasing.

2.2 Creep
Concrete creep is characterized as the time-dependent rise in strain under continued constant load that occurs after the initial loading pressure [8]. Studies have been conducted by [9] on both static and cyclic loading conditions of the Concrete creep. Four groups were manufactured from high-strength high-performance concrete (HSHPC) prism samples. The experimental results indicated that, compared with the creep strains under static loading, the creep strains under cyclic loading increase dramatically, furthermore, for the numbers of cyclic loading repeats. The impact of creep in HSC (High Strength Concrete) was analyzed by [10] and compared with standard strength concrete. Creep must be considered to ensure protection in the structures during the construction of buildings. Usually, over the long term, the HSC is higher than NSC (normal strength concrete) since the creep in HSC is smaller than NSC at all stress/strength proportions. The major reason for this behavior is that HSC comprises a lower volume of hydrates and water, resulting in higher strength and rigid construction with stronger resistance to deformation, the main explanation for this efficiency. In addition to basic and drying creep in compression, [11] review the relationship for both basic and drying creep in tension and comparing between them. The results demonstrate that basic compression creep is considerably more important than basic tension creep; with the lowering concrete age at loading, this variation increases. The basic creep in concrete is primarily caused by extra shrinkage under stress through self-drying.

3. Materials

3.1 Cement
Two different types of limestone cement had been used in this research Karasta cement (CK) and Tasluja cement (CT); both types are of grade 42.5R. In the laboratories of the Building Research Center, chemical and physical tests were conducted. The reports of the quality control department are just as seen in Tables 1 and 2, according to European Standard EN BS197-1:2011.

3.2 Sand
This experiment used Ekhaider natural sand as the fine aggregate. The sieve analysis reveals that from the experiments carried out in compliance with the requirements of Iraqi Specification No.45/1984 of particles passing standard sieves, the sand is found in zone 2, as shown in table 3. The physical and chemical properties of fine sand are shown in Table 4.
Table 1. Chemical properties of Karasta (CK) and Tasluja (CT) limestone Portland cement IL.

| Oxides (%) | Karasta test results | Tasluja test results | Specification limits |
|------------|----------------------|----------------------|----------------------|
| L.O.I      | 3.44                 | 2.21                 | Not more than 5      |
| SiO₂       | 18.39                | 17.81                | -                    |
| Al₂O₃      | 4.63                 | 4.19                 | -                    |
| Fe₂O₃      | 4.77                 | 4.91                 | -                    |
| SO₃        | 2.35                 | 2.44                 | Not more than 4%     |
| CaO        | 62.11                | 62.22                |                      |
| MgO        | 1.83                 | 1.95                 |                      |
| Cl⁻        | 0.01                 | 0.011                | Less than 0.1%       |
| LR         | 0.9                  | 0.47                 | Not more than 5%     |

Table 2. Physical properties of Karasta (CK) and Tasluja (CT) limestone Portland cement IL.

| Test                          | Tasluja     | Karasta     | Specification limits       |
|-------------------------------|-------------|-------------|---------------------------|
| Finance (Blaine) (m²/kg)      | 5105        | 4875        | 2500, min.                |
| Initial setting time (min)    | 90 min      | 75 min      | >60, min.                 |
| Compressive strength (MPa)    | 21          | 25          | >20                       |
| 2 days curing                 | 43          | 48          | >42.5                     |
| 28 days curing                |             |             |                           |

Table 3. Sand analysis according to the requirement of (IQS no.45/1984) Zone 2.

| Sieve No. | 10 mm | 4.75 mm | 2.36 mm | 1.18 mm | 600 μm | 300 μm | 150 μm |
|-----------|-------|---------|---------|---------|--------|--------|--------|
| Passing % | 100   | 93.3    | 77.7    | 66.6    | 54.4   | 26.3   | 3.1    |
| Iraqi specification | 100 | 100-90 | 100-75 | 90-55 | 59-35 | 30-8 | 10-0 |
| Finance modulus (F.M)        |         |         |         |         |        |        | 2.78   |

Table 4. Physical and chemical properties of fine aggregate.

| Property                  | Test result | Specification limits |
|---------------------------|-------------|----------------------|
| Specific gravity          | 2.6         | -                    |
| Absorption, %             | 0.72        | -                    |
| Density (kg/m³)           | 1580        | -                    |
| Sulphate content (SO₃)    | 0.2         | 0.50% (max)          |

3.3 Superplasticizer
Superplasticizer is an aqueous solution of adjusted polycarboxylates, commercially refers to (SikaViscocrete-5930). It complies with the requirements of Types G and F of ASTM C494-17. It is often used to obtain extreme water elimination, superior flow ability, and the highest possible cohesion. The limits of the SP used in this research were between (0.2-1.5) %.

3.4 Silica fume
Silica fume SF (condense micro-silica) was used as a mineral admixture (Sica company Iraq) and under the commercial name (Mega Add MS (D)). As seen in Table 5, it has been physically and chemically verified according to the specifications of ASTM C 1240-15.
Table 5. Physical and chemical requirements of silica fume.

| Physical requirement of silica fume | Specification limits |
|------------------------------------|----------------------|
| Accelerated Pozzolanic strength activity index at 7 days | min 105 |
| 112.8 | |

| Chemical requirement of silica fume | Specification limits |
|-------------------------------------|----------------------|
| SiO\(_2\) (%) | 85 %, min |
| Loss on Ignition (%) | 6%, max |
| Moisture content (%) | 3%, max |

3.5 Polypropylene Fiber
Polypropylene fiber (pp) Figure 1 is an embryonic material for construction that can be characterized as concrete with high mechanical strength and durability [12]. The manufacturer properties of pp fiber are as shown in Table 6.

Table 6. Manufacturer properties of Polypropylene fibers.

| Length (mm) | Diameter (µm) | Density (kg/m\(^3\)) | Tensile strength (MPa) |
|-------------|---------------|------------------------|------------------------|
| 12          | 32            | 910                    | 600-700                |

3.6 Polyvinyl Alcohol (PVA)
Polyvinyl alcohol is a synthetic polymer soluble in water and biodegradable, Figure 2. It is a dry solid that comes in granulated and powdered forms, with advanced bonding strength, film-forming, and emulsifying abilities. The kind used in this research is (BP-20) [13].

Figure 1. Polypropylene fiber.  
Figure 2. Polyvinyl Alcohol (powder).

4. Experimental work
Four mixes were prepared as shown in Table 7.

Table 7. Description of the mixes prepared.

| No. of the mix | Description |
|----------------|-------------|
| A1             | ECC mix with limestone cement (CK) and fibers (pp and PVA). |
| B1             | ECC mix with limestone cement (CT) and fibers (pp and PVA). |
| A2             | Reference ECC mix with limestone cement (CK) and without fibers (pp and PVA). |
| B2             | Reference ECC mix with limestone cement (CT) and without fibers (pp and PVA). |

Based on references [14,15] the required mixes that could be used for several construction purposes with sufficient ductility were produced after many trail mixes have been conducted in the University of Baghdad laboratories. The designed compressive strength that can be obtained was 42 MPa in 28 days of curing. The percentages of the design mixes are given in Table 8. The shrinkage and creep tests of the tested soil sample are shown in Figure 3.
Table 8. Concrete mixes (by weight).

| Type       | Cement | Sand | SF | Water | HRWR | Vf  | Acetate |
|------------|--------|------|----|-------|------|-----|---------|
| ECC, (%)   | CK     | CT   | -  | -     | -    | PP  | PVA     |
| ECC (%)    | 1      | 0.9  | 0.8| 0.45  | 0.013| 2   | 1       |
| Reference (%)| 1  | 0.9  | 0.8| 0.45  | 0.013| -   | -       |

Figure 3. Shrinkage and creep tests.

The dimensions of the mold used in the tests are:
- 100x100x400 mm prisms were prepared for the drying shrinkage test.
- 100 x200 mm cylinders were prepared for the creep test.

5. Results and discussion

5.1 Drying shrinkage

According to ASTM C490/C490M, the drying shrinkage test was performed for Portland Limestone cement (CK and CT) in Table 9. Also, Figures 4 and 5 represent the drying shrinkage test results after 1, 3, 6, 9, 14, 21, 29, 36, 43, 50, 57, 64, and 71 days of curing.

Table 9. Drying shrinkage test results.

| Age (days) | Indoor Drying shrinkage strain, ×10^-6 | Mixes, temperature 21ºC and humidity 35% |
|------------|----------------------------------------|-----------------------------------------|
|            | A1          | B1      | A2         | B2         |
| 1          | 0           | 0       | 0          | 0          |
| 3          | 12.1        | 6       | 29.1       | 13.3       |
| 6          | 12          | 7.8     | 22         | 15.6       |
| 9          | 29.1        | 15.8    | 54.9       | 41.8       |
| 14         | 51.8        | 34.8    | 84         | 74.2       |
| 21         | 64          | 55.1    | 135        | 87         |
| 29         | 70.1        | 62.3    | 142.9      | 96.6       |
| 36         | 77          | 68.1    | 155.2      | 100        |
| 43         | 82.8        | 72      | 174        | 111.4      |
| 50         | 85.6        | 83.1    | 205        | 135.6      |
| 57         | 95.5        | 93.2    | 281        | 167.6      |
| 64         | 105.6       | 104.1   | 294        | 177.7      |
| 71         | 132.7       | 120.2   | 486        | 316        |
Creep test was conducted on four mixes. The load intensity was 40 percent of the compressive strength at the age of loading. Strain measurements were made over a (100 mm) extensometer by means of a demic point. The length change of the specimen was measured by means of a length compress meter (extensometer), satisfying the requirement of ASTM C512-15. The results of tests are shown in Figures 6 and 7. Also, the variation of creep strain with for the four tested samples are given in Table 10.

From the results of creep test, it can be seen that the samples made with pp fibers and PVA solution have less drying shrinkage and creep than those containing no fibers, and this is due to the bonding and tensile strength of these fibers that mechanically make the samples stronger, and it is also obvious that the specimens with limestone cement type (CK) has higher drying shrinkage and creep than other specimens due to the chemical composition and calcium carbonate percent that added to the clinker [16,17].
Table 10. Creep test results.

| Age (days) | Creep strain×10^{-6} | A1  | B1  | A2  | B2  |
|------------|----------------------|-----|-----|-----|-----|
| 1          | 0                    | 0   | 0   | 0   | 0   |
| 7          | 28                   | 21  | 122 | 38.2|
| 14         | 37.2                 | 29  | 124 | 65.8|
| 21         | 80                   | 76  | 125.6| 119.8|
| 28         | 128                  | 94  | 145.8| 125.6|
| 35         | 138                  | 123 | 192 | 149 |
| 42         | 148                  | 134 | 213.8| 154 |
| 49         | 193                  | 187.6| 276 | 200 |
| 56         | 214.8                | 198.1| 350.2| 250 |
| 63         | 236                  | 211 | 422 | 254.4|
| 70         | 241                  | 237.5| 431 | 267 |
| 77         | 250                  | 241 | 456 | 345 |

Figure 6. Creep with curing age of ECC mix containing limestone cement types CK and CT.

Figure 7. Creep with curing age of Ref. mix containing limestone cement types CK and CT.

6. Conclusion
- Many samples were tested for two types of cement, Karasta (CK) and Tasiluja (CT) PLC. The results have shown a general reduction in both creep and drying shrinkage using CT type of cement.
comparing to CK type due to the chemical composition and calcium carbonate percent that added to the clinker and reduced its percentage. Less clinker leads to lower creep and shrinkage.

- Bendable concrete mixes showed better results in drying shrinkage and creep than reference mixes, and this is attributed to the presence of pp fibers and PVA solution that made the concrete stronger.

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