# Shrinkage Cracking of Restrained Reinforced High Strength Concrete Slabs

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## Abstract

This investigation was conducted to study the shrinkage cracking behavior of reinforced high strength concrete (**HSC**) slabs restrained from movement at their ends for different restrained cases. Reduced scale slab models-**2000×2000×100** mm- (which were believed to resemble as much as possible field conditions) were used to study the shrinkage behavior. Two end restrained beams are used to study free and restrained shrinkage cracking. One (**HSC**) mixture with compressive strengths (**65**) MPa were compared to normal strength concrete (**NSC**).The experimental observation for end restrained beams showed that; the tensile strain capacity, the elastic tensile strain capacity, the creep strain and the free shrinkage is less than of (**NSC**). Based on the observations of the slabs, it was found that the cracks did not develop in high strength concrete slabs during **120** days period of drying conditions and the drying shrinkage strain is less than (**NSC**), also the drying shrinkage strain was vary according to the change of restraint in the slabs. The experimental observation for end restrained beams showed that the free shrinkage at time of cracking was (**318** microstrains) and the maximum free drying shrinkage at age **28** days was (**350** microstrains). The tensile strain capacity was (**270** microstrains) at the crack time (**23** day), the creep strain for **HSC** end restrained beam specimen at cracking was (**174.5** microstrains).

Keywords: high strength concrete; drying shrinkage; restrained slabs; cracking

## الخلاصة

تم أجراء هذا البحث لدراسة سلوك تشققات الانكماش الحاصلة في السقوف الخرسانية المسلحة عالية المقاومة والمقيدة بسبب انكماش الجفاف. تم استخدام نماذج بحث مصغرة–2000×2000×100ملم–(والتي يعتقد إنها توفر ظروفا مشابهة للظروف الطبيعية الموقعية). هذه النماذج استخدمت لدراسة سلوك الانكماش (حركات السقف) وسلوك التشققات مثل (المسافة بين التشققات, عرض التشققات وأطوالها).استخدمت اثنان من العتبات الخرسانية المقيدة من النهايات لدراسة تشققات انكماش الجفاف الحر والمقيد. استخدمت خلطة خرسانية واحدة ذات معدل مقاومة انضغاط (65ميكا باسكال) نتائج انكماش هذه الخلطة قورنت مع النتائج المتوفرة للخلطات الخرسانية ذات المقاومة العادية والخلطات الخرسانية ذاتية الرص ووجد بان الانكماش الحر, انفعال الشد الاقصى ,انفعال الشد المرن وكذلك الزحف اقل من النتائج المستحصلة من الخرسانة ذات المقاومة العادية والخرسانة ذاتية الرص استنادا إلى مراقبة السقوف في هذا العمل، وجد أن الشقوق لم تتطور في السقوف الخرسانية عالية المقاومة خلال فترة تعرض للجفاف مدة 120 يوم. بينت المراقبة التجريبية للعتبات الخرسانية المقيدة أن الانكماش الحر في هذه الدراسة وفي وقت حدوث الشق هو ($318 \times 10^{-6}$ ملم/ملم ) والحد الأقصى لانكماش الجفاف في هذه الدراسة بعمر 28 يوما هو ($350 \times 10^{-6}$ ملم/ملم). وانفعال الشد الأقصى في العمل الحالي هو ($268 \times 10^{-6}$ ملم/ملم) في وقت حدوث الشق (23 يوما). أخيرا انفعال الزحف في العتبات الخرسانية المقيدة هو ($174.5 \times 10^{-6}$ ملم/ملم) للخرسانة عالية المقاومة.اما انكماش الجفاف في السقوف فكان متغير بتغير درجة التقيد من سقف الى اخر وعلى العموم كانت نتائج انكماش الجفاف اقل من الخرسانة العادية والخرسانة ذاتية الرص.

## Introduction

(HSC) has a simple definition that is "concrete with a compressive strength above the present existing limits in national Cods about 40 to 130 MPa" **[ACI Committee 363R, 1997**]. Shrinkage is the decrease of concrete volume with time. This decrease is due to change in moisture content of the concrete and physio-chemical changes, which occur without stress attributable to external actions to the concrete. Shrinkage is usually expressed as dimensionless strain (in/in. or mm/mm). Under given conditions of relative humidity and temperature, shrinkage is primarily a function of the paste, but is significantly influenced by the stiffness of the coarse aggregate. The interdependence of many factors creates difficulty in isolating causes and effectively predicting shrinkage without extensive testing **[Gupta *et. al,* 2009]**. The overall shrinkage of concrete can be classified into different types based on the type of loss of pore moisture that leads to the shrinkage such as; plastic shrinkage, autogenous shrinkage and drying shrinkage when concrete is in a plastic state, shrinkage resulting from water loss from the surface of hardening concrete, is called plastic shrinkage. The shrinkage caused due to the consumption of pore water by hydration reaction is called autogenous shrinkage, it has been well established that, as concrete dries, it shrinks. Shrinkage resulting from the drying of concrete due to exposure conditions is classified as drying shrinkage **[Aamidala, 2003]**.

## 1. Factors Influencing on shrinkage of high strength Concrete

### 1.1. Water/cement ratio (w/c)

The effects of w/c ratio on free and restrained shrinkage of normal and high-strength concretes Shrinkage were studied by **Bloom and Bentur,** and the results indicated, No clear trend of w/c ratio was found, **[Bissonnette *et. al,* 1999]** found that the influence of w/c ratio on the shrinkage of cementitious materials was relatively small. An average reduction in shrinkage for 0.35 w/c ratio (over 0.5 w/c ratio) pastes, mortars, and concretes was 7 to 10 percent.

### 1.2. Influence of Chemical Admixtures

The concrete with the higher dosage of superplasticizer (3 % of cement by weight superplasticizer content vs. 1.8 %) experienced higher shrinkage **[Bloom and Bentur, 1995]**. Water–reducing admixtures (WRA) probably cause a small increase in shrinkage. Their main effect is indirect in that the use of an admixture may result in a change in the water content or in the cement content of the mix, or in both, and it is the combined action of those changes that changes that influences shrinkage **[Neville, 1995]**. **Folliard and Berke [1997]** studied the "properties of high-strength concrete containing shrinkage reducing admixture" (SRA). And the result indicated that: The shrinkage-reducing admixture (SRA) effectively reduced the shrinkage of high-strength concrete, and resulted in a significant decrease in restrained shrinkage cracking. This shrinkage reduction was more pronounced when (SRA) was used in conjunction with silica fume. As reflected in the 52% reduction in drying shrinkage at 28 days and 43% reduction in drying shrinkage at 120 days, compared to silica fume concrete without SRA. the addition of SRA to the control concrete yielded a shrinkage reduction of 35% at 28 days and 29% at 120 days **[Folliard and Berke, 1997]**

### 1.3. Influence of Mineral Admixtures

#### 1.3.1. Silica fume

adding silica fume (10% of cement weight) to concrete mix greatly reduces the 3-year drying shrinkage, the stress due to shrinkage strain, and the rate of first month drying shrinkage of concrete. This is true whether concrete is subjected to controlled laboratory or hot-dry field curing conditions. Adding mineral and/or chemical admixtures to concrete mix has an appreciable influence on the total amount of drying shrinkage **[Alsayed,1998].**The shrinkage strain of concrete with replacement of cement by 10% of Silica fume at various ages are more (10%) than the shrinkage strain of concrete without Silica fume **[Gupta *et. al,* 2009]. [Rao, 2001]** concluded that Silica fume did not affect the total shrinkage; however, as the proportion of silica fume increased, the autogenous shrinkage of high-strength concrete increased and its drying shrinkage decreased **[Mazloom *et. al,* 2004].**

### 1.3.2. Fly ash

the shrinkage strains of concrete with replacement of cement by 10% of fly ash at various ages are more (6%) than the shrinkage strain of concrete without fly ash**[Gupta et. al, 2009]**.

## 3. Experimental program

The test procedures and materials used in the study are described in the following.

### 3.1. Free shrinkage test

The mould used to test the free shrinkage was made of steel channel section and the restrained provide by the flanges at the ends of the steel mould the free movement provide by the artificial crack (opining) in the web of ⊓-Channel –shaped steel mould. This mould is shown in Figure (1).concrete beams cast in this mould and subjected to drying shrinkage. The web should have been machined to minimize friction with concrete. In this case this was achieved by lining the web with polythelene sheets. The free shrinkage of concrete was determined by fixing demec points at both side of the gap for beams with artificial crack (opining) in the web of ⊓-Channel –shaped steel mold. Daily measurements were taken for the widening of the artificial crack in the middle of the beam, till little or no movement could be recorded **[AL-Rawi,1985]**.

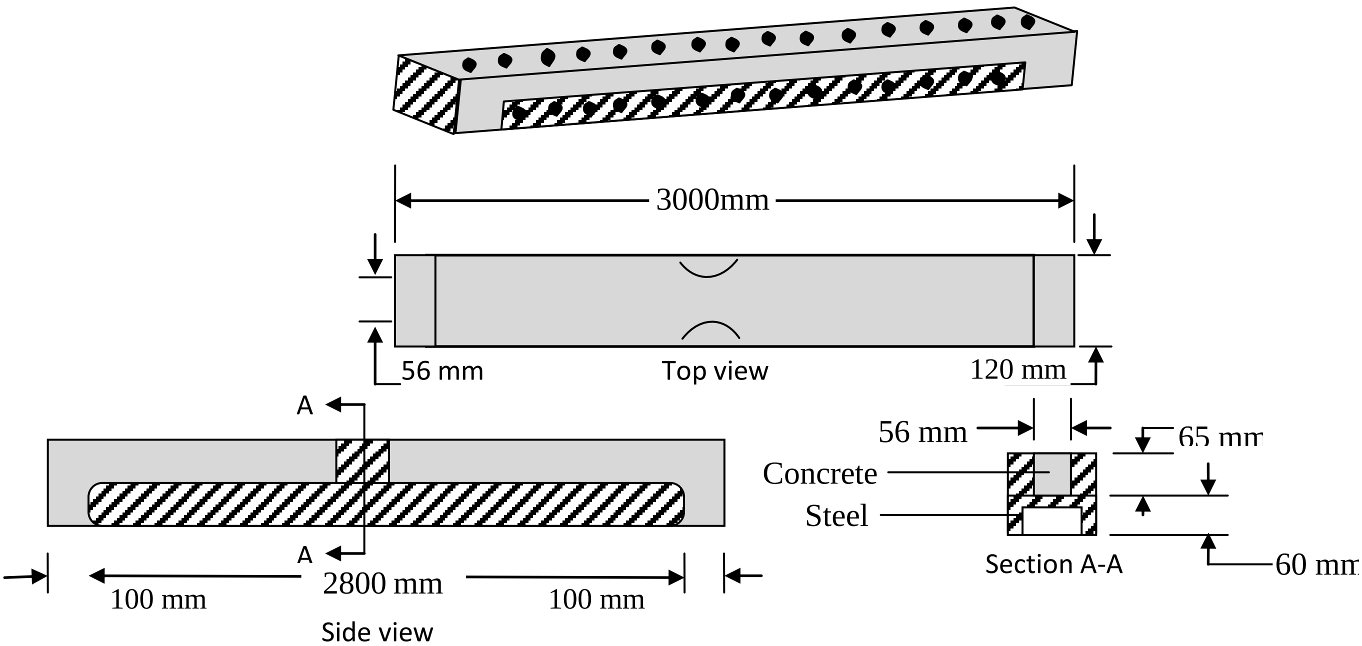



**Figure (1): Schematic diagram of end restrained beam**

### 3.2. Elastic tensile strain capacity test

The elastic strain capacity is the amount of strain that is instantly relieved due to the elastic recovery of restrained concrete upon cracking. It is defined as the observed free contraction of concrete at the onset of cracking. Elastic tensile strain capacity of concrete was measured by using two methods: The first is a direct method using the same shaped steel mould show in **Figure (1)** but without artificial crack in the middle of the beam. Soon after the first crack occurred crack width measure and divided on the length of the beam of concrete is the elastic tensile strain capacity. The second is an indirect method by dividing the flexural strength of concrete by the modulus of elasticity of concrete according to mentried in **[ACI-Committee 224, 2001].**

**3.3. Creep or relaxation test**

Creep strain of concrete subjected to restrained shrinkage is the difference between tensile strain capacity and elastic tensile strain capacity. It has been ignored by some authors, while other authors give it a value as much as 75 percent of the free shrinkage strain **[AL-Rawi,1985]**.

**3.4. Cracking time**

The cracking time is given in terms of the number of days required for cracking to occur.

**3.5. Loss in restraint**

The strain due to loss of restraint is obtained from continuous measurement on the demec points fixed to the beams surfaces. It is taken to be equal to the contraction strain in the web length during cracking time. **This result is listed in Table (6)**

**3.6. Slabs experiments**

In order to provide different restrained cases from the ends to the slab models, Square reinforced concrete rigid beams were cast in advance at first. With dimensions (2000×300×300 mm) (length × width × height respectively) for all beams as shown in **Figure (2)** a period of 4 months was allowed between the casting of the rigid beams and the casting of the slabs to permit a considerable amount of shrinkage to take place before casting the slabs

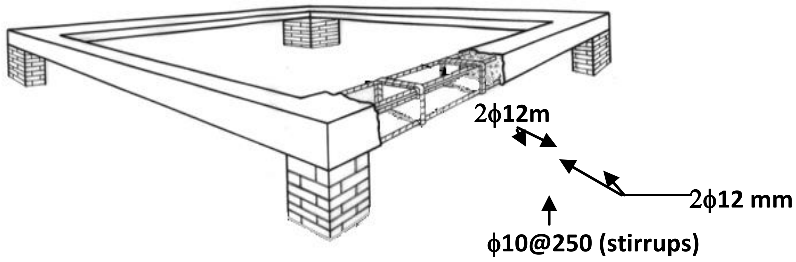
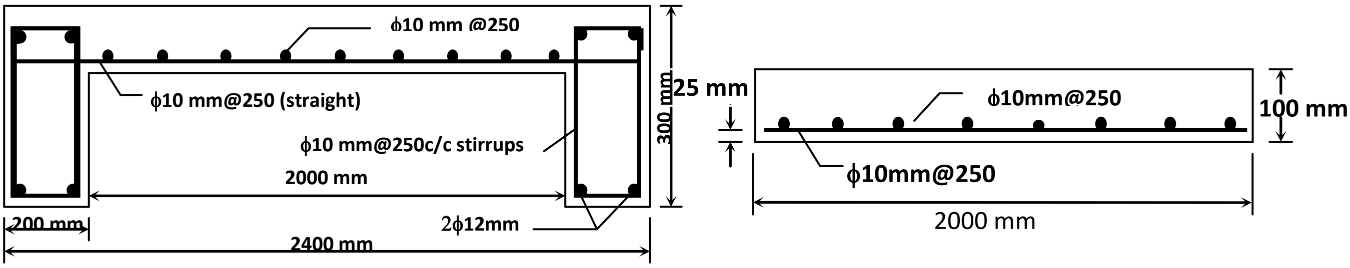



**Figure (2): Details of the restraining reinforced concrete rigid beams.**

Four slab models were cast on the above mentioned square rigid beams. These slabs were cast with different restrained cases (two end, three end and four end restrained), and another slab was cast without any restraint (free slab). The chosen dimensions for the slabs were (2000×2000×100mm) (length × width × thickness) respectively. The edge beams which attain the action of restraint are of cross-section 200×200 mm and c/c span of 2200 mm **Plate (1)** shows these slabs.

**Plate (1): Reinforced Concrete Slabs.**

The reinforcement used is of deformed steel bars grade 470 MPa with 10 mm-diameter for longitudinal bars (main reinforcement), and the steel ratio adopted in this work was the minimum ratio allowed **. Figure (3)** shows the details of reinforcement for slabs and edge beams.




A. Free Slab B. Restrained slab

**Figure (3): Details of the slabs A- without edge beams, B-with edge beams.**

## 3.7. Mix and caste of Slabs

One concrete mixture was selected for the investigation with compressive strength (65) MPa, the mix proportions are summarized in Table 1.The concrete was mixed using an electrical drum type mixer with a maximum capacity of 0.1 m3. Materials were put in the pan of the mixer, firstly coarse and fine aggregates were mixed together with small amount of mixing water. ($\frac{1}{4}$ Mixing water without superplasticizer) for 1 minute. Meanwhile the superplasticizer was mixed with the remaining water ($\frac{3}{4}$ of mixing water). Half of Cement and half of mixing water (with superplasticizer) were added as mixing proceeded for 3 minutes to make a homogeneous mix. Finally, the remaining (cement and water) were added to the mix as mixing proceeds for other 2 minutes. The total mixing time was about 6 min. Then the concrete mixes were caste into the plywood formwork of the slab. The caste and exposure of the slabs were carried out during the period from first of April to the half of July (3.5 months period).

**Table 1 mix proportion**

| Weight proportion | | | | | | Mix proportion kg/m3 | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cement | Sand | Gravel | w/c ratio | Superplasticizer (liter/100kg) cement | Slump (mm) | Cement | Sand | Gravel | Water |
| 1.0 | 1.16 | 1.77 | 0.29 | 0.8 | 190 | 560 | 650 | 991 | 162.5 |

## 3.8. Materials

Ordinary Portland cement complied with the Iraqi specification No.5/1984, well-graded natural sand conformed to the Iraqi specification No.45/1984, Zone (2) with fineness modulus (FM = 3.06), Crushed gravel conforms to the Iraqi specification No.45/1984 with maximum coarse aggregate size 14 mm, High range water reducing agent (HRWR) called Glenium 51 (sulfonated melamine – formaldehyde) was used in this work. This Superplasticizer is conformed to ASTM C494-04 classified as type F **[ASTM C494,2004]**

### 3.9. Strain and crack width measurements

Surface strain measurements were carried out by using demec points inserted in 3 rows on the slabs. The rows were at 100, 200 and 1000 mm distance from all the edges. The spacing between demec points in the same row was 200 mm apart. The demec points were positioned in the beams and slabs after the curing. An extensometer, with an accuracy of (0.002 mm/division) was used to measure strain in the panels of the slab (the panel is the distance between two consecutive demec points in the same row, panel length = 200 mm). The measurement devices are shown in **Plate [2].**

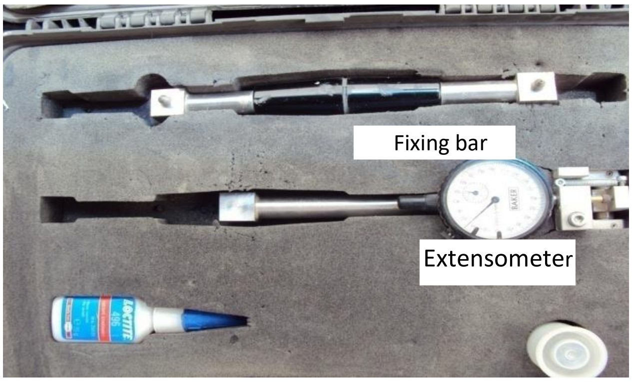



**Plate (2): Measurement Devices.**

The measurements were registered early in the morning after the curing period every 2 days through the first week then, measurements were taken at an average of 7 days for a total period of about 90 days.

## 4. Results and Dissection

### 4.1. Mechanical properties of HSC used

These results include the following characteristics of the concrete: (compressive strength, tensile strength, modulus of elasticity). These results summarized in **Tables (2, 3, 4 and 5).**

Table (2): Compressive Strength Results

| Compressive Strength (MPa) | | | |
|---|---|---|---|
| 7 days | 28 days | 60 days | 90 days |
| 49.7 | 65.4 | 69.6 | 74 |

Table (3): Splitting Tensile Strength Results

| Splitting Tensile Strength (MPa) | | | |
|---|---|---|---|
| 7 days | 28 days | 60 days | 90 days |
| 5.3 | 5.8 | 6.04 | 6.2 |

Table (4): Flexural Strength Results

| Flexural Strength (MPa) | | | |
|---|---|---|---|
| 7 days | 28 days | 60 days | 90 days |
| 6.1 | 6.9 | 7.2 | 7.7 |

Table (5): Static Modulus of Elasticity Results.

| Static Modulus of Elasticity (GPa) | | | |
|---|---|---|---|
| 7 days | 28 days | 60 days | 90 days |
| [illegible] | [illegible] | [illegible] | [illegible] |

### 4.2. Free Shrinkage of HSC End-Restrained Beams

Using the model described in free shrinkage test (concrete beam with a gap at its middle to ensure free movement), the free shrinkage strain of HSC was measured under the same indoor exposure conditions of the restrained slabs. **Figure (4)** and **Table (6)** show the free shrinkage strain development of HSC.

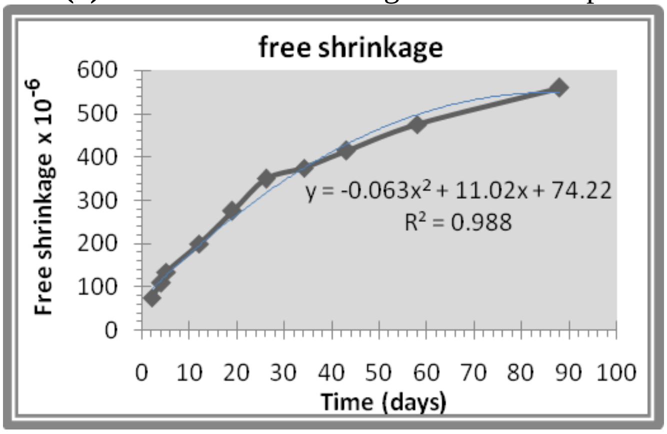



**Figure (4): Free shrinkage development of the HSC beam models**.

It can be seen from **Figure (4)** that the free shrinkage increases with the age progress and it is clear that the rate of shrinkage in early ages is greater than the rate in the later age. The reason of this behavior can be expected from the diffusion theory of drying that is the shrinkage is influenced strongly by the moisture loss. The moisture will be evaporated initially from the surface and near the surface with a high rate. And can likely be attributed to the greater cement content, this is accompanied by a considerably greater amount of heat and thus rate of hydration. This effect appears to decrease at later ages as the hydration process decrease with time. The drying shrinkage in this study at age 28days is (350 microstrain). This result is less than the free shrinkage strain of normal concrete (580,545 microstrain at 28 days) which was reported by **[AL-Wash,2005], [Kubba,2007]** respectively. The maximum drying shrinkage at (60) days was (490) microstrain, this results is compatible with the study carried out by **[Habeeb,2000]** and **[AL-Taee,2009]** respectively. They found that the shrinkage of high strength concrete having 80 MPa compressive strength ranged between (400-537) microstrain at (56) days and (460) microstrain at (60) days respectively.

### 4.3. Restrained Shrinkage Beams Test

Using the model described in Elastic tensile strain capacity test (End restraint molds having a channel section with a necking at the mid-span). The results of the direct determination of loss in restraint and other properties investigated under restrained shrinkage conditions are given in **Table (6).**

## Elastic Tensile Strain Capacity

Elastic tensile strain capacity of HSC beam models was obtained directly by measuring the immediate movement after cracking of concrete in the end restrained beams .the results are summarized in **Table (6).**

**Table (6):Shrinkage properties of HSC end restrained beams.**

| Free shrinkage at cracking date ($\times 10^{6}$) 1 | Loss of restraint ($\times 10^{-6}$) 2 | Tensile strain capacity ($\times 10^{-6}$) 3=1-2 | Elastic tensile strain capacity ($\times 10^{-6}$) 4 | Creep strain at cracking time ($\times 10^{-6}$) 5=3-4 | Time of crack in beam (day) |
|---|---|---|---|---|---|
| 318 | 50 | 268 | 93.5 | 174.5 | 23 |

Note: All values of free shrinkage strain, loss of restraint and elastic tensile strain capacity were measured directly in this study, while the values of tensile strain capacity and creep strain were calculated

Elastic tensile strain capacity of concrete was also measured indirectly by determination of tensile strength (flexural) and modulus of elasticity. The elastic tensile strain capacity is taken as the tensile strength divided by the modulus of elasticity. The results of these tests are illustrated in **Table (7).**

**Table (7): Results of The Calculated Elastic Tensile Strain Capacity of The HSC Beam Models (indirect method)**

| Elastic tensile strain capacity $\times 10^{-6}$ | | | |
|---|---|---|---|
| 90days | 60days | 28days | 7 days |
| 179.1 | 180 | 181.5 | 174.3 |

It can be seen from **Table (6)** and **Table (7)** that the elastic tensile strain capacity from direct method is less than of indirect tensile strain capacity. The result of the present work agreed with the results of **[AL-Taee,2009]** and **[AL-Abdaly,2007]** who studied the shrinkage behavior of high strength concrete and proved experimentally the soundness of this fact. On the other hand, these results are not in agreement with the shrinkage behavior of normal strength concrete where the elastic tensile strain capacity from direct method is greater than that from indirect method as found by **[AL-Rawi,1985], [AL-Wash,2005]** and **[Kadhum,2003].**

## 4.4. Restrained shrinkage of the Slabs

The measurement of movements of the slabs was carried out to investigate the effect of different restraint cases of the slabs on the shrinkage and cracking behavior. These measurements were conducted for a drying shrinkage period of 4 months.The movements of the slab were measured at three rows (10, 20 cm a part from the edge and at the center) of the slab by using a demec point. In addition to the measurement of slab movement, the movement of the rigid beams was also recorded during the same period. The contraction of the rigid beams during the exposure period of the slabs was called “Loss of restraint – L.O.R.”.

### 4.4.1. Restrained shrinkage of reinforced concrete free slab

**Figures (5 to 7)** show the shrinkage development with age of reinforced concrete free slab

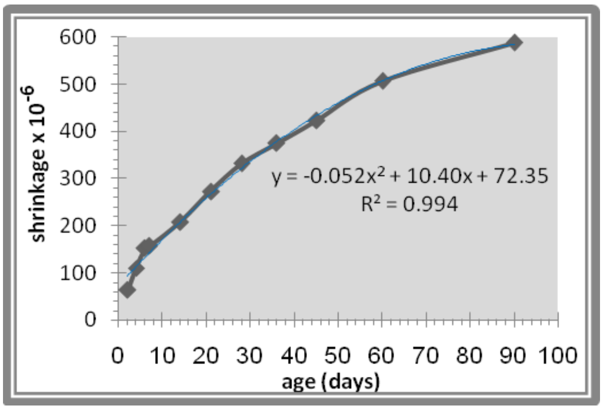



Figure (5): Shrinkage development with age for reinforced concrete free slab at 10 cm from the free edge.

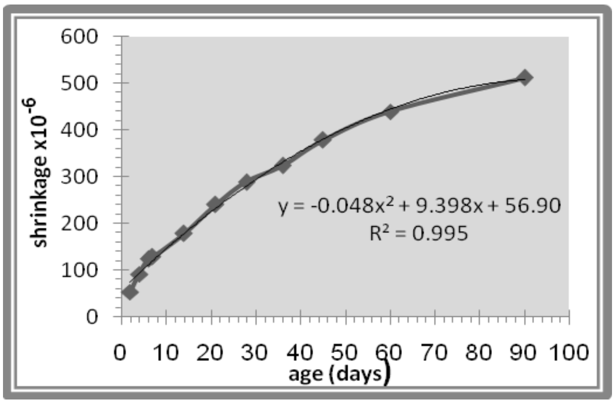



Figure (6): Shrinkage development with age for reinforced concrete free slab at 20 cm from the free edge.

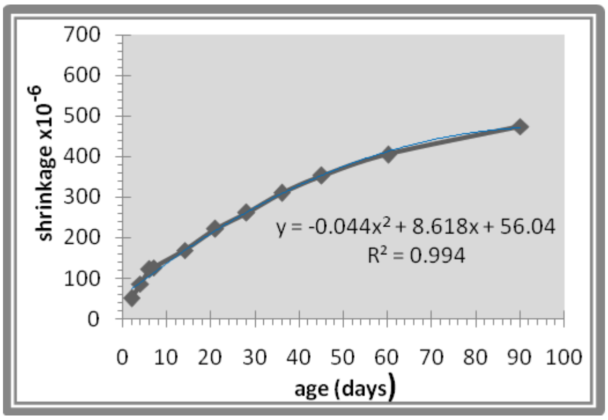


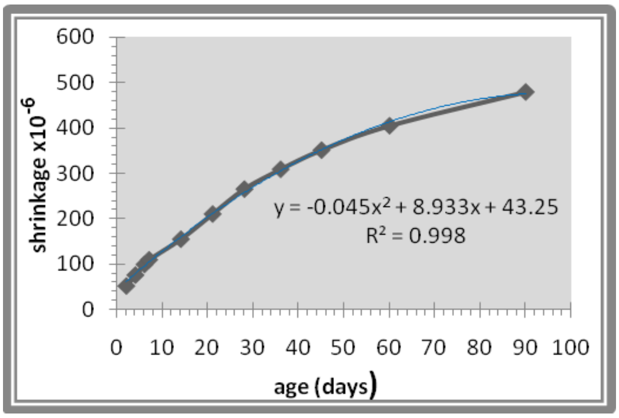

Figure (7): Shrinkage development with age for reinforced concrete free slab at center.

The shrinkage strain at 10 cm from the edge was less than that at the free shrinkage beam models by (2%) also the shrinkage strain at 20 cm from the edge was less than that at the free shrinkage beam models by (16%) and the shrinkage strain at center was less than that at the free shrinkage beam models by (21%).

From this Figures it can be observed that movements of the slab decreases towards the centerline of the slab from the restrained edges and the free shrinkage strains of the slabs were not uniform with distance from the edge to the center of the slab. The drying shrinkage in the free slab is less than drying shrinkage strain of normal and self compacting concrete which was reported by **[Kadhum,2003], [Kubba,2007]** respectively.

**4.4.2. Restrained shrinkage of four ends restrained reinforced Concrete slab**

Figures (8 to 10) show the shrinkage development with age of four end restrained of reinforced concrete slab.




(8): Shrinkage development with age for four end restrained of reinforced concrete Slab at 10 cm from the restrained edge

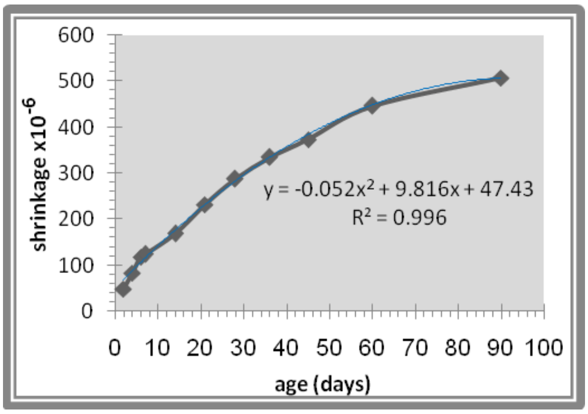



Figure (9): Shrinkage development with age for four end restrained of reinforced concrete Slab at 20 cm from the restrained edge

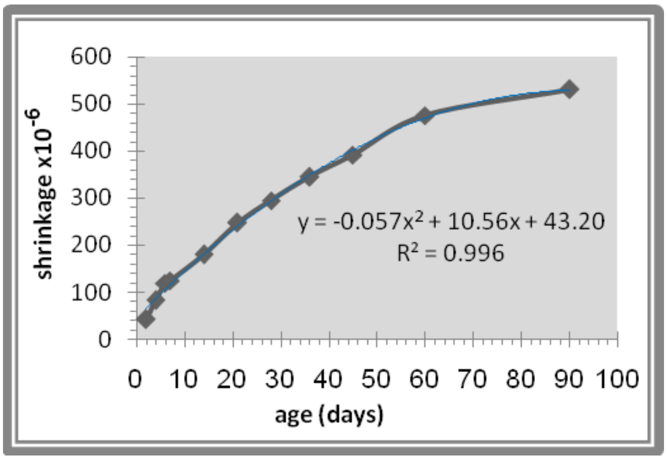



Figure (10): Shrinkage development with age for four end restrained of reinforced concrete slab at center.

The shrinkage strain at 10 cm from the edge was less than that at the free shrinkage beam models by (25%) also the shrinkage strain at 20 cm from the edge was less than that at the free shrinkage beam models by (18.5%) and the shrinkage strain at center was less than that at the free shrinkage beam models by (16.5%)

From these Figures it can be observed that movements of the slab increase towards the centerline of the slab from the restrained edges and the free shrinkage strains of the slabs were not uniform with distance from the edge to the center of the slabs. The drying shrinkage in the four ends restrained slab is less than drying shrinkage strain of normal and self compacting concrete which was reported by **[Kadhum,2003], [Kubba,2007]** respectively.

**4.4.3. Restrained movement of two ends restrained reinforced concrete slab**

**Figures (11 to 16)** show the measured movement and shrinkage development with age of two end restrained reinforced concrete slab.

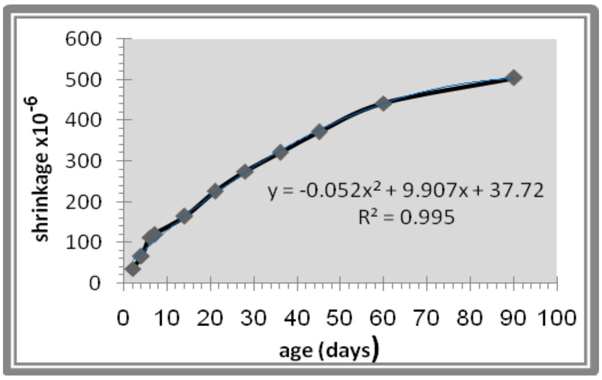



Figure (11): Shrinkage development with age for two end restrained of reinforced concrete slab at 10 cm from the free edge

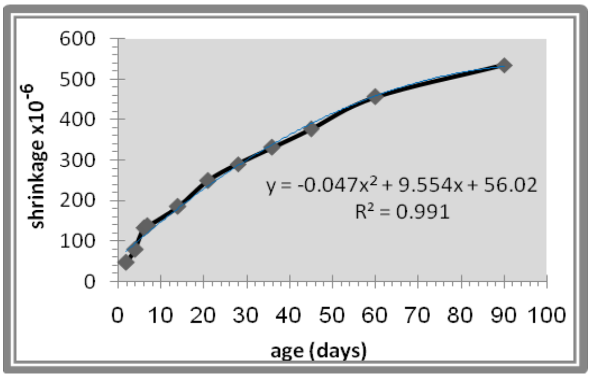



Figure (12): Shrinkage development with age for two end restrained of reinforced concrete slab at 10 cm from the restrained edge.

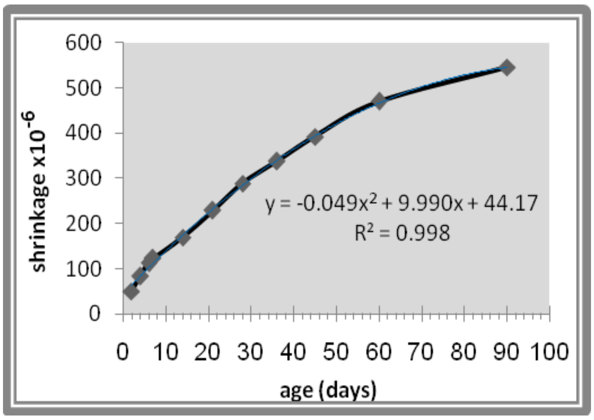



Figure (13): Shrinkage development with age for two end restrained of reinforced concrete slab at 20 cm from the free edge.

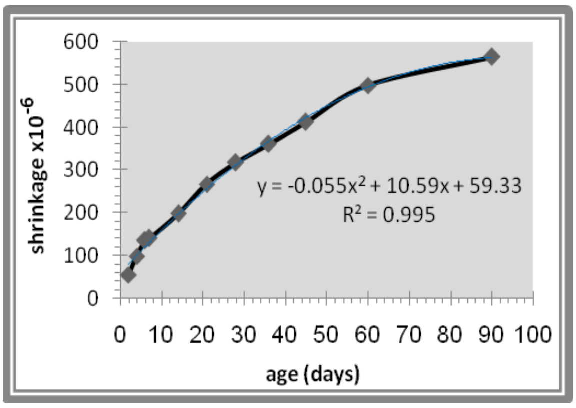



Figure (14): Shrinkage development with age for two end restrained of reinforced concrete slab at 20 cm from the restrained edge

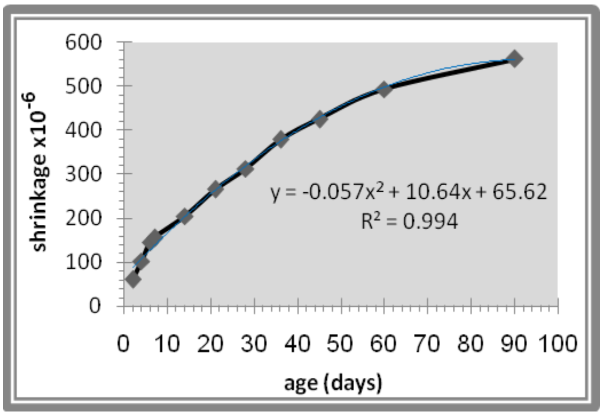



Figure (15): Shrinkage development with age for two end restrained of reinforced concrete slab at center 1.

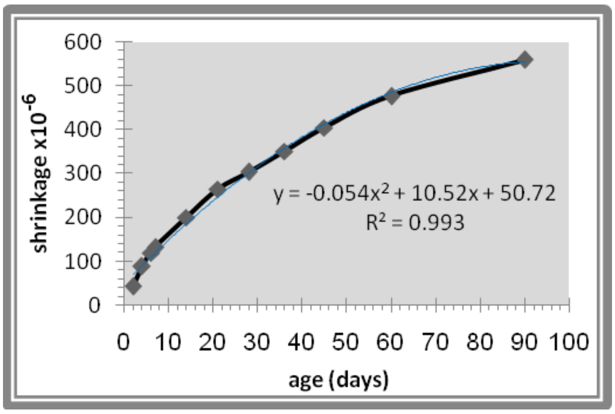



Figure (16): Shrinkage development with age for two end restrained of reinforced concrete slab at center 2

From these Figures it can be observed that:

1. The shrinkage strain at 10 cm from the free edge was less than that at the free shrinkage beam models by (22.5%).
2. The shrinkage strain at 10 cm from the restrained edge was less than that at the free shrinkage beam models by (14.9%).
3. The shrinkage strain at 20 cm from the free edge was less than that at the free shrinkage beam models by (17.8%).
4. The shrinkage strain at 20 cm from the restrained edge was less than that at the free shrinkage beam models by (7.9%).
5. The shrinkage strain at center (100cm from free edge) was less than that at the free shrinkage beam models by (12.2%).
6. The shrinkage strain at center (120cm from restrained edge) was less than that at the free shrinkage beam models by (5.1%). From these results it can be observed that movements of the slab increase towards the centerline of the slab from the edges and the free shrinkage strains of the slabs were not uniform with distance from the edge to the center of the slabs. The drying shrinkage in the two ends restrained slab is less than drying shrinkage strain of normal and self compacting concrete which was reported by **[Kadhum,2003], [Kubba,2007]** respectively.

**4.4.4. Restrained movement of three ends restrained reinforced concrete slab**

**Figures (17 to 21)** show the measured movement and shrinkage development with age of three end restrained of reinforced concrete slab.

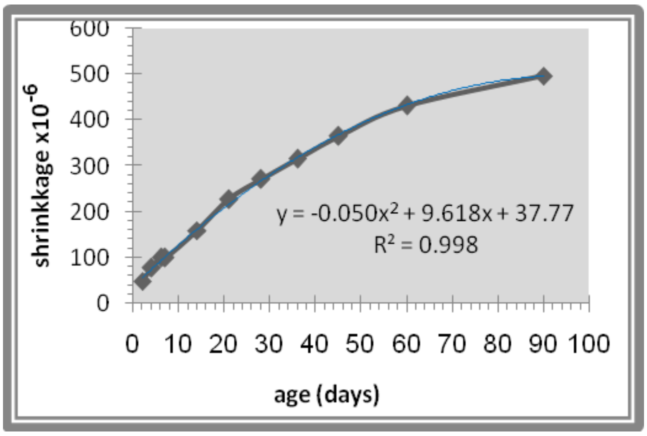



Figure (17): Shrinkage development with age for three end restrained of reinforced concrete slab at 10 cm from the restrained edge.

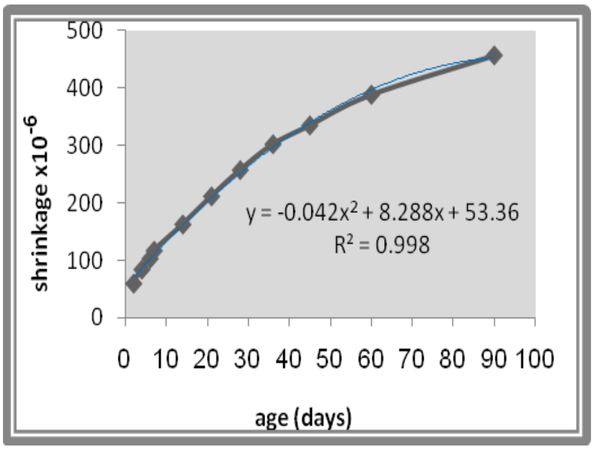



Figure (18): Shrinkage development with age for three end restrained of reinforced concrete slab at 10 cm from the free edge.

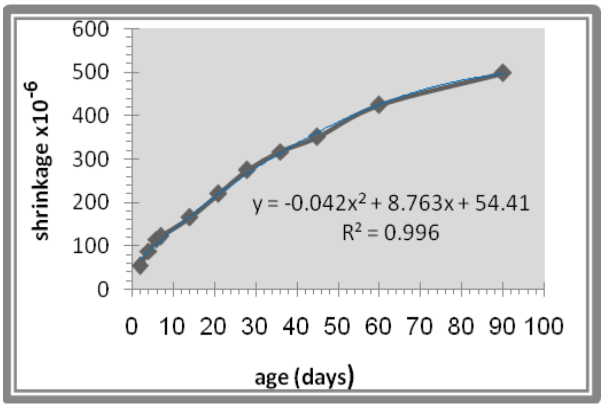



Figure (19): Shrinkage development with age for three end restrained reinforced concrete slab at 20 cm from the restrained edge.

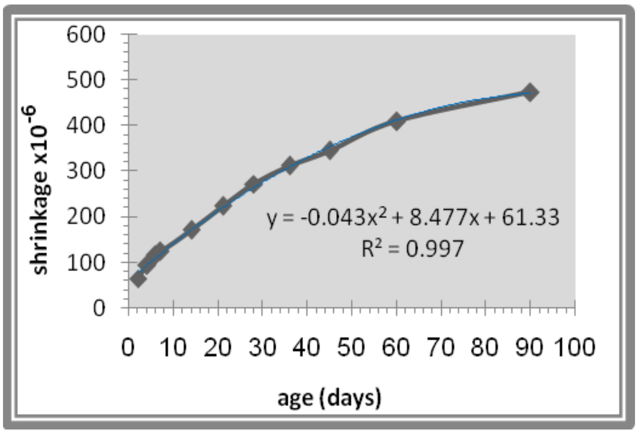



Figure (20): Shrinkage development with age for three end restrained of reinforced concrete slab at 20 cm from the free edge

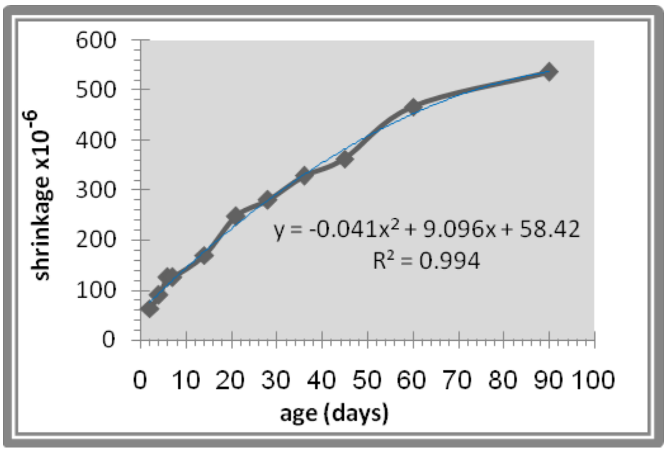


Figure (21): Shrinkage development for three end restrained of concrete slab at center.

From these Figures it can be observed that:

1. The shrinkage strain at 10 cm from the free edge was less than that at the free shrinkage beam models by (24.2%).
2. The shrinkage strain at 20 cm from the free edge was less than that at the free shrinkage beam models by (19.3%).
3. The shrinkage strain at center from the free edge was less than that at the free shrinkage beam models by (15.3%).
4. The shrinkage strain at (10cm, 20cm and center 2) was less than that at the free shrinkage beam models as average by (21.9%, 13.7% and 8.7%) respectively.

From these results it can be observed that movements of the slab increase towards the centerline of the slab from the edges and the free shrinkage strains of the slabs were not uniform with distance from the edge to the center of the slabs. The drying shrinkage in the three ends restrained slab is less than drying shrinkage strain of normal and self compacting concrete which was reported by **[Kadhum,2003], [Kubba,2007]** respectively.

### 4.5. Cracking time

Cracking time is the time required for first crack to occur. From observation of the slabs it was found that the crack did not occurs at any slabs at the period of the exposure to drying shrinkage. But cracking are present in high strength concrete beam modules one crack occur at 23 days with crack width (0.273 mm) and increase with time, the development of crack width with time were summarized in Table (8).

Table (8): Crack Development in Beams Models.

| Crack width (mm) | Time of crack in beam (days) |
|---|---|
| 0.273 | 23 |
| 0.285 | 35 |
| 0.295 | 45 |
| 0.319 | 60 |
| 0.325 | 90 |

## 5. Conclusions

The main findings from that perspective can be summarized as follows:

1. The drying shrinkage of HSC is less than the drying shrinkage strain of normal concrete and Self-Compacting Concrete.

2. It was found from the end-restrained beam specimens results that the tensile strain capacity at age of cracking is less than that of normal strength concrete.
3. The creep strain in high strength concrete in this study is less than that of normal strength concrete.
4. Elastic tensile strain capacity calculated by indirect method (flexural tensile strength divided by the modulus of elasticity) is higher than of direct method (elastic tensile strain capacity of concrete was obtained directly by measuring the immediate movement after cracking of concrete in end restrained beams) by about 89 % .
5. The experimental observations indicated that the cracking did not develop in reinforced high strength concrete slabs.
6. The maximum shrinkage values decreases towards the centerline of the slab from the edges for reinforced concrete free slab and increases towards the centerline of the slab from the restrained edges for (two, three and four) ends restrained reinforced concrete slab
7. The maximum shrinkage strains present at the free slab at 10 cm from the edge and the minimum shrinkage strains were present at the four restrained edges slab at 10 cm from the edge.

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