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Determination of Tensile Strain Capacity of Fresh Concrete: A new test method

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Abstract: Measuring physical properties of fresh concrete is important to understand the behaviour of the early state of concrete. Plastic shrinkage occurs at the very early stage due to evaporation of water from the concrete surface. When concrete is restrained against plastic shrinkage, tensile strain is developed and when it exceeds the tensile strain capacity, cracks occur. This phenomenon is called as plastic shrinkage cracking. In order to assess the risk of plastic shrinkage cracking tensile strain capacity of fresh concrete should be measured. Fresh concrete means the concrete before the initial setting time which is still in a semi liquid state. The paper presents a test method developed to measure the strain distribution along a fresh concrete sample. Based on this test method tensile strain capacity of a selected mix proportion with three different types of cements, i.e., Ordinary Portland Cement, Fly ash blended and Portland Limestone Cement were determined. Results indicate that concrete with fly ash blended cement has a higher tensile strain capacity than other two cement types.

Keywords: fresh concrete, plastic shrinkage cracking, tensile strain capacity

1. Introduction

Measuring physical properties of fresh concrete is important to understand the behaviour of the early state of concrete. Plastic shrinkage occurs at the very early stage due to evaporation of water from the concrete surface. When concrete is restrained against plastic shrinkage, tensile strain is developed and when it exceeds the tensile strain capacity, cracks occur. This phenomenon is called as plastic shrinkage cracking. Thus evaluation of tensile strain capacity of fresh concrete helps to determine the risk of cracking due to restrained plastic shrinkage.

It has been often reported that cracking had occurred in various types of concrete mixes but there is no procedure to evaluate exactly how vulnerable the mix is for cracking or what mixes has low risk of cracking. As the cracking is mainly due to tensile strain development due to volume change, tensile strain capacity can indicate the probability of such occurrence.

Although there are ample data on strain capacity of hardened concrete, only very few can be found on fresh concrete. Fresh concrete means the concrete before the initial setting time which is still in a semi liquid state. From right after mixing of concrete to 3 – 4 hours is considered as initial setting time period during which concrete changes from plastic state to solid state. According to the studies done by Byfors [1], Hammer [2] and Roziere et al [3] the tensile strain capacity goes through a minimum value as a function of age. It reached approximately 0.05% at 6-8 hours after mixing. However, plastic shrinkage cracking can occur before that as tensile strain developed due to plastic shrinkage could exceed the tensile strain capacity in the plastic state (where tensile strain capacity haven't reached its minimum value). Almost all the tests done in previous studies have started 2 hours after mixing has finished. Therefore those test results do not indicate tensile strain capacities at very early stage of concrete.

2. Development of a test method

2.1 Previous Test methods reported

Developing a sound test method for this purpose is quite challenging. Kasai et al [4] and Hannat et al [5] have been concerned about developing a method with minimum friction as they were to measure both tensile stress and tensile strain. Load was applied vertically or horizontally and displacement was measured with extensometers, electronic deflectometers, LVDTs' and using image processing. Among the various apparatuses Hannat et al [5] has developed a horizontal loading type machine with two air bearing plates to minimize friction. His apparatus was further improved by Hammer [2] and Roziere et al [3] to obtain tensile strain capacity values using LVDTs and image processing. It was also noted that the strain capacity changes with the time, strain loading rate, background temperature and evaporate rate [2][3].

Based on the literature survey following drawbacks were identified that should be addressed when developing a test method to test fresh concrete.

a) Using a rigid container to hold concrete will not ensure a proper grip when applying strain as concrete is in plastic state

b) Measuring average strain along the sample length predicts a lower tensile strain capacity as local strain at the region of cracking could be higher than the average strain

Hence the following key features were identified to be included when developing a test method.

a) Sample should be placed on a mold or casing to support it, as fresh concrete is in semi-liquid state and it can flow. A flexible casing would ensure a proper grip.

b) Strain should be applied to the flexible mold and the mold will transfer it to the concrete.

c) Contactless method should be adopted to measure strain.

d) Local strain will give more accurate results than average strain throughout the sample.

e) Test should be repeatable.

2.2 Test method developed

Taking the above features into account the following test method was developed. (Figure 1)

a)Fresh concrete was placed on a rubber mold (800mm x 100mm x 40mm). It was supported by a steel frame but Perspex sheets were inserted between the mold and the steel frame to allow smooth movement.

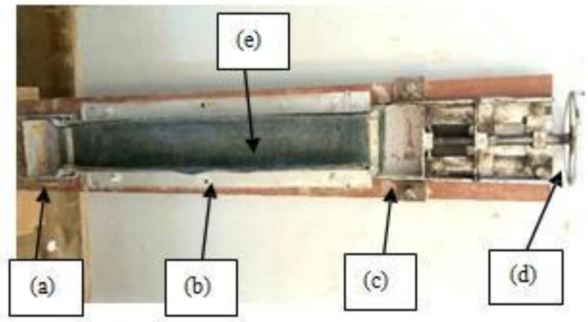


Figure 1: Test apparatus. (a) fixed end, (b) supporting frame, (c) moving end, (d) rotating wheel to apply strain, (e) rubber mold

a) Rubber mold was fixed on to two steel casings (100mm x 100mm x 40mm) at its ends. One end was fixed and pulled from the other end by rotating the wheel attached to the steel casing. Concrete sample inside will move along with it thus the strain applied would be transferred to the sample.

b) Markers were placed on the sample which will act as reference points to measure strain. (Figure 2)

Figure 2: Fresh concrete sample with markers

a) Strain was applied at a rate of 0.3 mm/s. (Tensile strain capacity distribution with time depends on the strain application rate. Higher the strain rate, the variation is more)

b) A camera placed above the sample was used to capture images continuously from the start to until the point of appearance of the first crack. (Figure 3)

c) Images were analysed and pixel count (modified by a scale factor) between two markers at the beginning and at the crack initiation point was used to calculate strain at failure.

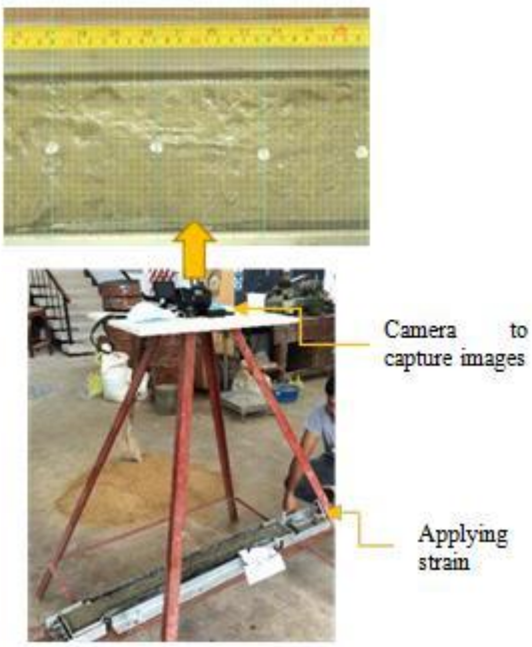


Figure 3: Test procedure and a captured image

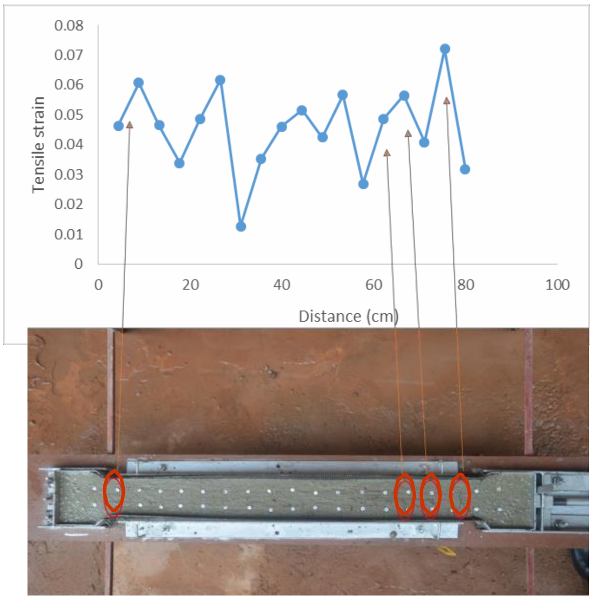


Figure 4: Strain distribution and cracks occurred at initial testing stage

3. Experimental Program

3.1 Initial testing

Initial testing was done using 1:5 cement sand mortar mix. The test was carried out according to the steps mentioned above and the tensile strain capacity was calculated using the following equation.

$$\epsilon_T = \frac{(Px_f \times S_f) - (Px_i \times S_i)}{(Px_i \times S_i)} \quad (1)$$

ϵ_T – Tensile strain capacity

Pxf – No. of pixels at failure
Sf - Scale factor at failure
Pxi – No. of pixels at start
Si - Scale factor at start

A scale factor was used to account for the distortion of the image due to curvature so that the modified pixel count will give the straight distance between two markers.

Test results showed a strain distribution as shown in Figure 4. It indicates that the peaks corresponded to the cracks appeared which are circled in Figure 4.

3.2 Cement types

After verifying the testing procedure with initial testing with cement mortar, further tests were carried out to study the influence of cement type on the tensile strain capacity. Three common cement types used in Sri Lanka were chosen. They were;

1. Ordinary Portland Cement (OPC)
2. Fly ash blended (20% replacement of OPC)
3. Portland Limestone Cement (PLC)

3.3 Mix proportions

DoE mix design method [6] was used to determine the mix proportions. Cement type was varied keeping other parameters constant. Mixes were designed for a slump of 160mm and a characteristic strength of 30N/mm^2. The selected mix proportions and measured slump and strength results are given in Table 1.

Table 1 Composition of concrete mixtures (kg/m3)

Parameter	OPC	Fly Ash Blended (20%)	PLC
Coarse Aggregates (20mm)	1059	1059	1059
Fine Aggregates	706	706	706
Cement	410	328	410
Fly Ash	-	82	-
Water	205	205	205
W/B	0.5	0.5	0.5
Slump (mm)	155	170	160
$f_{c,28d}$ (N/mm^2)	41.5	40.4	40.3

3.4 Experimental procedure

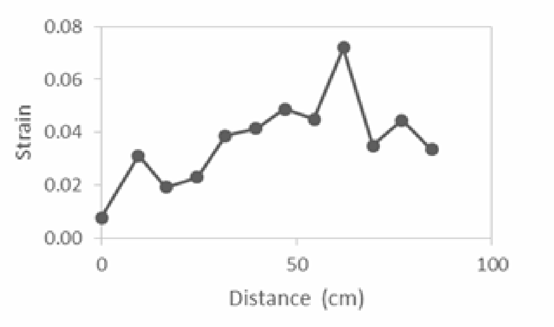
Test was carried out to simulate the practical situation of placing concrete. Required quantity of concrete was mixed in a concrete mixer at once and kept inside the mixer. The lid mixer drum was closed to prevent evaporation of water. At every 10 minutes concrete was agitated and taken out at the required time for the test. This is to simulate condition of fresh concrete in an agitator truck during transporting.

Acquired Images were processed using Adobe Photoshop CS3. A grid line was created to represent an individual pixel by a square. Number of pixels between adjacent markers were counted. Position of each marker was also recorded using the reference steel measuring tape placed along the sample. So the scale factor corresponding to each region between two adjacent markers can be calculated. Strain was calculated using Eq. (1) and plotted along the sample length.

4. Results and Discussion

4.1 Results

Strain distribution was plotted along the sample length (Figure 5). Distance zero represents the fixed end and distance increases towards the strain application end (moving end). Displacement of each marker relative to its original position before applying the strain was also plotted along sample length. (Figure 6)



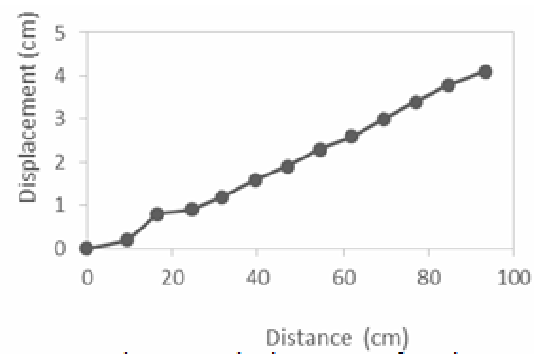


Figure 6: Displacement of markers

Generally the peak strain value corresponds to the cracking location. Therefore it can be taken as the tensile strain at the failure i.e tensile strain capacity. From the strain distribution it is evident that the local strain at the location of cracking is significantly higher than the average strain along the sample.

In order to further clarify the variation of strain, especially the sudden peak at the location of cracking, displacement of adjacent markers to the cracking point were plotted against the duration of strain application (See figure 7).

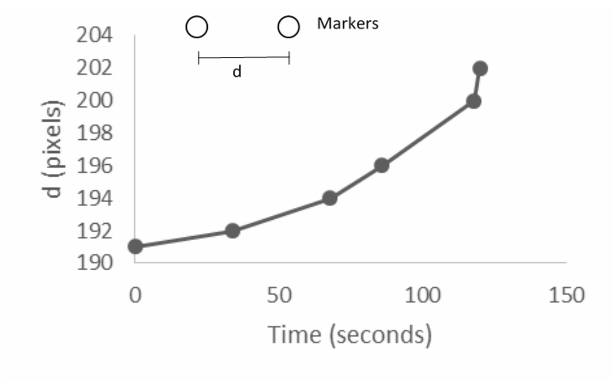


Figure 7: Displacement of two adjacent markers during application of strain

As indicated by figure 7, at the time of cracking there is a sudden increase of displacement between markers which resulted as a peak in strain distribution.

4.2 Tensile strain capacity for concrete with different cement types

Figure 8 shows the variation of tensile strain capacity of each mix with time

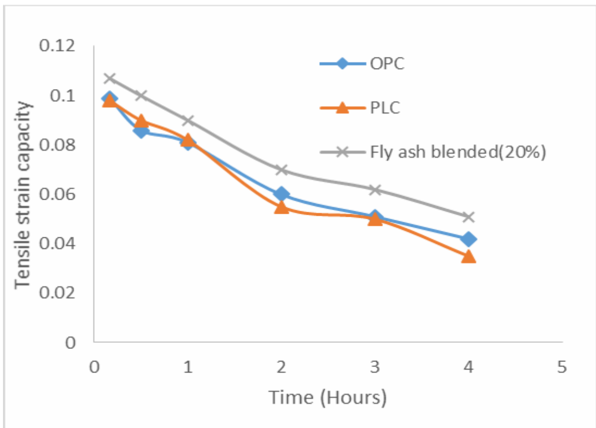


Figure 8: Tensile strain capacity for concrete produced with different cement types

It can be seen that tensile strain capacity decreases non-linearly with time. Concrete becomes stiff and moves from liquid state to semi-liquid state and then to early hardening state. Cohesiveness decreases and becomes minimum and then increases again when concrete hardens. As the test was conducted before the hardening stage strain capacity continuously decreases with time.

Concrete with fly ash blended cement shows a higher tensile strain capacity (8% - 21%) than OPC and PLC. According to Mehta et al [7] Fly ash particles are spherical while OPC and PLC cement particles are irregular shaped. Furthermore studies done by Owens [8] and Thomas [9] disclose that spherical fly ash particles are finer and more cohesive. As a result of that fly ash blended cement concrete can undergo more tensile strain than other two cement types before cracking. According to Owens [8], for equal slump, fly ash blended cement concrete has more free water. Therefore concrete with fly ash blended cement can last longer in the liquid state which has high tensile strain capacity than semi-liquid state. These two phenomenon explains the reason for the results obtained from this experiment.

5 Conclusions

Based on the results obtained from this experimental investigation following conclusions can be made.

- Measuring local strain yields more accurate results than average strain across a sample as the local strain at the location where crack occurs is higher than the average strain calculated from the total length of the sample.
- Tensile strain capacity decreases non-linearly with time during the plastic stage of concrete
- According to results obtained from the experiment, concrete with Fly ash blended cement is less vulnerable to early age cracking than OPC and PLC. The observation is based on the conditions where other external factors contributing to plastic shrinkage were kept same.

Further studies should be conducted to determine the influence of cement type for early age cracking when concrete is placed and kept undisturbed.

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