Determination of Tensile Strain Capacity of Fresh Concrete

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ABSTRACT: Measuring physical properties of fresh concrete is important to understand the behavior of the early phase of concrete. The measurement of tensile strain capacity of fresh concrete predicts the risk of cracking due to restrained shrinkage. Fresh concrete means the concrete before the hardening phase which is still in a semi liquid state. i.e. from right after mixing of concrete to 3 – 4 hours. Several research studies have been conducted but complex test methods have been developed to measure both stress and strain and the average strain was measured. The paper contains the procedure adopted to develop a simple test method to measure the local strain along a sample. After verifying the test method, influence of cement type for early age tensile strain capacity was studied. Ordinary Portland Cement, Fly ash blended and Portland Limestone Cement were used. Concrete was mixed as a large quantity and kept inside the mixer and agitated every 10 minutes before being taken out for testing. The method simulates the conditions where concrete is produced and kept inside a truck mixer for a while before placing. Results indicate that fly ash blended concrete has a higher tensile strain capacity than other cement types thus the mix is less vulnerable for early age cracking. Further tests should be done to determine the influence of cement type for tensile strain capacity of undisturbed concrete.

1 INTRODUCTION

Measuring physical properties of fresh concrete is important to understand the behavior of the early phase of concrete. The measurement of tensile strain capacity of fresh concrete predicts the risk of cracking due to restrained 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 is the mix for cracking or what mixes have 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 an occurrence.

Fresh concrete means the concrete before the hardening phase which is still in a semi liquid state. Right after mixing of concrete to 3 – 4 hours is considered as the time frame, as concrete changes from plastic phase to early hardening phase during that time. According to the studies done by Byfors (1980), Hammer (2007) and Roziere et al (2015) they all indicate that tensile strain capacity goes through a minimum value as a function of age. It reaches approximately 0.05% at 6-8 hours after mixing. However almost all the tests have started 2 hours after mixing had finished. Hence strain capacities at very early stages of concrete are hard to find.

2 DEVELOPING A TEST METHOD

Developing a sound test method for this purpose is quite challenging. Kasai et al (1972) and Hannat et al (1999) 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 other apparatus, Hannat et al (1999) developed a horizontal loading type machine with two air bearing plates to minimize friction. His apparatus was further improved by Hammer (2007) and Roziere et al (2015) to obtain tensile strain capacity values using LVDTs and image processing. It was also noted by Hammer (2007) that the strain capacity changes with the time, strain loading rate, background temperature and evaporate rate.

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

a) Sample should be placed on a mould or casing to support it, as fresh concrete is in semi-liquid state hence it can flow.
b) Strain should be applied to the mould and the mould 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.

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

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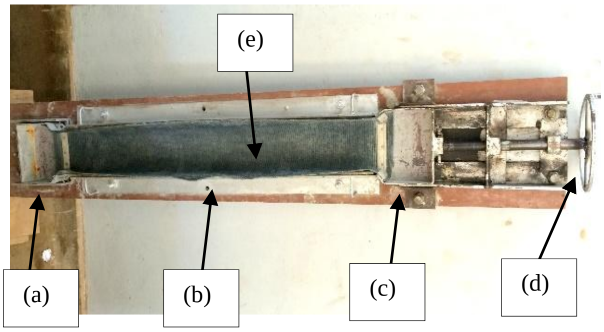

Fig. 1 Test apparatus. (a) fixed end, (b) supporting frame, (c) moving end, (d) rotating wheel to apply strain, (e) rubber mould

a) Concrete was placed on a rubber mould.

b) Rubber mould was fixed on one side and pulled from the other side. Concrete sample inside will move along with it. Thus the strain applied would be transferred to the sample.

c) Markers were placed on the sample which will act as reference points to measure strain.

d) A camera placed above the sample was used to capture images continuously from start until the point of appearance of the first crack. (Fig. 2)

e) Images was 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.

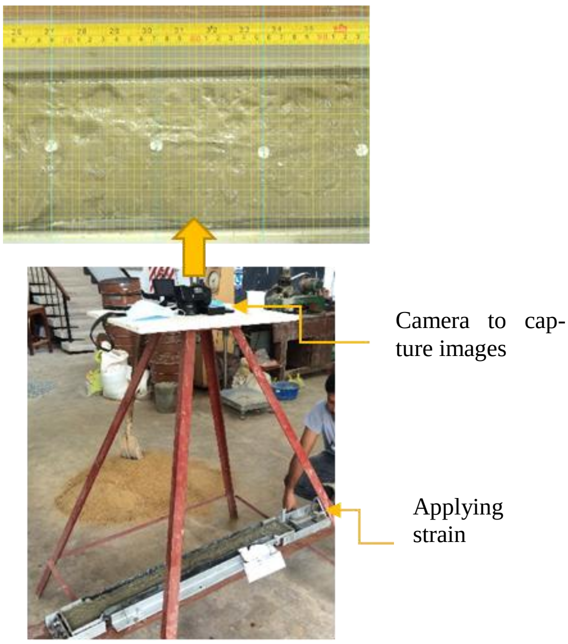

Fig. 2 Test procedure and captured image

3 EXPERIMENTAL PROGRAM

3.1 *Objective of the Test*

Objective of the research was to study the effect of cement type for the tensile strain capacity. Therefore 3 common cement types used in Sri Lanka were chosen. They were;

1. Ordinary Portland Cement (OPC)
2. Fly ash blended
3. Portland Lime Cement (PLC)

3.2 *Concrete Mixtures*

DoE mix design method was used to determine the mix proportions. Cement type was varied maintained other parameters constant. Mixes were designed for a slump of 160mm and a characteristic strength of 30N/mm^2.

Table 1 Composition of concrete mixtures (kg/m^3)

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/C	0.5	0.5	0.5
Slump (mm)	155	170	160
$f_{c,28d}$ (N/mm^2)	41.5	40.4	40.3

3.3 *Experimental procedure*

Test was carried out to simulate the practical situation of placing concrete. The entire quantity of concrete was mixed in a mixing drum at once and kept inside. The lid was closed to prevent evaporation. Every 10 minutes concrete was agitated and taken out at the required time for the test. This will simulate concrete being kept inside a truck mixer for a while and then placing it.

Images were processed using Adobe Photoshop CS3. A grid line was created to represent an individual pixel by a square. The number of pixels between adjacent markers was counted. The 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.

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

Where ϵ_T is the tensile strain capacity, Px_f is the no. of pixels at failure, S_f is the Scale factor at failure, Px_i is the no. of pixels at start and S_i is the scale factor at start.

4 RESULTS AND DISCUSSION

4.1 *Results*

Whole batch was mixed at once and a sample was taken out from the mixer at the time of testing (10min, 30 min, 1hour, 2hour, 3 hour and 4 hour) and then tested. The mix was agitated every 10 minutes. OPC, Fly Ash blended and PLC cement types were tested according to this procedure.

The strain distribution was plotted against the sample length (Fig.3) 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 against sample length. (Fig. 4)

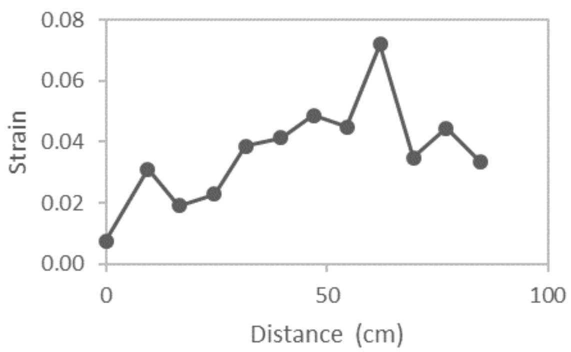

Fig. 3 Strain distribution along a sample

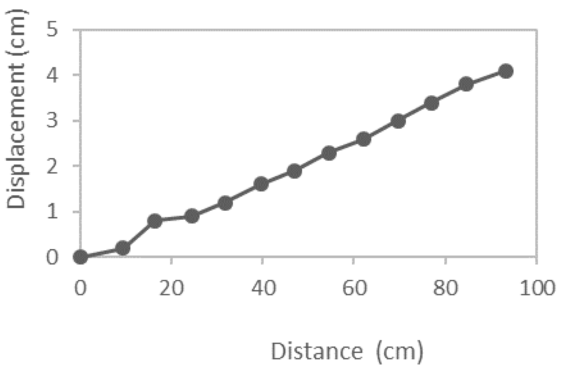

Fig. 4 Displacement of markers

4.2 *Influence of cement type on tensile strain capacity*

Strain distribution provides more accurate value for tensile strain capacity as it considers local strain instead of average strain.

Fig. 5 summarizes the results obtained. Strain capacity decreases with time. Concrete becomes stiff and moves from liquid phase to semi-liquid state and then to early hardening phase. Cohesiveness decreases and reaches a minimum and then increases again when concrete hardens. As the test was conducted before the hardening phase strain capacity continuously decreases with time.

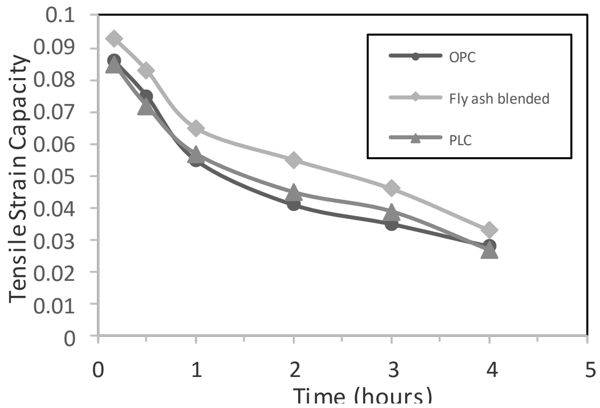

Fig. 5 Tensile strain capacity for concrete produced using different cement types

Fly ash blended concrete shows tensile strain capacities slightly higher than OPC and PLC. According to Mehta et al (2013) Fly ash particles are spherical while OPC and PLC cement particles are irregular shaped. Furthermore studies done by Owens (1979) and Thomas (2007) disclose that spherical fly ash particles are finer and more cohesive. As a result of that fly ash blended concrete can undergo more tensile strain than other two cement types before cracking. For equal slump, fly ash blended concrete has more free water according to Owens (1979). Therefore concrete can last longer in the liquid phase which has high tensile strain capacity than semi-liquid phase. These two phenomenon explain the reason for the results obtained from the experiment.

5 CONCLUSIONS

Based on the experiment and results obtained 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 with time during the plastic phase of concrete.
- Fly ash blended concrete is less vulnerable for early age cracking than OPC and PLC. The observation is valid only when the concrete is agitated until it has been placed.
- Further studies should be conducted to determine the influence of cement type for early age cracking when concrete is placed and kept undisturbed.

ACKNOWLEDGMENTS

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