Effect of Drying Shrinkage of Concrete on Tension Stiffness of RC Member under Sustaining Load

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1. Introduction.

Currently in common practice, when designing a reinforced concrete member that will be subjected to bending loads, the main assumption that is considered is that when the tensile stress of the member reaches the tensile strength of concrete and cracks are generated, at that moment, the tensile strength is carried completely by the reinforcement and the stress in concrete is neglected. However, in the real behavior of an RC member, once it cracks, the tensile forces are distributed to the concrete in-between cracks due to the bond relationship between the concrete and the reinforcement. This behavior is known as tension stiffening [1].

Although this behavior is of great importance to predict more accurately the actual behavior of real RC structures subjected to sustaining loads, usually caused by its own structural weight, only few researches have studied this behavior [1]. The conclusions that have been reached by previous researches state that the cause of the long-term decreasing of tension stiffening in RC members is due to time-dependent mechanisms of concrete, such as, creep and shrinkage [2][3][4], however, in these researches, these mechanisms, mainly drying shrinkage, have not been properly measured, meaning that they have not obtained a completely reliable experimental data.

Based on this, this study aims to experimentally investigate the time-dependent behavior of drying and non-drying conditions on tension stiffening effect in RC members under sustaining loads.

2. Experimental Study.

2.1. Specimen Details.

4 RC specimens with 100mm (height) × 100mm (width) × 1000mm (length) of geometry were cast and tested with a uniaxial tensile test. At the same time, 4 representative prismatic specimens with dimensions of 100mm (height) × 100mm (width) × 400mm (length) were used to measure the free shrinkage of concrete during the tensile tests. From the 4 specimens, 2 of them were sealed using vinyl and waterproof tape to investigate the effect of drying on tension stiffness of RC members. **Fig-2.1** shows the specimens' dimensions and sealing conditions.

2.2. Testing Procedure.

Using the designed frame shown in **Fig-2.2** the specimens were mounted having the measuring equipment shown in **Fig-2.3** installed in them. The test

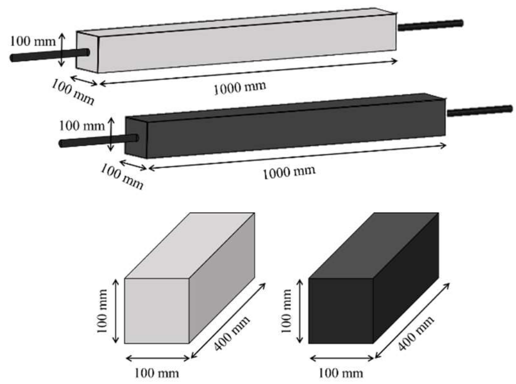

Fig-2.1: Specimen Dimensions and Sealing Conditions

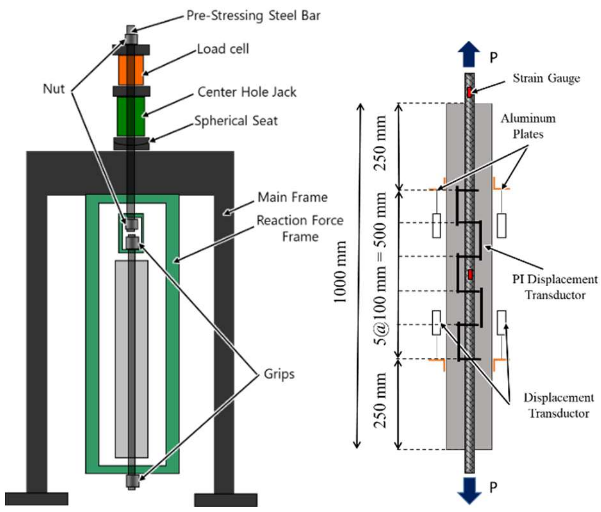

Fig-2.2: Frame and Equipment for Tensile Test

Table-2.1: Testing Conditions of Specimens

Specimen	Drying Condition	Load Condition
A	With Drying	Sustained
B	Without Drying	Sustained
C	Without Drying	Instantaneous
D	With Drying	Instantaneous

area for this experiment was of 500mm at the center of the specimen to focus only on the deterioration of bond, neglecting stress concentration at the edges.

The load value was measured using a load cell, the average strain of the specimen was measured dividing the displacement measured from the displacement transduces over the 500mm test area, and the crack width were measured with the PI gauges.

2 specimens were tested using instantaneous loads, by increasing the load until the yielding point of steel, and ending the test. The other 2 specimens were subjected to a 1000μ steel strain load and it was sustained for 25 days. **Table-2.1** shows the specimens' testing conditions.

3. Experimental Results and Discussion.

The main focus of testing was to obtain the behavior of the average tensile stress of concrete on each condition. In order to do this, the following equation was used to obtain the tensile stress of concrete.

$$\bar{\sigma}_{ct} = \frac{P - E_s \bar{\varepsilon} A_s}{A_c}$$

Where,

P: Load (N)

E_s: Young's Modulus of Steel (N/mm^2)

$\bar{\varepsilon}$: Average Strain (μ)

A_s: Cross-Sectional Area of Steel (mm^2)

A_c: Cross-Sectional Area of Concrete (mm^2)

However, during the curing period, minimum free shrinkage was measured on all of the specimens. Although the measured free shrinkage was significantly lower compared to what would have been without the specimens being sealed, the influence on the tension stiffness caused by the shrinkage prior loading was taken into consideration, assuming that the shrinkage of concrete was restrained by the reinforcement. The following equations were used to obtain the average tensile stress of concrete with the effect of the minimum shrinkage prior loading.

$$\bar{\sigma}'_c = \bar{\sigma}_{ct} + E_c(\varepsilon_{sh} - \varepsilon_0)$$

$$\bar{\varepsilon}' = \bar{\varepsilon} + (\varepsilon_{sh} - \varepsilon_0)$$

$$\varepsilon_0 = \frac{\varepsilon_{sh}}{1 + \frac{E_s A_s}{E_c A_c}}$$

Where,

$\bar{\sigma}_{ct}$: Measured Average Tensile Stress of Concrete (N/mm^2)

$\bar{\sigma}'_c$: Average Tensile Stress of Concrete Considering Effect of Free Shrinkage Restraint (N/mm^2)

$\bar{\varepsilon}$: Measured Average Strain (μ)

$\bar{\varepsilon}'$: Average Strain Considering Effect of Free Shrinkage Restraint (μ)

ε_0: Strain Caused by Shrinkage Restraint Prior Testing (μ)

ε_{sh}: Measured Free Shrinkage Strain (μ)

3.1. Effect of Sustained Loading.

Figure-3.1 shows the comparison of the average tensile stress of concrete vs. average strain relationships of specimens B and C. Both of these specimens were not subjected to drying throughout their testing periods. Specimen B was subjected to sustained loading and specimen C to instantaneous loading.

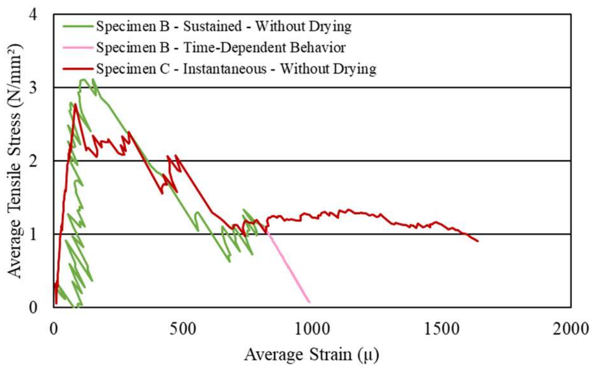

Fig-3.1: Effect of Sustained Loading – Without Drying

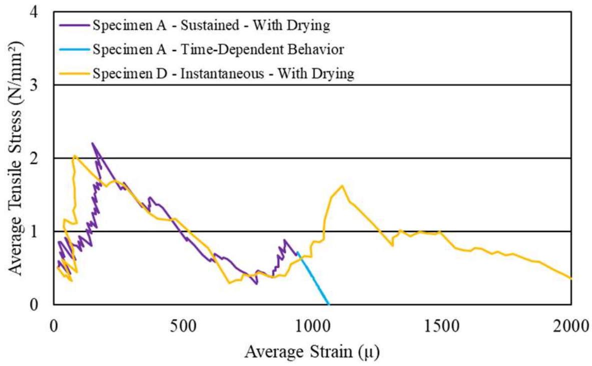

Fig-3.2: Effect of Sustained Loading – With Drying

Figure-3.2 shows the comparison of the average tensile stress of concrete vs. average strain relationships of specimens A and D. Both of these specimens were subjected to drying throughout their testing periods. Specimen A was subjected to sustained loading and specimen D to instantaneous loading.

By looking at the both of the comparisons of the relationships, it can be seen that throughout the instantaneous loading periods of both of the specimens in each of the drying conditions, the tensile stress vs strain relationships are similar, but once the sustained loading periods of specimens B and A begin, the tensile stress of concrete does not follow the behavior of specimens C and D of keeping an almost constant value, instead, the average tensile stress of concrete starts to decrease drastically with minimum strain development.

As a conclusion, it can be stated that the effect that sustained loading has on RC members, consists on significant reductions of average tensile stress with minimum strain development. This behavior can be attributed to the deterioration of bond between concrete and steel reinforcement caused by constant loads. In other words, sustained loading has a tension stiffness decay effect on RC members.

3.2. Effect of Drying.

After testing the specimens, it was confirmed that drying produces an effect on the tension stiffness of RC members.

Fig-3.3 shows the effect of drying on RC specimens subjected to instantaneous loads. By looking at this graph it can be stated that the obtained results agree on the findings of previous works relating the effect of drying prior to loading on RC members. Pre-drying causes shrinkage of concrete that is restrained by the steel reinforcement of the specimen, this results in the generation of tensile stress in the specimen, causing a lower tension stiffening effect of RC members.

As for specimens subjected to sustained loading, **Fig-3.4** shows the effect that drying produced. Since specimen A was also subjected to drying 4 days prior to loading, the same tension stiffness decrease effect can be seen on the comparison of the instantaneous loading periods of both of the specimens, with specimen A having lower values of average tensile stress compared to specimen B. However, when comparing the time-dependent behaviors of both of the specimens, it can be noted that specimen A, subjected to drying, had a lower value decrease of average tensile stress of concrete in comparison to specimen B. Based on this, it can be stated that on specimens subjected to sustained loading, drying causes lower loss of average tensile stress over time in comparison to specimens without drying.

However, when the comparison of the specimens is done focusing on the percentage loss of average tensile stress over time, another conclusion can also be obtained. **Figure-3.5** shows the loss of average tensile stress of concrete over time as a percentage, obtaining the percentage by dividing the time-dependent value of tensile stress over the initial value of tensile stress. Looking at the graph, it can be noted that approximately during the first day of sustained loading, the tensile stress reduces to about 60% of its initial value on both cases, and by the end of the sustained loading period both of the specimens have a tensile stress value of about 10% of its initial value. Based on this, it could be said that there is no actual effect of drying on tension stiffness of specimens subjected to sustained loading, however, it can be noted that the decay rate of tension stiffness of the specimen that was subjected to drying is faster in comparison to the specimen that was not.

4. Conclusions.

- Sustained loading has a tension stiffness decay effect on RC members. This proves the deterioration of bond between concrete and steel reinforcement caused by constant loads.
- In RC members subjected to instantaneous loading, drying has a greater tension stiffness decrease effect in comparison to RC members that are not subjected to drying.
- In RC members subjected to sustained loading, drying produces a greater reduction of average tensile stress. However, looking at the loss ratio from the initial value of tensile stress, drying does not show a significant effect on the tension stiffness of RC members, other than a higher decay rate.

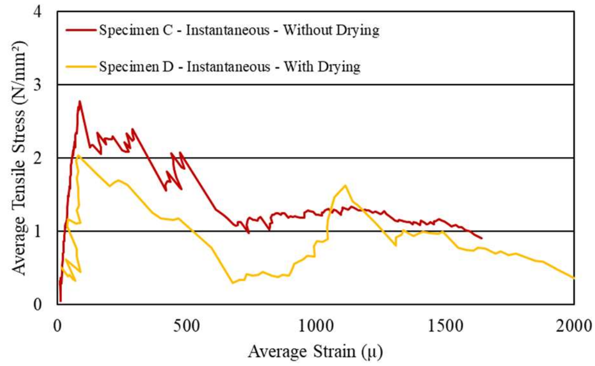

Fig-3.3: Effect of Drying – Instantaneous Loading

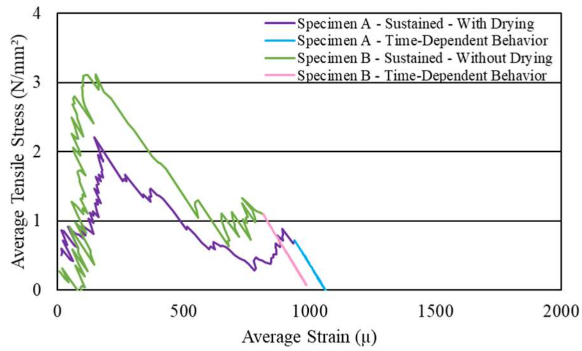

Fig-3.4: Effect of Drying – Sustained Loading

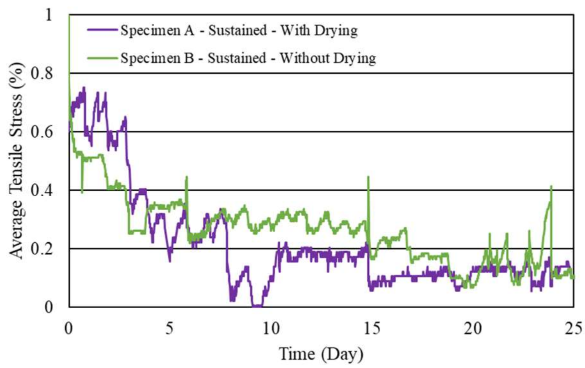

Fig-3.5: Time-Dependent Effect of Drying – Sustained Loading

References.

[1] Mark Han Qing Wu, 2010, *Tension Stiffening in Reinforced Concrete– Instantaneous and Time-Dependent Behavior,* Doctoral thesis of University of New South Wales, Sydney, Australia, pp.1-120.

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[4] Scott, R. H. and Beeby, A. W., 2005, *Long-Term Tension-Stiffening Effects in Concrete*, ACI Structural Journal, Vol. 102, No. 1, pp. 31-39.