نموذج رقم (1)

## إقــــرار

**أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:**

The Effect of Steel Fibers and Forta Ferro Fibers on Shrinkage properties of Normal Concrete.

أقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وإن هذه الرسالة ككل أو أي جزء منها لم يقدم من قبل لنيل درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

## DECLARATION

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification

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**Faculty of Engineering _ Graduate Studies**
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**Design and Rehabilitation of Structures**

# The Effect of Steel and Forta Ferro Fibers on Shrinkage Properties of Normal Strength Concrete

**دراسة تأثير المواد الفايبر ومواد البولي بروبيلين على خصائص التمدد والانكماش في الباطون**

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A research submitted in partial fulfillment of the requirements for the degree of master of science in civil engineering – design and rehabilitation of structures

**May 2015**

بسم الله الرحمن الرحيم

الجامعة الإسلامية – غزة
The Islamic University - Gaza

مكتب نائب الرئيس للبحث العلمي والدراسات العليا هاتف داخلي 1150

الرقم: ج س غ/35/ Ref

التاريخ: 2015/05/25 Date

# نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ علاء عبدالقادر محمد بشير لنيل درجة الماجستير في كلية *الهندسة* قسم الهندسة المدنية– تصميم وتأهيل المنشآت وموضوعها:

**دراسة تأثير المواد الفايبر ومواد البولي بروبلين على خصائص التمدد والانكماش في الباطون**

**The Effect of Steel Fibers and Forta Ferro Fibers on Shrinkage properties of Normal Concrete**

وبعد المناقشة التي تمت اليوم الاثنين 07 شعبان 1436هـ، الموافق 2015/05/25م الساعة العاشرة والنصف صباحاً، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

| | | |
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| أ.د. سمير محمد شحادة | مناقشاً داخلياً | ............ |
| د. مصطفى ماهر الطيب | مناقشاً خارجياً | ............ |

وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في كلية *الهندسة*/ قسم الهندسة المدنية- تصميم وتأهيل المنشآت.

*واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.*

والله ولي التوفيق،،،

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# ABSTRACT

Shrinkage in concrete is a problem which faces most of concrete structures especially in the horizontal surface that causes cracks. Drying shrinkage cracks are caused by evaporation of water of cement paste after setting, where rapid evaporation occurs. The rapid evaporation destroys the integrity of the surface and reduces its durability. To increase the life of a concrete structure, it is necessary to minimize the formation of drying shrinkage cracks.

The main goal of this research is to minimize drying shrinkage of concrete using steel and polypropylene fibers (forta ferro) that are available in local markets at several percentages. It is also aimed at studying the effect of fibers on physical properties of concrete. Many trial mixes were prepared to improve the mechanical properties compare with that's of mixes without fibers.

This research comprises two phases: the first phase is to study the effect of steel and polypropylene fibers (forta ferro) on shrinkage properties of concrete by different percentage (0.5% ,1.0 % and 1.5% of volume) of fibers according American standard (ASTM C -157). The second phase is to study the effect of forta ferro and steel fiber on the fresh and hardened mechanical properties of concrete such as, workability, compressive strength and split cylinder strength, by different percentage of steel and forta ferro fibers.

The results showed that steel fibers reduced shrinkage in normal concrete by up to 16.4% at 1.5% , while the forta ferro fibers reduced the shrinkage in normal concrete by up to 38.31% at 1% . The results also showed that the steel and forta ferro fibers improved the compressive strength up to 13% and splitting strength up to 35% .

# الملخص


الانكماش في الخرسانة هي مشكلة تواجه معظم المنشآت الخرسانية وخصوصا في الاسطح الافقية مما ينتج عنه تشققات , وهده التشققات تحدث نتيجة تبخر المياه الداخلية الموجودة في الخرسانة بعد الجفاف مما ينتج عنه تدمير الاسطح ونقصان حجم الباطون وبالتالي تقليل العمر الزمنى للخرسانة , لذلك من الضروري تجنب التشققات في الخرسانة لزيادة العمر الزمنى لها.

إن الهدف الرئيسي من هذا البحث هو تقليل نسبة الانكماش في الخرسانة باستخدام الالياف المعدنية والياف البولي بروبيلين (فورتا فيرو ) المتوفرة في الاسواق المحلية بنسب مختلفة وكذلك دراسة تأثير هده الالياف على الخواص الفيزيائية للخرسانة ، حيث تم في هذا البحث تنفيذ العديد من الخلطات التجريبية للحصول على خصائص جديدة ومقبولة وفي نفس الوقت تتحمل ضغط كسر اكبر من الخرسانة العادية وكدلك قوة شد اكبر من تحمل الخرسانة العادية في المعالجة العادية.

ويشتمل هذا البحث على قسمين , القسم الاول دراسة تأثير الياف الحديد والياف البولي بروبيلين على خاصية الانكماش في الخرسانة في الطروف القياسية حسب المواصفات بنسب مختلفة(0.5%, 1.0% و1.5% من حجم العينات) للألياف باستخدام قوالب خاصة حسب المواصفات الامريكية. اما القسم الثاني دراسة الخواص الميكانيكية للخرسانة في الحالة الطازجة والحالة الصلبة مثل الخواص التشغيلية ومقاومة الضغط والكسر ومقاومة الشد باستخدام الاسطوانة القياسية. وتمت أيضاً دراسة تأثير أضافة نسب مختلفة من ألياف الحديد والياف البولي بروبيلين على هذه الخواص.

أظهرت النتائج بان الياف الحديد تساعد في تقليل الانكماش والتمدد في الخرسانة بنسب تصل الى 16.4% عند 1.5% , اما الياف البولي بروبيلين فقد اطهرت النتائج بانها تقلل الانكماش بنسبة تصل الى 38.31% عند 1% , كما واطهرت النتائج ان الياف الحديد والبولي بروبيلين تساعد في تحسين الخواص الميكانيكية والفيزيائية للخرسانة العادية حيث تزيد من قوة الضغط بنسبة تصل13% وكدلك تحسين قوة الشد في الخرسانة الى 35% .

# DEDICATIONS

I dedicate my thesis work to my father, mother, wife, sons and daughter for their endless love, support and encouragement.

To those who taught us letters of gold and words of jewel of the utmost and sweetest sentences in the whole knowledge. Who rewarded to us their knowledge simply and from their thoughts made a lighthouse guides us through the knowledge and success path, to our honored teachers and professors.

To our true friends who share us their feelings and hard work, through our research accomplishment.

## ACKNOWLEDGMENTS

I would like to express my sincere appreciation to my supervisors, Dr. Mohamed Arafa and Dr. Mamoun Alqedra for their help and guidance in the preparation and development of this work. The constant encouragement, support and inspiration they offered were fundamental to the completion of this research.

Special thanks go to the material and soil lab of the Islamic University of Gaza, for their logistic facilitations and their continuous support. Finally, I would like to thank everyone who gave advice or assistance that contributed to complete this research.

# ABBREVIATIONS

| | |
|---|---|
| **ACI** | American Concrete Institute |
| **ASTM** | American Society for Testing and Materials |
| **SF** | Steel Fibers |
| **FF** | Forta Ferro Fibers |
| **W/C** | Water / Cement ratio |
| **NSC** | Normal Strength Concrete |
| **SCC** | Self-Compacting Concrete |
| **RPC** | Reactive Powder Concrete |
| **UHSC** | Ultra High Strength Concrete |
| **UHPC** | Ultra High Performance Concrete |
| **MAS** | Maximum aggregate size |
| **SFRC** | Steel Fiber Reinforced Concrete |

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# Chapter 1
# Introduction

## 1.1 Background

Concrete is the most important building material. One of disadvantage of concrete its brittleness. Fibers have been used since Biblical times to strengthen brittle materials. Since then, the concept of dispersed fiber in cement-based materials has been considerably developed **(Shihada, 2010)**

There are four main types of shrinkage: plastic, autogenous, carbonation and drying shrinkage, plastic shrinkage is caused by evaporation of water during the first hours of casting before setting, autogenous shrinkage is an important component of volume changes resulting in the occurrence of cracks, carbonation shrinkage is a phenomenon very recently recognized. carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement, calcium hydroxide gets converted to calcium carbonate and also some other cement compounds are decomposed, drying shrinkage is also caused by evaporation of cement paste water after setting. Technically, drying shrinkage will continue for the life of the concrete but most shrinkage will occur within the first three or four months after placement **(Ramseyer, 2006, Holt and Leivo, 2004).**

In the past, several techniques have been proposed for studying shrinkage induced cracking in cement based materials including a ring type specimen, a linear specimen with anchored ends, a linear specimen held between a movable anda fixed grip and a plate type specimen. These tests are well idealized in nature but do not represent the actual condition of restraints in practice. A technique producing restraints comparable to the reality was recently developed **(Siddique et al., 2007)**.

The effect of forta ferro and steel fibers on the shrinkage properties of normal strength concrete will be studied. Trial mixes of fibers will be added to get better properties of drying shrinkage and mechanical properties (compressive strength and splitting strength).

## 1.2 Problem Statement

Drying shrinkage of concrete is the reduction in volume caused by the withdrawal of water from hardened concrete stored in unsaturated air to the surroundings. It is also defined as the time dependent strain measured at constant temperature in an unloaded and unrestrained specimen **(Gilbert, 1988).**

Similarly, the use of fibers materials in fiber concrete presents potentials to create durable concrete, particularly steel fibers and forta ferro have become popular in recent years for the reinforcement of concrete materials, mainly due to their effectiveness in reducing cracking .

In this research, two types of fibers in different contents are used in the concrete mixes to study the potential of reducing drying shrinkage in reinforced concrete structures.

## 1.3 Research Objectives

The main goal of the current research is to study the effect of forta ferro and steel fibers on shrinkage properties of normal performance concrete with a high w/c ratio. This can be achieved through the following objectives:

1- Study shrinkage properties of normal strength concrete without fibers, and study shrinkage properties of normal concrete with forta ferro and steel fibers. Then, a comparative study of concrete with and without fibers to identify the effect of fibers on reducing shrinkage.
2- Determine the optimum amounts of forta ferro fibers and steel fibers that should be used to decrease the drying shrinkage.
3- Obtain mechanical properties of fibers concrete such as compressive strength and splitting tensile strength

## 1.4 Scope of Work

The scope of work is to study the effect of two types of fibers (Steel and Forta Ferro fiber) on drying shrinkage of normal strength concrete, This study is to be carried out on specimens according ASTM C-157 to determine the optimum percentage of forta ferro and steel fibers to minimize drying shrinkage of wet normal performance concrete with a high w/c ratio and find out the extent of their impact on the mechanical properties of concrete by testing the fibrous concrete for compressive and splitting strength.

## 1.5 Methodology

1- Studying and reviewing previous researches related to reducing shrinkage cracking

2- Executing the testing program.

Testing program consists of the following:

a) Test the shrinkage properties of normal strength concrete without fibers.

b) Test the effect of forta Ferro fibers on the shrinkage properties of normal strength concrete with different percentages.

c) Test the effect of steel fibers on the shrinkage properties of normal strength concrete with different percentages.

3- Analyze the result to determine the optimum mix for reducing shrinkage.

4- Perform the required tests on the optimum mix (compressive strength and splitting tensile strength) and analyze the data.

5- Result analysis and recommendation.

6- Preparation of thesis document.

## 1.6 Research layout

This research contains five chapters as follow:

**Chapter (1) Introduction**

This chapter introduces a brief introduction on the effect of steel fiber and forta ferro fibers on the shrinkage of normal strength concrete and the problem discussed in this research in addition the methodology used.

**Chapter (2) literature Review**

This chapter illustrates studies on drying shrinkage of natural and effect of steel fiber and forta Ferro on concrete.

**Chapter (3) Materials and Experimental Program**

This chapter presents the materials used in this research and its properties both fresh or hardened and the tests applied on the drying shrinkage of normal strength concrete.

**Chapter (4) Test Results and discussion**

This chapter explains the results and summarizes the fresh and hardened properties of concrete and drying shrinkage properties of concrete.

**Chapter (5) Conclusion and recommendation**

This chapter includes the main conclusions and recommendation drawn from this research.

**References**

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Type of concrete shrinkage

There are four main types of shrinkage in concrete; plastic, autogenous, carbonation and drying shrinkage.

1- Plastic shrinkage cracking occurs when moisture evaporates from the surface of freshly placed concrete faster than it is replaced by bleed water, the surface concrete shrinks. Due to the restraint provided by the concrete below the drying surface layer, tensile stresses develop in the weak, stiffening plastic concrete in fresh concrete **(ACI 224, 2007)**, To avoid plastic shrinkage, evaporation rates should not exceed 0.5kg/$m^2$/h **(Mindess et al., 2003)**.

**2-** Autogenous shrinkage can also occur due to chemical shrinkage. Concretes that have a finer pore structure will be more susceptible to autogenous shrinkage. Pozzolanic reactions with mineral admixtures, such as silica fume, or faster setting cements with higher amounts of C3A can lead to a finer pore structure. Mix proportioning is one method used to address autogenous shrinkage **(Holt and Leivo, 2004).**

3- Carbonation shrinkage occurs when the concrete is exposed to air with high concentrations of carbon dioxide and about 50% relative humidity for long periods. The concrete behaves as if it were exposed to drying conditions with a relative humidity far below the actual humidity **(Brown et al., 2001).** The conditions mentioned above occur most often in structures like parking garages, while bridges seldom have these conditions **(Mindess et al., 2003).** Therefore, this type of shrinkage is outside the scope of this work,

4- Drying shrinkage is caused by the loss of moisture from the cement paste constituent after setting **(ACI 224,2007)**, **(Wong et al., 2007)** defined drying shrinkage of concrete is the reduction in volume caused by the withdrawal of water from hardened concrete stored in unsaturated air to the surroundings, It is also defined as the time dependent strain measured at constant temperature in an unloaded and unrestrained specimen**(Gilbert, 1988)**.The following sections explain more the drying shrinkage cracking.

## 2.2 Drying Shrinkage Cracking

Drying shrinkage is caused by evaporation of cement paste water after setting **(ACI 224,2007)**, Drying shrinkage is of greater significant than plastic shrinkage and can lead to cracking and warping of structural elements

Drying shrinkage, probably the most significant contributor to macroscopic dilation, is caused by the migration of water from pores and capillaries. Drying shrinkage is usually described with a delusion model, Micro crack formation and internally created stresses produce creep, modify the time-dependent deformation and result in a complex nonlinear delusion process **(Chern and Young, 2000).**

Shrinkage presents the greatest value at the member surfaces exposed to drying and de-creases towards the interior of the member **(Gilbert, 1988)**.If drying conditions are the same at both top and bottom surfaces of the specimen, the total strain would be uniform over the depth of the specimen; however, if drying occurs at a different rate from the top and bottom surfaces, the total strain distribution becomes inclined and warping of the member would result. Drying shrinkage induces tension and results in the formation of cracks, leading to service ability and durability problems. Factors that affect drying shrinkage of concrete include constituents, porosity, age of concrete, curing temperature, relative humidity, moisture content and types of admixtures used **(Barr et al,. 2003)**.

## 2.3 Factors effecting Drying Shrinkage

Since drying shrinkage is related to moisture loss from the concrete, it is influenced by external factors that affect drying and internal factors related to the concrete and its constituents.

### 2.3.1 External Factors

The external factors affecting loss of moisture from concrete are ambient conditions, and size and shape of the concrete member.

1- Ambient conditions: Air temperature, relative humidity and wind velocity will affect the loss of moisture from the concrete surface**. (ACI 308, 2001)** discusses how any combination of these factors affects the evaporation rate, Different ambient conditions on opposite sides of a member result in differential drying out, hence differential shrinkage with the possible consequence of warping when all other factors are equal, the typical effect of varying relative humidity on the drying shrinkage of concrete is "higher drying shrinkage is to be expected with rise in ambient temperature, with decrease in relative humidity, with increase in air movement around the concrete, and with increase in the length of time for which concrete is subjected to drying conditions"**( Zhang and Li, 2001)**

2- Member geometry: Large, thick concrete members dry out more slowly than small, thin ones. For the same drying period, shrinkage of large-size members is lower than the smaller-size ones which can dry out to their cores more quickly **(CCAA, 2002)**.

### 2.3.2 Internal Factors

The internal factors affecting drying shrinkage of concrete are those related to its constituents: cements, aggregates, admixtures; concrete mix design; water-cement ratio and water content; aggregate properties and volume fraction; and those related to the construction of the concrete: placing, compaction and curing.

**1- Water content**

The drying shrinkage of concrete increases with increasing its water content. The variation in shrinkage with water content may be explained by the difference in types of water lost at the various stages of drying mentioned earlier. It is also associated with the modulus of elasticity of the concrete. Concrete of high water content (and high water-cement ratio) has a lower strength and lower modulus of elasticity and hence has a greater tendency to shrinkage. The effect of water cement ratio on drying shrinkage is illustrated in **Figure (2.1**). As can be noted, at ages beyond 28 days, higher water-cement ratios lead to significant increase in drying shrinkage **(Soroka, 1979)**.

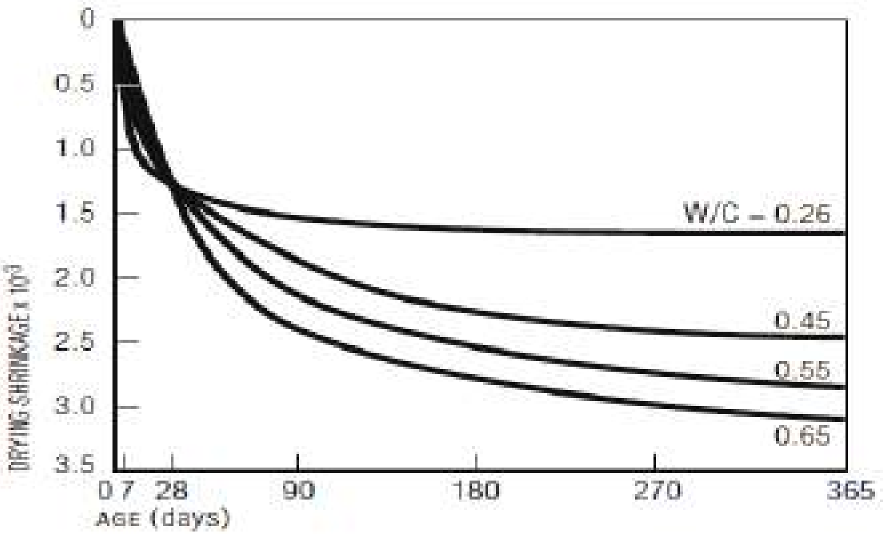


**Figure 2.1:** Effect of water-cement ratio on shrinkage of cement paste**(Soroka,1979)**

**(Hindy et al,.1994)** studied concretes with water-cementations (w/cm) ratios of 0.22 and 0.28 to compare the effect of water- cementitious ratio on shrinkage. After 28 days of drying, they found that the 0.28 w/cm and the 0.22 w/cm mixes exhibited shrinkage of 392 and 362 µm, respectively. Similarly, after 365 days of drying, the 0.28 and 0.22 w/cm mixes exhibited shrinkage of 702 and 630 µm, respectively. They also stated that the increase in w/cm increased the shrinkage by providing more space for free water diffusion and reducing the rigidity of the solid matrix that resists shrinkage.

2- **Aggregates**

Aggregate serves to restrain drying shrinkage, so increasing the aggregate content will lead to a decrease in concrete shrinkage because it allows for a mixture with less paste. It has been shown by many authors that in an increase in aggregate size and/or increase in aggregate content, both resulting in an increase in aggregate volume, which provides a restraint for the concrete and reduction shrinkage**. (Rao, 2001)**. **Figure (2.2)** shows the relationship between the aggregate and drying shrinkage on concrete (**Rao, 2001)**.

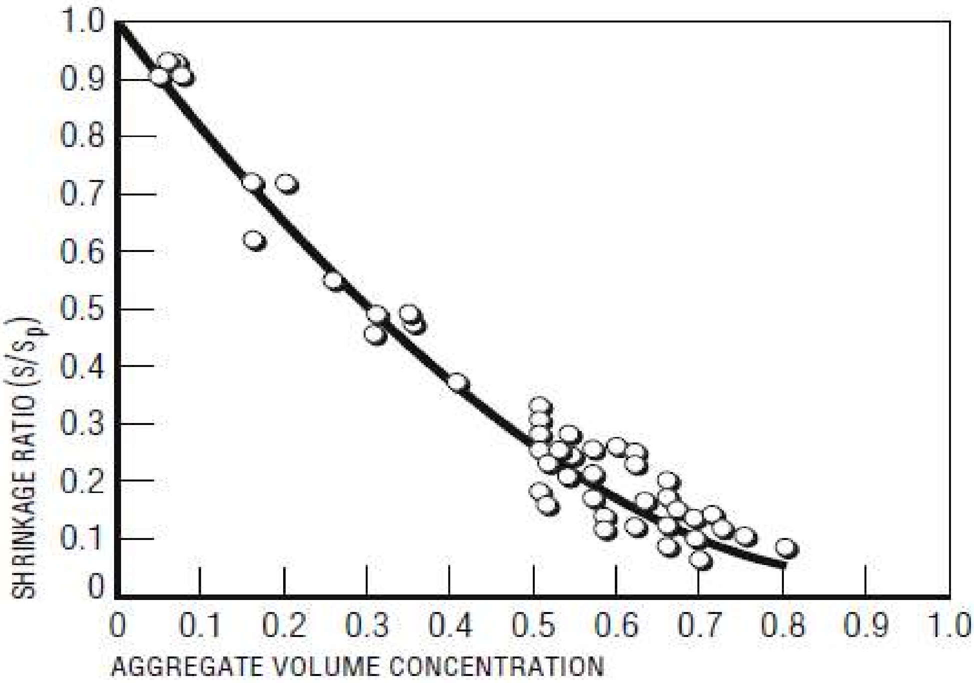


**Figure 2.2:** Effect of aggregate volume concentration on shrinkage **(Rao, 2001)**

Aggregate type was also found to have a significant impact on shrinkage. Typically, concretes containing aggregates with a lower modulus of elasticity produce more shrinkage because of the aggregate's diminished restraining ability. Aggregates with higher absorptions and lower specific gravities typically have a lower modulus of elasticity and, thus, are more susceptible to shrinkage **(Neville and Brooks , 2010)**.

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**Figure 2.3** shows how the aggregate effect on restraining the shrinkage and compare it with mortar and cement paste **(Mindess el al,.2003),** The figure shows that the neat cement is shrinking than mortar and concrete, in other words, the aggregates play important role in enhancement shrinkage properties which restraining shrinkage.

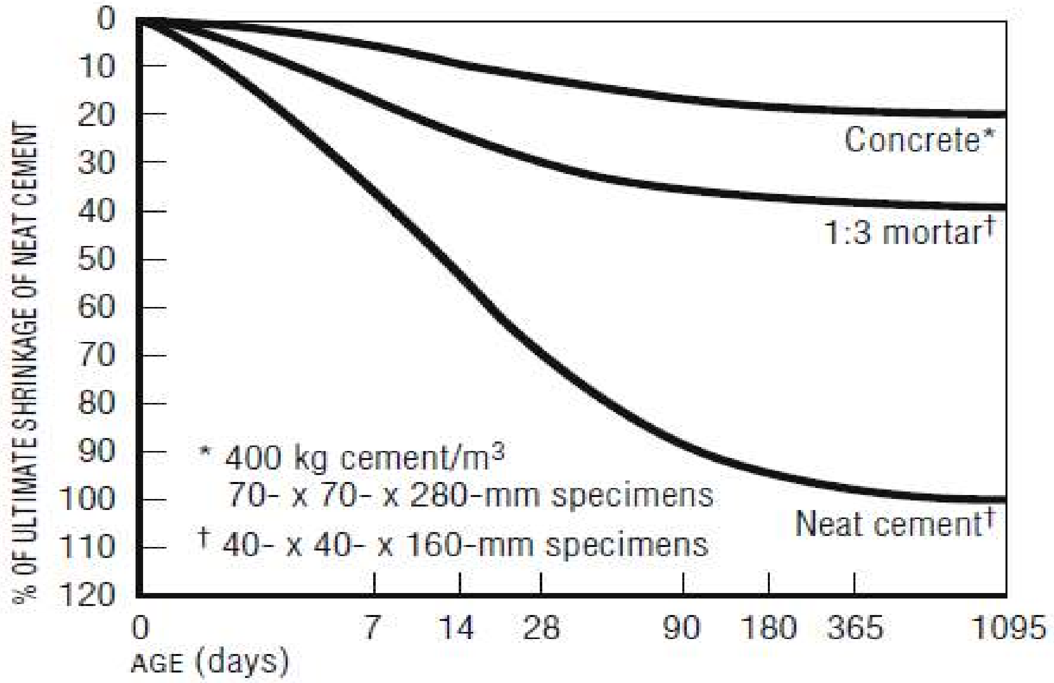


**Figure 2.3 :** Comparative drying shrinkage of concrete, mortar and neat cement paste at 50% relative humidity **(Mindess el al,.2003),**

In summary, hard, dense aggregates with low absorption and high modulus of elasticity are important for the production of concrete of low drying shrinkage. The effect of aggregate on restraining the drying shrinkage of concrete is governed by:

1- The volume fraction of the aggregate
2- The modulus of elasticity of the aggregate
3- The shrinkage of the aggregate upon drying **(CCAA, 2002)**

**3- Cement Fineness**

Cement fineness can also be a factor in concrete shrinkage. Finer cement is one cause of a finer pore structure. A finer pore structure can cause the meniscus that forms within the pores upon drying, to have a greater radius of curvature leading to greater surface tension. This can lead to more shrinkage **(Holt and Leivo, 2004)**.

Although it is generally concluded that the composition of cement can affect drying shrinkage, the effect is not completely determined, The effect of Tri calcium aluminate (C3A) and alkali content have been observed to have a dominant effect. In turn, the effect of

C3A and alkali content on shrinkage is influenced by the gypsum content of the cement, ie shrinkage of cements of the same C3A content differs for different gypsum contents **(Lindquist et al,.2005).**

**4- Construction practice**

Concrete placing, compaction and curing are important factors in minimizing the magnitude of drying shrinkage. Adding further water on site during placing of concrete to restore slump or to aid with final finishing will increase the drying shrinkage of concrete.

Proper compaction and curing are required to produce dense concrete of reduced capillaries and/or with discontinuous capillaries, resulting in reduced loss of moisture from the concrete and reduced drying shrinkage. Applying appropriate curing measures immediately after finishing the concrete will prevent drying of the concrete surface especially in hot weather conditions.

Studies have found that proper curing of concrete is essential to decreased cracking on bridge decks, which can improve the overall performance of a bridge deck **(Lindquist et al.,2005).** However, the effect of the length of the curing period as a factor to decrease overall shrinkage of concrete has been debatable. Some authors feel that prolonged moist curing delays the advent of shrinkage but ultimately has little effect on the magnitude of shrinkage **(Neville and Brooks, 2010)**.

**5- Admixtures**

There are many types of admixtures available for incorporation in concrete to achieve/ enhance certain properties or to achieve economy or both. Generally, admixtures affect shrinkage of the concrete to a varying degree depending on their formulation, their interaction with the cement, their interaction with other admixtures in the mix, and on the variations or adjustments, they bring about in the proportions of the concrete mix. A detailed discussion of the effect of various admixtures can be found elsewhere **(Ribeiro and Fiho, 2006)**, it is well established that admixtures containing calcium chloride can increase the drying shrinkage of concrete**.**

## 2.4 Reducing Drying Shrinkage of concrete

Some of the measures that can be taken to reduce the drying shrinkage of concrete include:

1- Use the minimum water content (consistent with placing and finishing requirements).
2- Use highest possible volume fraction of good quality aggregate and maximum possible aggregate size.

3- Use shrinkage limited cement (Type SL) where available.
4- Do not use admixtures known to increase drying shrinkage, eg those containing calcium chloride.
5- Ensure concrete is properly placed, compacted and cured.
6- Ensure forms is ample strength to sustain strong vibration of low-slump concretes.
7- Project drawings should include an adequate system of contraction joints to provide for shrinkage. **(ACI 224, 2004)**

## 2.5 Effect of Fibers on concrete

Fibers provide internal restraint as well, particularly against movement before curing, they are produced from different materials in various shapes and sizes, Typical fiber materials are (**ACI 544, 2002** )

1- **Steel Fibers**

These fibers compared to traditional fabric reinforcement, have a tensile strength typically 2-3 times greater and a significant greater surface area to develop bond with the concrete matrix **(ACIFC, 1999)**. Steel fibers will continue to provide restraint after curing, the type of fibers are straight, crimped, twisted, hooked, ringed, and paddled ends. In addition, the diameter range from 0.25 to 0.76mm. **ASTM A 820** provides a classification for four general types of steel fibers based on the product used in their manufacture **(ACI Committee 544, 1996)**:

- Cold-drawn wire
- Cut sheet
- Melt extracted
- Other fibers

2- **Synthetic Fibers**

Synthetic fibers are manufactured fibers resulting from research and development in the petro- chemical and textile industries. Synthetic fiber reinforced concrete utilizes fibers derived from organic polymers, which are available in a variety of formulations **(ACI 544, 1996).** Synthetic fiber types that have been tried in Portland cement concrete based matrices are: acrylic, aramid, carbon, nylon, polyester, polyethylene and polypropylene. For many of these fibers there is little reported research or field experience, while others are found in

commercial applications and have been the subject of extensive reporting **(ACI 544, 1996)**. Synthetic, organic fibers have low modulus of elasticity and high elongation properties while steel, glass, asbestos and carbon fibers had high modulus of elasticity **(Manolis et al, 1997).**
The most popular synthetic fibers used in concrete ground floor-slabs are Polypropylene (micro-synthetic) and structural (macro-synthetic).

### 2.5.1 The effect of Fibers on shrinkage properties of concrete

Drying shrinkage strain is of considerable importance to pavement applications because it has a direct contribution to the spacing of the joints. There are conflicting evidences regarding the effectiveness of fibers in limiting both free and restrained drying shrinkage strain in steel fiber reinforced concrete (SFRC).

Generally, steel fiber concrete is more durable than plain concrete, having a positive influence on the shrinkage behavior of concrete by reducing the number and controlling the width of cracks (**ACI 544, 2002)**. **Ramakrishnan (1988)** reported that the most significant consequence of fiber addition to concrete is the delay and control of tensile cracking in the composite material.

**Zhang and Li (2001)** showed that the fiber aspect ratio is an important material parameter that strongly influences the composite shrinkage behavior. For the same fiber content, composite shrinkage decreases nonlinearly and gradually shifts to a constant with an increase in the fiber aspect ratio. A critical fiber aspect ratio exists regarding a composite shrinkage reduction and a further increase in the fiber aspect ratio beyond this critical value does not contribute to reducing the composite shrinkage

**Edgington et al.(1974)** found that the shrinkage properties of concrete over period of three month was unaffected by the present of the steel fibers. **litvin (1985)** also reported in his study that steel fibers concrete with compressive strength of 21-30 MPa has 5% to 7% less shrinkage than its corresponding plain concrete

Work which was conducted by **(chern and young, 2000)** to study the influence of steel fiber parameters testing age and ratio of the specimen volume to the exposed surface on shrinkage characteristics of concrete. It was found that steel fibers restrain deformation more effectivity at later ages due to the development of higher interfacial bond strength between fibers and matrix. Therefore, the older the steel fiber reinforced concrete (SFRC) the less shrinkage strain. It was also evident that both higher fiber content and aspect ratio was found to yield less shrinkage than those of lower values.

**Ramseyer (2006)** shows that fibers slightly decrease ASTM unrestrained shrinkage results, measured from 24 hours to 28 days, He also showed that fibers drastically reduce early age shrinkage, depending on the dosage level; higher is better, up to a certain point that is different for each fiber. **Victor et al. (2009)** showed that the use of steel fibers and the application of thermal treatment decreased 14-day drying shrinkage by more than 57% and by 82% respectively.

Polypropylene showed a great ability to eliminate plastic shrinkage; however, the drying shrinkage of the polypropylene reinforced concrete with w/c ratio 0.45, 0.55 and 0.65 is 2%, 5% and 11% respectively, lower than its corresponding plain concrete mixes at the age of 70 days. Various studies indicated that the shrinkage of polypropylene reinforced concrete depends on different factors , which the most important are w/c ratio , age of concrete, fiber content , and fiber length to maximum aggregate size ratio **Al-tayyib et al., (1988)**, However, **Zollo (1984)** reported in his study a 75% reduction in shrinkage of polypropylene reinforced concrete.,.

**Kao (2005)** found that drying shrinkage was greatly reduced by the addition of fibers. Each fiber described a curve, the shrinkage decreased with increasing dosage of polypropylene fibers up to a point, and then increased as more fibers were added. The optimum dosage varied, but with all fibers, reduction of at least 50% of the early age shrinkage was realized.

### 2.5.2 The effect of Fibers on mechanical properties of Concrete

#### 1- The effect of Fibers on fresh properties of concrete

Knowledge of the fresh concrete properties is considered essential for proper design and application of fiber reinforced concrete mixes **(Ramakrishnan, 1988)**.

Achieving adequate workability is one of the most important problems generated when using steel fiber reinforced concrete. The inclusion of the fibers into the concrete mix influences its workability, with increasing in the fiber volume and aspect ratio leading to decreased workability **(Hannat, 1978 and Swamy, 1974)**.

No workability problem was encountered for the use of hooked steel fibers up to 1.5 percent in the concrete mix. The straight fibers produce balling at high fiber content and require special handling procedure. **(Faisal, 1990)**

**(ACI 544, 2002**) reported that in the typical ranges of volume fractions used for steel-fiber reinforced concrete (0.25 to 1.5 volume percent), the addition of steel fibers may reduce the measured slump of the composite as compared to plain concrete in the range of 25 to 102mm.
**Kao (2005)** worked with polymer fibers, and found a strong reduction in the slump of a concrete with the addition of the fibers. This trend depended somewhat on the type of fibers; the smaller the fiber, the more rapidly the slump decreased.
Polypropylene fibers act mechanically. They impart a cohesive effect by holding water at or near the surface of the concrete, delaying evaporation and increasing cement hydration **(Knapton, 2003)**. The slump of fiber-dosed concrete is not significantly affected by the addition of polypropylene fibers.
**Balaguru and Khajuria (1996)** obtained similar results on the slumps of mixes with fibers; their work with polymeric fibers showed slumps decreasing with increasing fiber dosage levels. With plain concrete, they had a slump of 8.9 inches; at the highest dosage rate, about 4 lb/yd3, they had a slump of only 1.6 inches. However, the decreased slump did not result in a similar increase in the difficulty of vibratory compaction.

**2- The effect of Fibers on hardened properties of concrete**

**A- Compressive strength**

Compressive strength is slightly affected by the presence of fibers, with observed increases ranging from 0 to 15% **(Amir et al, 2002),** also **(Shendet et al 2012)** observed that compressive strength increases from 11 to 24% with addition of steel fibers.
The introduction of polypropylene fibers into the concrete mix has generally no significant effect on the 28-days compressive strength of concrete cubes **(Knapton, 2003). Aulia (2002)** in testing a number of aggregates and mixes with polypropylene fibers found that “the use of 0.2 % of polypropylene fibers by volume resulted in low influence on both the compressive strength and modulus of elasticity of concrete. Essentially, there was no difference between the compressive strength with and without fibers.
**Almassri et al. (2012)** Studied the effect of polypropylene fiber on ultra-high performance self-compacting concrete (UHPSCC). Local available materials and the inclusion of polypropylene fiber with different volume fraction are investigated to produce UHPSCC with different mechanical properties, these properties includes fresh properties, compressive strength, splitting tensile strength and flexural strength. The research showed that the addition

polypropylene fiber causes a small improvement of the compressive strength of UHPSCC within range (1%-7%).

**B- Splitting strength**

Fibers have significant effect on splitting strength of concrete**. Shendet et al (2012)** observed that splitting strength increases from 3 to 41% with addition of steel fibers. In addition, **(Amir et al 2002)** reported that direct tension improved significantly, with increases of the order of 30 to 40% of steel fibers.

**Almassri et al. (2012)** showed that the addition polypropylene fiber improves the splitting strength of UHPSCC within range (20%-30%) according to the fiber percentage ,**Faisal (1990)** observed that the splitting tensile strength improves 57% by adding polypropylene , **Li (2002)** noted a moderate improvement in bending strength with the addition of Polypropylene fibers, but stated that the major difference was in the behavior after reaching the ultimate load. Instead of brittle failure, the fiber mix showed somewhat ductile behavior, with ultimate deflection four times that of the plain concrete.

The effect of forta ferro and steel fibers on shrinkage properties of normal strength concrete will be studied.

# Chapter 3

# Materials and Experimental Program

## 3.1 Introduction

This chapter discusses the characteristics of constituent materials used to measure the effect of forta ferro and steel fibers on shrinkage properties of normal strength concrete, and the experimental program linked to this research.

The purpose of the experiments is to investigate the reduction of drying shrinkage of concrete using steel and forta ferro fibers.

## 3.2 Experimental program

The experimental program was carried out to investigate the effects of adding steel and forta ferro fibers on the shrinkage properties of the concrete mix. All test specimens were cast from one batch of the same mix. The experimental design and the basic tests carried out on materials used or casting concrete samples are discussed in this chapter, followed by a brief description about mix deign and curing procedure adopted. At the end, tests conducted on the specimens are discussed.

This study was designed to investigate the use of two types and three contents of fibers reinforcement in concrete specimens. The first type used is a Polypropylene fiber (Forta Ferro) for the percentages of 0.5%, 1% and 1.5% by volume. The second type is used steel fibers with the same percent's see **Figure (3.1),** and test for drying shrinkage according **ASTM C157** and **ASTM C490** standards. The study of mechanical properties includes compressive strength and splitting strength.

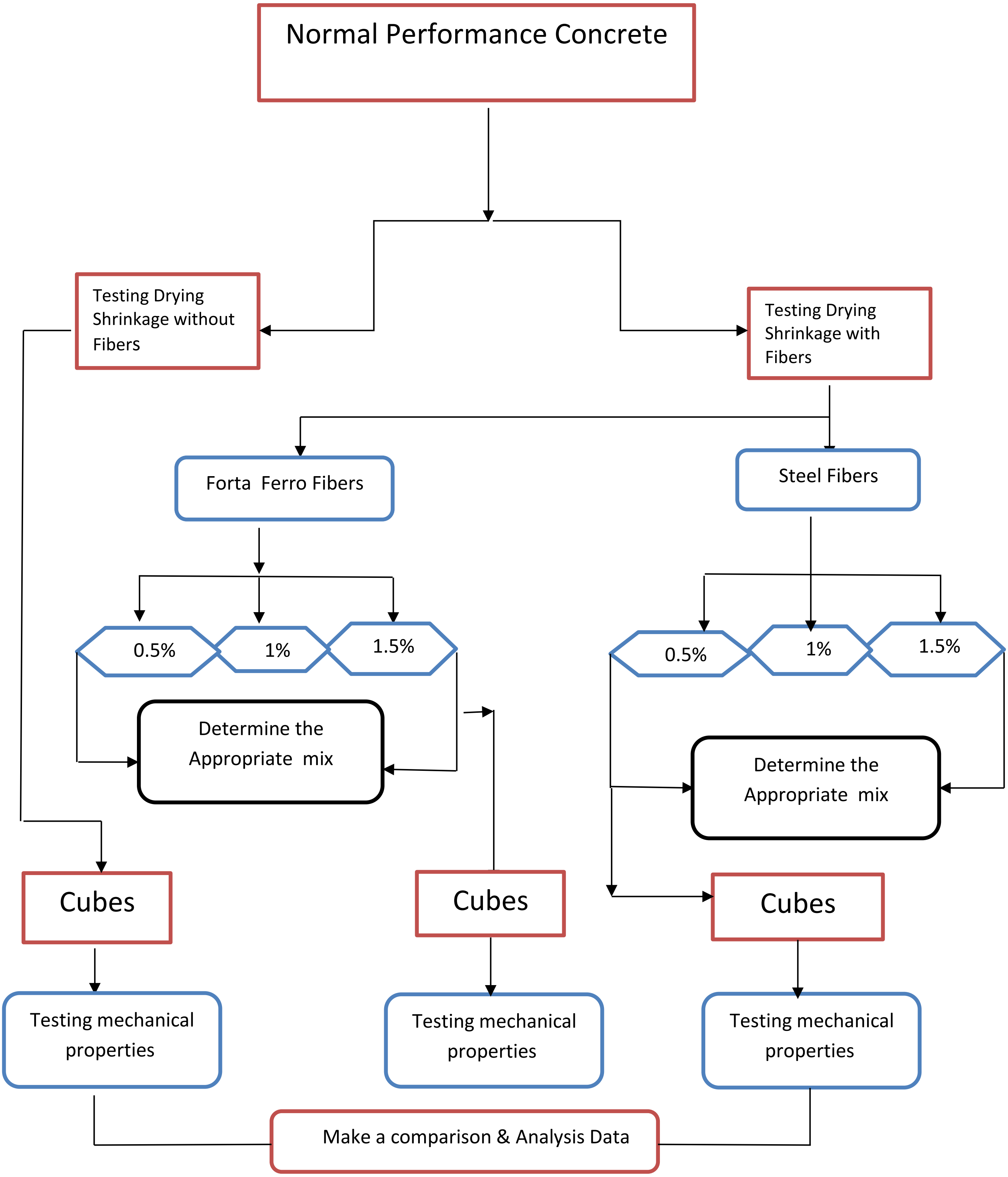


**Figure 3.1 : Experimental program**

## 3.3 Characterizations of constituent Materials

Most of the materials used in this study are materials obtained from the local markets. The detailed properties of the materials used are as follows:

### 3.3.1 Cement

In this research, ordinary Portland cement CEM I B LL 42.5N. **(Figure 3.2)** was used for the production of normal concrete. The results of physical and mechanical analyses of the cements are summarized in **Table (3.1**)

**Figure 3.2:** Ordinary Portland cement

**Table 3.1:** Cement characteristics according to manufacturer sheet tests

| Type of test | | Ordinary Portland Cement | |
|---|---|---|---|
| | | **Results** | **BS EN 197-** |
| **Setting time ( Vicat test ) hr : min** | Initial | 1 hr 35 min | > 60 min |
| | Final | 3 hr 5 min | |
| **Normal Consistency (%)** | | 26.5 | |
| **Mortar compressive strength (MPa)** | 3-Days | 18.20 | Min. 10 |
| | 7-Days | 29.80 | |
| | 28-Days | 42.6 | Min 42.5<br>max 62.5 |

### 3.3.2 Fine Aggregates

The sand used in three experimental program was locally obtained. The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and then was washed to remove the dust. The aggregates sieve analysis is shown in **Figure (3.3).** Properties of the fine aggregate used in the experimental work are tabulated in **Table (3.2)** with fineness modulus (FM) =2.27.

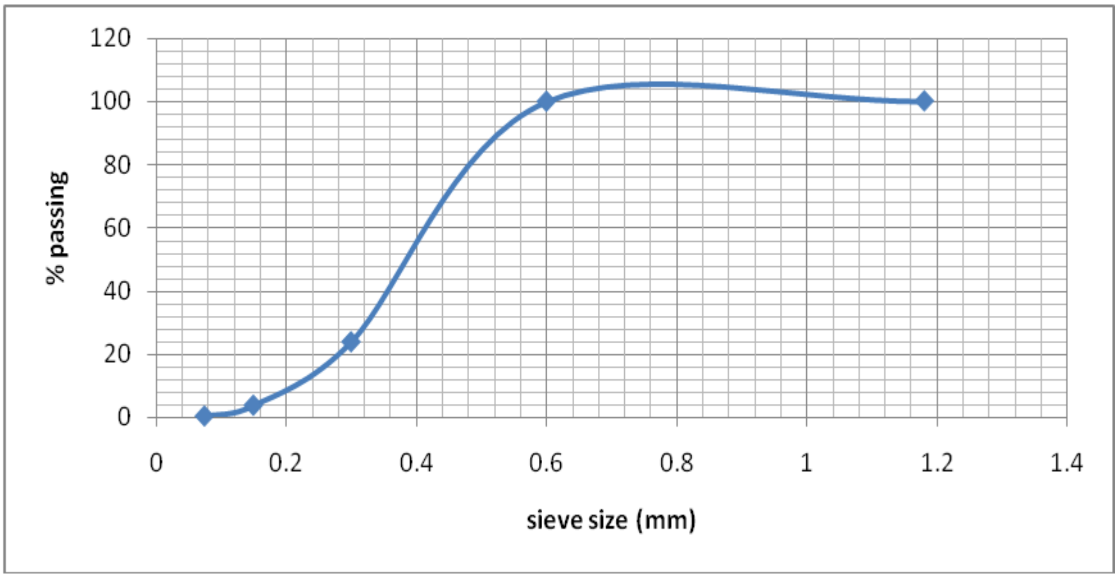


**Figure 3.3:** Sieve analysis results for fine aggregates

**Table 3.2:** Properties of fine aggregates

| ***S.No.*** | ***Characteristics*** | ***Value*** |
|---|---|---|
| 1 | Type | Uncrushed (natural) |
| 2 | Unit weight (γ) kg/m3 | 1600 |
| 3 | Specific gravity (SG) | 2.36 |
| 4 | Total water absorption | 1% |
| 5 | Moisture Content (MC)% | 1.6 % |
| 6 | Fineness Modulus | 2.72 |
| 7 | Grading Zone | Gaza Dune sand |

### 3.3.3 Coarse Aggregates

Crushed limestone obtained from the West Bank quarries is generally used as a coarse aggregate. Its decided the maximum size of the coarse aggregate. Locally available coarse aggregate having the maximum size of 20 mm was used in this work. The aggregates were washed to remove dust and dirt and were dried to surface dry condition. The aggregates were tested per **(ASTM C127, 2004)** and **(ASTM C128, 2004)** Standard Specifications. The sieve analysis results on coarse aggregate is given in **Figure (3.4)**, and their properties used in the experimental work are tabulated in **Table (3.3).**

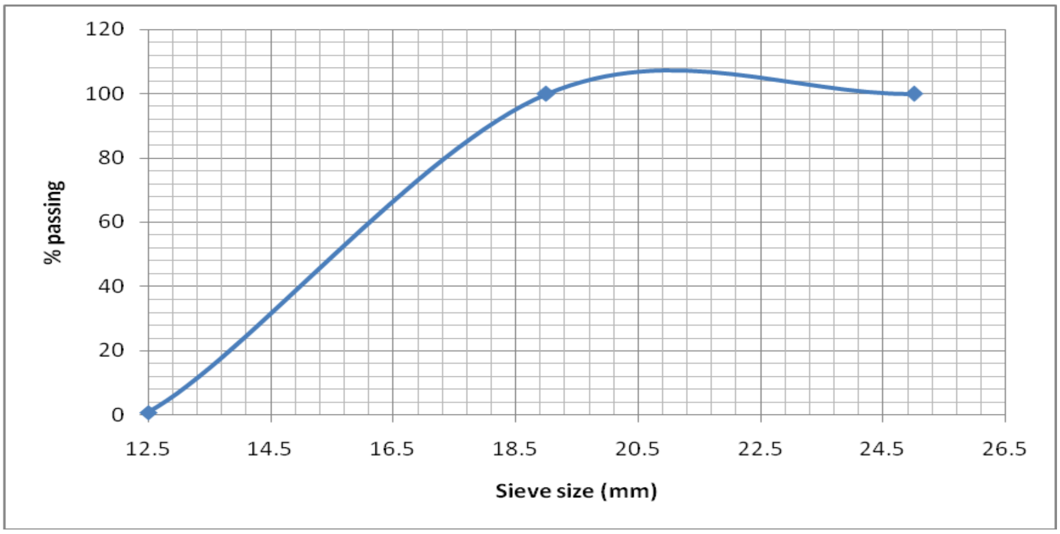


**Figure 3.4:** Sieve analysis results for coarse aggregates

**Table 3.3:** Properties of Coarse aggregates

| S.No. | Characteristics | Value |
|---|---|---|
| 1. | Type | Coarse |
| 2. | Maximum size | 20 mm |
| 3. | Specific gravity (20 mm) | 2.65 |
| 4. | Total water absorption (20 mm) | 2.2% |
| 5. | Fineness modulus (20 mm) | 7.68 |
| 6. | Grading Zone | West bank |

### 3.3.4 Polypropylene fiber

FORTA FERRO polypropylene fiber used in this research, it's a high performance bundle twisted fiber, appropriate for all concrete ground slab and precast applications. See **Figure (3.5).**

**Figure 3.5:** FORTA FERRO polypropylene fiber

FORTA FERRO is produced from 100% virgin copolymer/polypropylene consisting of a twisted bundle non-fibrillated monofilament and a fibrillated network fiber. This twisted bundle delivery system ensures that the fiber mixes well into the concrete and distributes evenly throughout the concrete matrix. The fiber absorbs maximum energy without breakage and is designed to retain its cross sectional shape thus avoiding brittle failure in high load situations, see **Figure (3.6). [FORTA FERRO Company]**


**Figure 3.6:** Physical Properties of FORTA FERRO polypropylene fiber

### 3.3.5 Steel Fibers

The fibers are used to improve hardened concrete properties and improve the ductility of the normal concrete. The steel fibers used in this investigation are clean of rust or oil of straight steel wire fibers. The used steel fibers are chopped or cut from steel wires. **See Figure (3.7).**

The steel wires are cut into the desired length around 13 mm and diameter 0.25 mm, with length/diameter ≈ 52, Tensile strength ≈ 277 MPa and density of 7.8 g/cm$^3$.

**Figure 3.7:** Steel Fibers

### 3.3.6 Water

Tap water was used in all concrete mixtures and in the curing of all the tests specimens. The water source was used from the soil and material laboratory at IUG, which is considered safe to drink. The principle concept of using water in concrete is "If you can drink it, you can make concrete with it".

## 3.4 Design of Mixes

The concrete mix is designed according to **(ACI 211.1, 2003)**to obtain compressive strength of 25 MPa at 28 days and a 150mm slump with water to cement ratio of 0.5

The mix proportions of reinforcement concrete is shown in **Table (3.4)**with **(free w/c ratio = 0.50)**.

**Table 3.4:** Mix proportions, per one cubic meter of concrete.

| Materials | Weight per one Cubic Meter $kg/m^3$ |
|---|---|
| Cement | 360 |
| Coarse aggregate | 1080 |
| Fine aggregate (crushed sand) | 775 |
| Water | 185 |

For the fiber specimens, four mixes with steel fiber (SF) contents of 0, 14.4, 28.8 and 43.2 $Kg/m^3$ are used, respectively. In addition, four mixes with forta ferro (FF) contents of 0, 1.63, 3.27 and 4.91 $Kg/m^3$ are used, respectively

In case of fibrous concrete, the weight of the SF and FF for different volume fractions was calculated as follows:

**(Wt) fiber=(SG*1000)*(Vd) concrete*%of fiber content** where 0.91 is the specific gravity of forta ferro fiber.& 7.8 specific gravity of steel fiber, Vd is the volume of concrete

**Table (3.5)** and **Table (3.6)** shows the steel and forta ferro fibers contents for the four mixtures used in this study

**Table 3.5:** Steel Fibers contents in concrete per cubic meter

| % Volume of steel Fibers | Steel Fiber Content $Kg/m^3$ | Steel Fiber Content Kg/beam |
|---|---|---|
| SF 0.0 | 0 | 0 |
| SF 0.5 | 14.4 | 0.023 |
| SF 1.0 | 28.8 | 0.046 |
| SF 1.5 | 43.2 | 0.069 |

**Table 3.6:** Forta Ferro Fibers contents in concrete per cubic meter

| % Volume of Forta Ferro Fibers | Forta Ferro $Kg/m^3$ | Forta Ferro Kg/beam |
|---|---|---|
| FF 0.5 | 1.63 | 0.0026 |
| FF 1.0 | 3.27 | 0.0052 |
| FF 1.5 | 4.91 | 0.0078 |

### 3.5 - Mixing procedures

1) Added cement, aggregate, sand and 50% of fibers in the mixer pan, and mixing for 2 minutes **See Figure (3.8)**
2) Added water to the dry materials, slowly for 1 minutes.
3) Mixing for minimum 5 min, during the mixing added remained fiber.
4) After final mixing, the mixer is stopped, turned up with its end right down, and the fresh homogeneous concrete is poured into a clean plastic pan.
5) All specimens were cast and covered to prevent evaporation.

**Figure 3.8:** The drum mixer

## 3.6 Equipment and Test Specimens

### 3.6.1 Workability and Slump test

The slump test is used to determine the workability of concrete based on **(ASTM C143, 2004)**,. Slump of concrete was determined at the site for the different contents of forta ferro fibers, SF and all concrete mixes.


**Figure 3.9:** Slump cone

### 3.6.2 Compressive Strength Test

Twenty one cubic specimens of size 150 mm × 150 mm × 150 mm were cast for conducting compressive strength test, three for each percentage of steel & forta ferro fiber. The compressive strength test was based on **(**BS 1881, 2002**)** and was carried at the end of the 28 days of curing. The compressive strength of any mix was taken as the average strength of three cubes according the following procedure.

1. After preparing the required quantity, the mixing water was added to the coarse aggregate in the mixer and mixed for 3 minutes. Next, fine aggregate, cement and the rest of the mixing water were added while the mixer is running for additional 3 minutes, then the fibers were added to the mixture and mixed for an additional 3 minutes.

2. Emptying the concrete mixture from the mixer to a proper container.

3. After preparing the cubic molds of (15×15×15cm) and the specimens mold is filled with concrete in 3 stages and tamping for each layers.

4. Level the surface of the molds and clean its external surface.

5. Put the molds in a humid place for 24 hours, remove the cubic concrete from the molds and place them in a curing tank until the time of the compressive test. Figures (3.10) and (3.11) show photos of concrete specimens.

**Figure 3.10 :** Cube specimens

**Figure 3.11 :** Cubes at curing basin

The compressive strength of the specimen, $\sigma_{comp}$ (in MPa), is calculated by dividing the maximum load carried by the cube specimen during the test by the cross sectional area of the specimen **Figure (3.12).**

$$\boldsymbol{\sigma\ comp = \frac{P}{A}}$$

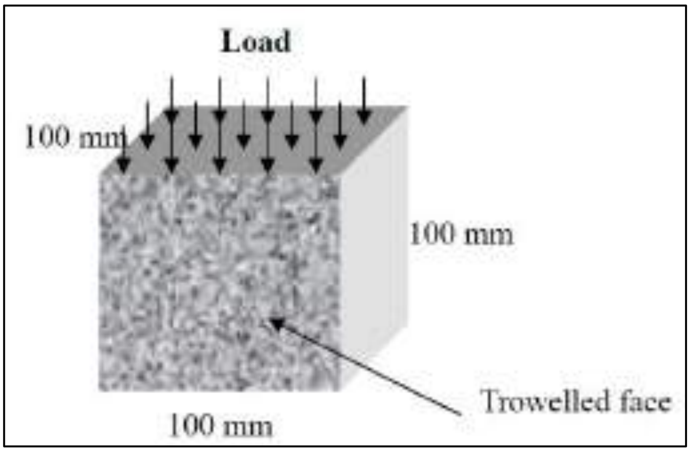


**Figure 3.12:** Force applied on the 100 mm cube

The compressive strength was determined at different ages 7, and 28 days. At least three of these cubes were tested for each period the mean value of the specimens was considered as the compressive strength of the experiment.

### 3.6.3 Split Tensile Strength Test

The tensile strength of the mix is judged in terms of split tensile strength. For this, twenty-one cylindrical specimens of size 150 mm in diameter and in height 300 mm were cast. three for each percentage of steel fiber & forta ferro fiber based on **(ASTM C496, 2004)**. The test was conducted at the end of 28 days of curing and the average of three samples was taken as the representative split tensile strength of the mix. Total number of 21 cylinders were manufactured. The splitting tensile strength of RPC was measured based on **ASTM C496-2004** Standard test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.

This test often referred to as the split cylinder test, indirectly measures the tensile strength of concrete by compressing a cylinder through a line load applied along its length. The failure of concrete in tension is governed by micro cracking, associated particularly with the interfacial region between the aggregate particles and the cement. The load applied (compressive force) on the cylindrical concrete specimen induces tensile and shear stresses on the aggregate particles inside the specimen, generating the bond failure between the aggregate particles and the cement paste. Usually, splitting tensile strength test is used to evaluate the shear resistance provided by concrete elements.

However, the most important advantage is that, when applying the splitting procedure, the tensile strengths are practically independent either of the test specimen or of the test machine sizes, being only a function of the concrete quality alone. Thus, much inconvenience is eliminated, particularly with respect to the scale coefficient, which is involved in direct tensile tests. For this reason, this procedure is considered to reproduce more exactly the real concrete tensile strength.

The tensile strength of concrete is evaluated using a split cylinder test, in which a cylindrical specimen is placed on its side and loaded in diametrical compression, so to induce transverse tension. Practically, the load applied on the cylindrical concrete specimen induces tensile stresses on the plane containing the load and relatively high compressive stresses in the area immediately around it.

When the cylinder is compressed by the two plane-parallel face plates, situated at two diametrically opposite points on the cylinder surface then, along the diameter passing through the two points, as shown in Figure 3.13, the major tensile stresses are developed which, at their limit, reach the fracture strength value **ASTM C496-2004** indicates that the maximum fracture strength can be calculated based on the following equation.

$$F_{sp} = \frac{2P}{\pi DL}$$

Where: **P** is the fracture compression force acting along the cylinder;

**D** is the cylinder diameter;

$\pi$ = 3.14;

**L** is the cylinder length.

The load and stress distribution pattern across the cross section if it is assumed that the load is concentrated at the tangent points then, over the cross section, only tensile stresses would be developed. In practice, however, the load is distributed over a finite width owing to material deformations. Therefore, over the cross section, horizontal compressive stresses are developed too, in the close vicinity of the contact point between the press platens and the material. Since the compressive stresses only develop to a small depth in the cross section, it may be assumed that the tensile stresses are distributed evenly along the diameter where the splitting takes place, the test set up and the illustrations of the test are shown in **Figure (3.13**) and **Figure (3.14).**

**Figure 3.13:** Split cylinder test setup for cylinder 150 x 300mm

This test can be completed in a standard concrete compression-testing machine, with only one special requirement: the bearing plates that load the specimen. Split cylinder tests were conducted on 6 x 12 in. (150 x 300mm) cylinders, tensile stress in the cylinder and the maximum tensile stress occur at the center of the cylinder.

All cylinder specimens were tested after 28 days from casting. Three cylinders were tested for each patch, the mean values of the specimens were considered as split cylinder strength.

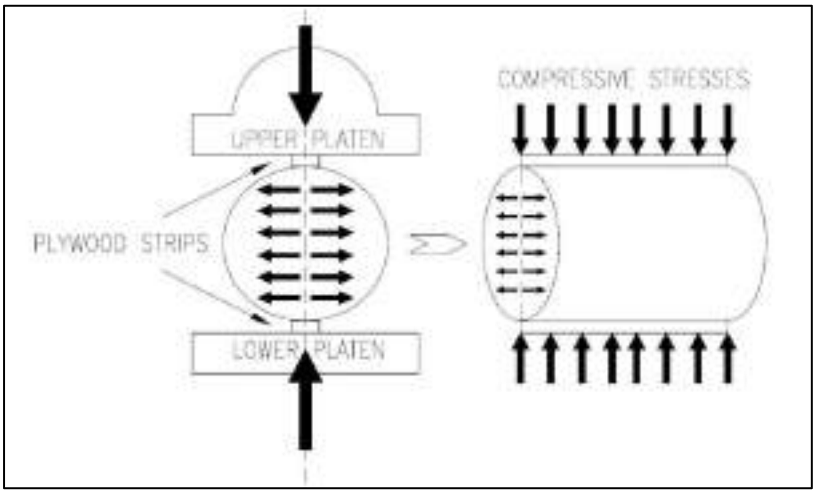


**Figure 3.14:** Force applied on cylinder

### 3.6.4 Drying Shrinkage

For the drying shrinkage test, 21 beams were cast to monitor the influence of incorporation the forta ferro and steel fiber in the concrete mix, each beams have a dimension 250 × 75 × 75 mm of concrete prism. The shrinkage measurement according **ASTM C157** and **ASTM C490**

**Figure 3.15:** VLT gauge datum discs

**ASTM C157** "Standard test Method for length change of hardened Hydraulic" is used to determine the shrinkage of concrete by the following steps

1- The beam dimension 250 mm X75mm X 75mm steel mold ( refer to ASTM C490 and ASTM C157 ). The mold shall be carefully hand worked around each gauge stud at the edge of mold.

**Figure 3.16 :** beam mold for shrinkage test75x75x250mm

2- Place the concrete in the mold in two approximately equal layers in accordance with the general instructions for placing concrete in specimens given in Practice C 192, with fixing two suds at the edge of beam.
3- Cure the test specimens in the molds in a moist cabinet or room in accordance with Specification C 511. Protect specimens from dripping water
**4-** Store the specimens in drying room with capacity to maintain temperature of 23,0 ±1.7 C and relative humidity of 50 ±4% , Horizontal drying room racks must allow for non-restricted air circulation around shrinkage specimens **(ASTM C157).**
5- Remove specimens from the molds at an age of 23± 1⁄2 h after the addition of water to the cement during the mixing operation, striking off the mold carefully specially around the gauge studs.
6- Immerse the samples in lime-saturated water maintained at 30 minutes, after that take the initial reading and take it as reference a dial gauge with reading 0.01mmx10mm **(ASTM C157).**
7- Fixed the two studs at the edges of beams on the studs of apparatus to measure the change in length according **(ASTM C490) as** initial reading**.**

**Figure (3.17):** Beam Shrinkage test Apparatus

8- After the initial comparator reading, store the specimens in lime-saturated water] until they have reached an age of 28 days, including the period in the molds. At the end of the curing period, make a second comparator reading after the specimens have been brought to a more closely controlled temperature as was done prior to the earlier reading and in the same manner described above, but in this research many comparator reading were taken in this period to see the behavior of drying shrinkage in the water.

9- Air Storage—Store the specimens in the drying room, so that the specimens have a clearance of at least 1 in. or 25 mm on all sides. Take comparator readings of each specimen after periods of air storage after curing of 4, 7, 14, and 28 days, and after 8, 16, 32, and 64 weeks. Preferably, take these readings in a room maintained at a relative humidity of 50 ±4 % while the specimens are at a temperature of 73 ±3°F [23 ±2°C].

- **Length Change Calculation**

  The pertinent value calculated from shrinkage test result is $\epsilon$ is the length change in percent (%) of specimen relative to specimen relative to the specimen initial 1 day reading

$$\epsilon = \frac{R - R1}{L}$$

  $\epsilon$: Length Change Sample in (mm)

  R: Final Reading

  R1: initial comparator reading of specimen minus comparator reading of reference bar at that same time; in millimeters

  L: Beam length, 250 mm

  Calculate length change values for each specimen to the nearest 0.001 % and report averages to the nearest 0.01 %.

- **Drying Shrinkage Apparatus**

  The instrument consists of a channeled base over which two vertical pillars are fixed. An adjustable cross plate in the top. A dial gauge in **Figure (3.17)** reading to 0.01mm x 10 mm, can be fixed to the top cross plate. The plunger end of the dial gauge can be located upon 6.5 mm diameter ball or other reference point cemented in the specimen. On the base there is similar recessed seating in which can be placed a second ball or reference point in the specimen. Completed with stainless steel standardization bar with insulated grip and 6.5 mm diameter. Balls mounted in the ends. Length comparator and reference bar **(refer to ASTM C 490)**

# CHAPTER 4:
# RESULTES AND DISCUTION

In this chapter, the results of the effect of the steel fibers and forta ferro on drying shrinkage, workability, compressive strength and splitting strength are discussed. Comparison between the control concrete and the fibers added concrete is presented.

## 4.1 Drying Shrinkage Results of Steel Fibers

The drying shrinkage for different contents of Steel fibers were measured for a period of four months using VLT dial gauge for length change measure. Three dosage of steel fiber are added 0.5%, 1.0% and 1.5% by total volume of concrete have been used to study drying shrinkage properties of concrete according ASTM C 157 Standard. Three beams of each fibers ratio are casted and the average of three test results is taken for more accurate results.

### 4.1.1 Steel Fibers Samples of 0.5% content.

The result of shrinkage in term of axial strain are presents in **Table 4.1**. **Table 4.1** includes the shrinkage of plain concrete and 0.5% fibrous concrete. These results are also drawn in **Figure 4.1**

The result of shrinkage of plain concrete and 0.5% steel fibrous concrete showed the following stages:

1- At first stage that the samples immerged in the lime water , the samples of plain concrete and 0.5% steel fibrous concrete starts to expand until reaching 253 micro strain and 239 micro strain respectively, the rate of expansion was increases with time until 28 days by as show in **Figure 4.1**

2- After 28 days the samples removed from the water and storage in drying room, the rate of shrinkage increased until reaching zero at 34 and 33 days for plain concrete and 0.5% fibrous concrete respectively, the rate of shrinkage continue was commenced increasing with linear relationship until reaching -250 micro strain for plain concrete and -220 micro strain for 0.5% fibrous concrete

3- The rate of shrinkage increased until reaching a permanent level of -415 and -395 micro strain for plain concrete and 0.5 % fibrous concrete by nonlinear relationship.

**Table 4.1**: Drying Shrinkage of 0.5%SF and Plain Concrete

| **Time (days)** | **Strain plain concrete (Micro strain)** | **Strain SF 0.5% (Micro strain)** |
|---|---|---|
| 1 | 40 | 36 |
| 3 | 144 | 131 |
| 7 | 195 | 172 |
| 10 | 220 | 198 |
| 14 | 235 | 219 |
| 20 | 245 | 223 |
| 25 | 250 | 231 |
| 28 | 253 | 239 |
| 29 | 124 | 110 |
| 32 | 23 | 10 |
| 35 | -89 | -80 |
| 38 | -169 | -158 |
| 42 | -241 | -221 |
| 45 | -305 | -263 |
| 50 | -342 | -294 |
| 57 | -368 | -331 |
| 62 | -389 | -351 |
| 75 | -401 | -369 |
| 90 | -408 | -381 |
| 105 | -412 | -388 |
| 120 | -415 | -395 |

It can be seen from the results in **Table 4.1** that the 0.5% fibrous concrete samples minimized the drying shrinkage 5.5% at lime water stage and 4.8% at drying stage because the interfacial bond strength between fibers and concrete component is greater than bond strength between the component in the concrete.

The above mention finding agree well with finding several studies such **Chern and Young (2000), Ramseyer (2006)**, **litvin (1985) and Victor et al. (2009))** that's showed the drying shrinkage of samples decrease nonlinearly and gradually shifts to a constant with increasing the steel fibers, also **litvin (1985)** reported in his study that steel fibers concrete with compressive strength of 21-30 MPa has 5% to 7% less shrinkage than its corresponding plain concrete without thermal shrinkage , but **Victor et al. (2009)** showed that the use of steel fibers and the application of thermal treatment decreased 14-day drying shrinkage by more than 57% and by 82% respectively

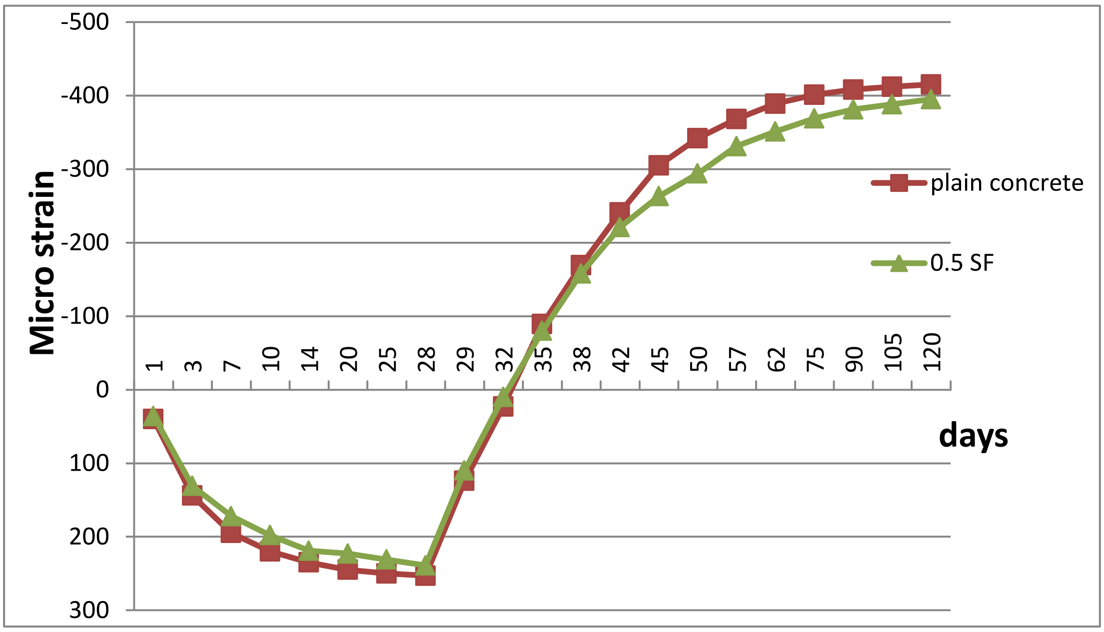


**Figure 4.1** : The effect of 0.5%SF on Drying shrinkage of concrete

### 4.1.2 1.0% of Steel Fibers Samples

The result of shrinkage in term of axial strain are presents in **Table 4.2**. **Table 4.2** includes the shrinkage of plain concrete and 0.5% fibrous concrete. These results are also drawn in **Figure 4.2.** The result of shrinkage of plain concrete and 1.0 % steel fibrous concrete showed the following:

At the first stage that the samples immerged in the limewater, the shrinkage of concrete started as concrete solidities and reached 253 and 228 micro strain for plain concrete and 1.0 % fibrous concrete respectively. The rate of expansion was increasing with time until 28 day as shown in **Figure 4.2**. After 28 days the samples removed from the water and stored in drying room, a recovery of the shrinkage of concrete commenced with a linear relationship until reaching -250 micro strain for plain concrete and -180-for1.0% fibrous concrete. Then the rate of shrinkage increased until reaching a permanent level of -415 and -369 micro strain for plain concrete and 1.0% fibrous concrete.

**Table 4.2**: Drying shrinkage of 1.0%SF and Plain Concrete

| Time (days) | Strain plain concrete (Micro strain) | Strain SF 1.0% (Micro strain) |
|---|---|---|
| 1 | 40 | 31 |
| 3 | 144 | 123 |
| 7 | 195 | 165 |
| 10 | 220 | 187 |
| 14 | 235 | 198 |
| 20 | 245 | 218 |
| 25 | 250 | 225 |
| 28 | 253 | 228 |
| 29 | 124 | 99 |
| 32 | 23 | -1 |
| 35 | -89 | -88 |
| 38 | -169 | -144 |
| 42 | -241 | -199 |
| 45 | -305 | -241 |
| 50 | -342 | -282 |
| 57 | -368 | -322 |
| 62 | -389 | -341 |
| 75 | -401 | -354 |
| 90 | -408 | -361 |
| 105 | -412 | -365 |
| 120 | -415 | -369 |

Its can be seen from the results in **Table 4.2** that the 1.0% fibrous concrete samples minimized the drying shrinkage 9.8% at lime water stage and 11.0% at drying stage because the interfacial bond strength between fibers and concrete component is greater than bond strength between the component in the concrete.

The above mention finding agree well with finding several studies such **Chern and Young (2000), Ramseyer (2006)**, **litvin (1985) and Victor et al. (2009))** that's showed the drying shrinkage of samples decrease nonlinearly and gradually shifts to a constant with increasing the steel fibers, also **litvin (1985)** reported in his study that steel fibers concrete with compressive strength of 21-30 MPa has 5% to 7% less shrinkage than its corresponding plain concrete without thermal shrinkage , but **Victor et al. (2009)** showed that the use of steel fibers and the application of thermal treatment decreased 14-day drying shrinkage by more than 57% and by 82% respectively

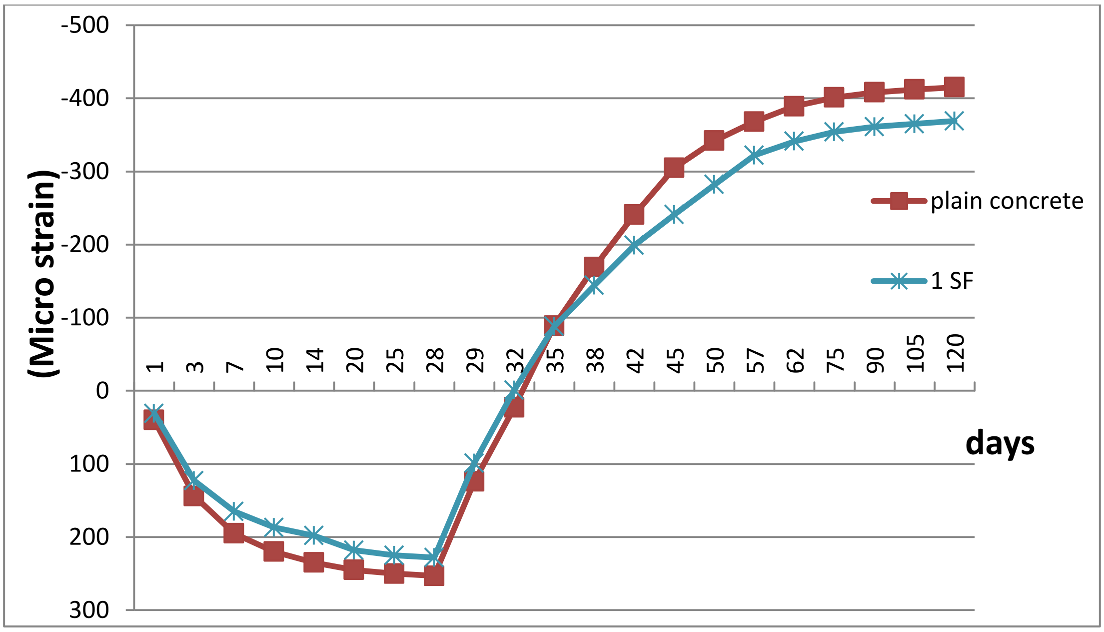


**Figure 4.2 :** The effect of 1.0%SF on Drying shrinkage of concrete .

### 4.1.3 1.5% of Steel Fibers Samples

The result of shrinkage in term of axial strain are presents in **Table 4.3**. **Table 4.3** includes the shrinkage of plain concrete and 0.5% fibrous concrete. These results are also drawn in **Figure 4.3**

The result of shrinkage of plain concrete and 1.0 % steel fibrous concrete showed the following stages:

1- At the stage that the samples immerged in the limewater, the shrinkage of concrete started as concrete solidities and reached 253 and 213 micro strain for plain concrete and 1.5 % fibrous concrete respectively. The rate of expansion was increasing with time as shown in **Figure 4.3**
2- After 28 days the samples removed from the water and storage in drying room, a recovery of the shrinkage of concrete commenced with a linear relationship until reaching -120 micro strain for 1.5% fibrous concrete.
3- The rate of shrinkage increased until reaching a permanent level of -415 and -347 micro strain for plain concrete and 1.5% fibrous concrete by nonlinear relationship.

Its can be seen from the results in **Table 4.3** that the 1.5% fibrous concrete samples minimized the drying shrinkage 15.8% at lime water stage and 16.3% at drying stage because the interfacial bond strength between fibers and concrete component is greater than bond strength between the component in the concrete.

The above mention finding agree well with finding several studies such **Chern and Young (2000), Ramseyer (2006)**, **litvin (1985) and Victor et al. (2009))** that's showed the drying shrinkage of samples decrease nonlinearly and gradually shifts to a constant with increasing the steel fibers, also **litvin (1985)** reported in his study that steel fibers concrete with compressive strength of 21-30 MPa has 5% to 7% less shrinkage than its corresponding plain concrete without thermal shrinkage , but **Victor et al. (2009)** showed that the use of steel fibers and the application of thermal treatment decreased 14-day drying shrinkage by more than 57% and by 82% respectively

**Table 4.3**: Drying shrinkage of 1.5%SF and Plain Concrete

| Time (days) | Strain plain concrete (Micro strain) | Strain SF 1.5% (Micro strain) |
|---|---|---|
| 1 | 40 | 26 |
| 3 | 144 | 115 |
| 7 | 195 | 154 |
| 10 | 220 | 175 |
| 14 | 235 | 184 |
| 20 | 245 | 197 |
| 25 | 250 | 208 |
| 28 | 253 | 213 |
| 29 | 124 | 82 |
| 32 | 23 | -11 |
| 35 | -89 | -76 |
| 38 | -169 | -125 |
| 42 | -241 | -187 |
| 45 | -305 | -235 |
| 50 | -342 | -268 |
| 57 | -368 | -297 |
| 62 | -389 | -318 |
| 75 | -401 | -330 |
| 90 | -408 | -342 |
| 105 | -412 | -345 |
| 120 | -415 | -347 |

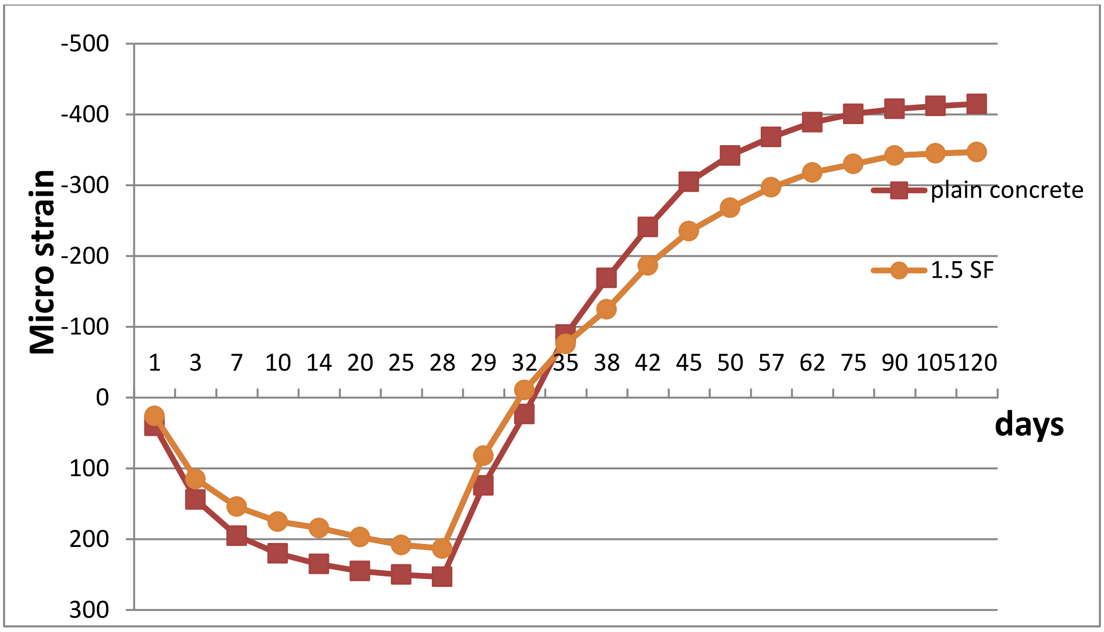


**Figure 4.3 :** The effect of 1.5%SF on Drying shrinkage of concrete

### 4.1.4 Comparison between Shrinkage of Plain Concrete and Steel Fibrous Concrete Samples.

A comparison between the drying shrinkage of plain concrete and 0.5%, 1.0% and 1.5% steel fibrous concrete sample is shown in **Table 4.4** and **Figure 4.4**. The result shown in **Table 4.4** and **Figure 4.4** that SF with 0.5% ,1% and 1.5 % decrease the drying shrinkage by 5.5% ,11% and 16.4% respectively, the results in **Figure (4.4)** show that the drying shrinkage decrease with increase the SF in Concrete.

At 1.5% SF content, the drying shrinkage decrease 16.4% in comparison with the control concrete mix. This finding agrees with the observation made by other researchers such as **Chern and Young (2000), Ramseyer (2006)**, **litvin (1985) and Victor et al. (2009))**

**Table 4.4:** Maximum Drying Shrinkage of SF

| ***Beams Type*** | ***Maximum Shrinkage (-) ( Micro Strain )*** | ***Maximum Shrinkage (+) (Micro Strain)*** | ***Increase in Strain (%)*** | ***Decrease in strain (%)*** |
|---|---|---|---|---|
| **Plain concrete** | -415 | 253 | | |
| **SF 0.5%** | -395 | 239 | 5.5% | 4.8% |
| **SF 1.0%** | -369 | 228 | 9.8% | 11.0% |
| **SF 1.5%** | -347 | 213 | 15.8% | 16.4% |

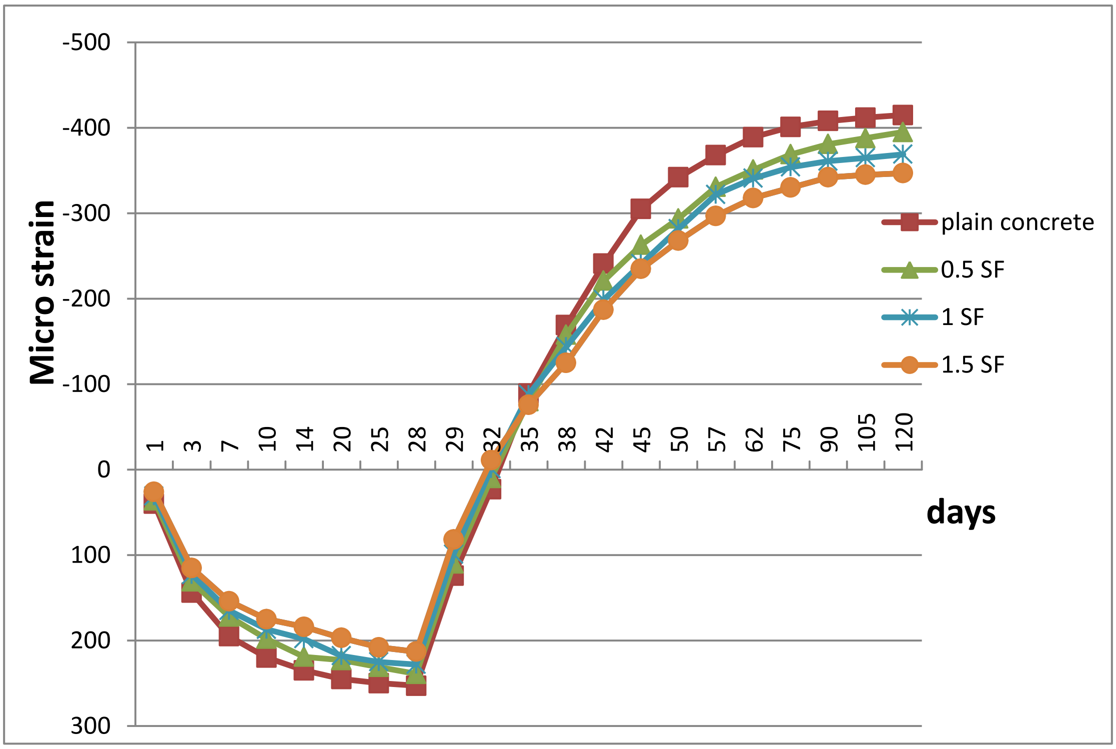


**Figure 4.4** : The effect of SF on drying shrinkage properties of concrete

## 4.2 Drying Shrinkage Results of Forta Ferro Fibers

The drying shrinkage for different contents of forta ferro fibers were measured for period of four months using VLT dial gauge for length change measure. Three dosage of FF fiber are added 0.5%, 1.0% and 1.5% by total volume of concrete have been used to study drying shrinkage properties of concrete according ASTM C 157 Standard. Three beams of each Fibers ratio are casted and the average of three test results is taken for more accurate results.

### 4.2.1 0.5% of Forta Ferro Fibers Samples

The result of shrinkage in term of axial strain are presents in **Table 4.5**. **Table 4.5** includes the shrinkage of plain concrete and 0.5% fibrous concrete. These results are also drawn in **Figure 4.5**

The result of shrinkage of plain concrete and 0.5 % forta ferro fibrous concrete showed the following stages:

1- At the stage that the samples immerged in the limewater, the shrinkage of concrete started as concrete solidities and reached 253 and 228 micro strain for plain concrete and 1.5% forta ferro fibrous concrete respectively. The rate of expansion was increasing with time as shown in **Figure 4.5**

2- After 28 days the samples removed from the water and storage in drying room, a recovery of the shrinkage of concrete commenced with a linear relationship until reaching -200 micro strain for 0.5% fibrous concrete and -250 for plain concrete.

3- The rate of shrinkage increased until reaching a permanent level of -415 and -335 micro strain for plain concrete and 1.5% fibrous concrete by nonlinear relationship.

It can be seen from the results in **Table 4.5** that the 0.5% fibrous concrete samples minimized the drying shrinkage 9.8% at lime water stage and 19.2% at drying stage because the interfacial bond strength between fibers and concrete component is greater than bond strength between the component in the concrete.

The above mention finding agree well with finding several studies such as **Kao (2005)** that's found that drying shrinkage was greatly reduced by the addition of fibers. Each fiber described a curve, the shrinkage decreased with increasing dosage of polypropylene fibers up to a point, and then increased as more fibers were added**. Zollo (1984))** that's reported in his study a 75% reduction in shrinkage of polypropylene reinforced concrete. **And Al-tayyib et al (1988)** reported that's the drying shrinkage of the polypropylene reinforced concrete with w/c ratio 0.45, 0.55 and 0.65 decreases 2%, 5% and 11% respectively, lower than its corresponding plain concrete mixes at the age of 70 days.

**Table 4.5**: Drying shrinkage of 0.5%FF and Plain Concrete

| Time (days) | Strain plain concrete (Micro strain) | Strain FF 0.5% (Micro strain) |
|---|---|---|
| 1 | 40 | 32 |
| 3 | 144 | 110 |
| 7 | 195 | 155 |
| 10 | 220 | 186 |
| 14 | 235 | 205 |
| 20 | 245 | 215 |
| 25 | 250 | 223 |
| 28 | 253 | 228 |
| 29 | 124 | 150 |
| 32 | 23 | 45 |
| 35 | -89 | -58 |
| 38 | -169 | -150 |
| 42 | -241 | -212 |
| 45 | -305 | -264 |
| 50 | -342 | -291 |
| 57 | -368 | -310 |
| 62 | -389 | -320 |
| 75 | -401 | -325 |
| 90 | -408 | -328 |
| 105 | -412 | -332 |
| 120 | -415 | -335 |

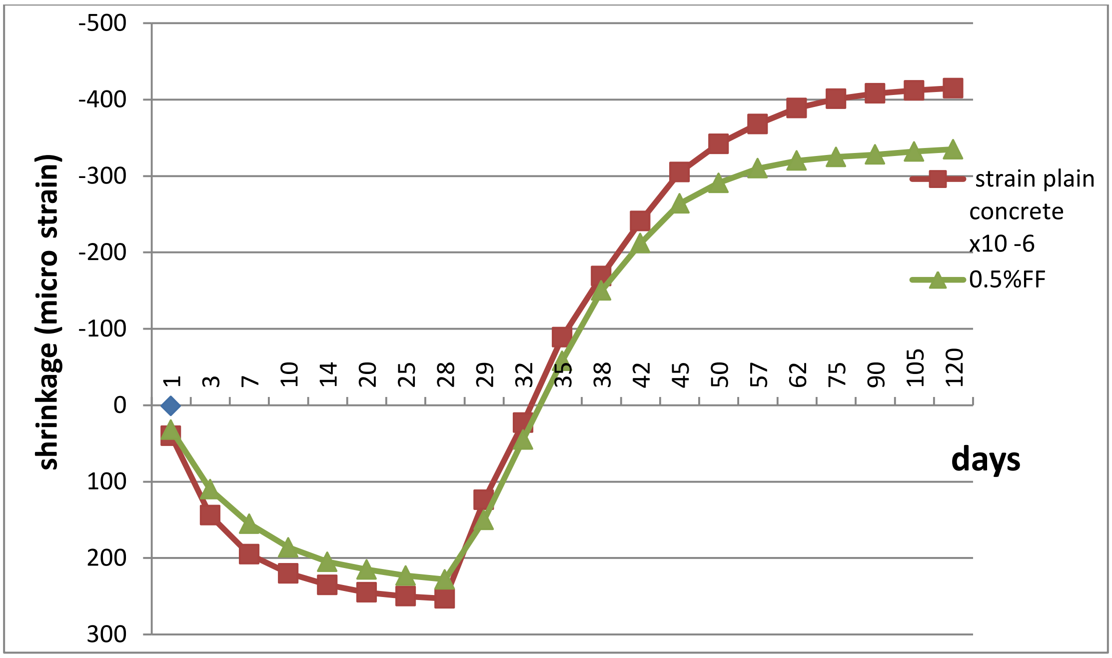


**Figure 4.5** : The effect of 0.5%FF on Drying shrinkage of concrete

### 4.2.2 1.0% of Forta Ferro Fibers Samples

The result of shrinkage in term of axial strain are presents in **Table 4.6**. **Table 4.6** includes the shrinkage of plain concrete and 1.0% FF fibrous concrete. These results are also drawn in **Figure 4.6**

The result of shrinkage of plain concrete and 1.0 % forta ferro fibrous concrete showed the following:

At the stage that the samples immerged in the limewater, the shrinkage of concrete started as concrete solidities and reached 253 and 182 micro strain for plain concrete and 1.0% forta ferro fibrous concrete respectively. The rate of expansion was increasing with time as shown in **Figure 4.6**.After 28 days the samples removed from the water and storage in drying room, a recovery of the shrinkage of concrete commenced with a linear relationship until reaching -250 and -100 micro strain for both plain concrete and 1.0% fibrous concrete respectively. Then the rate of shrinkage increased until reaching a permanent level of -415 and -256 micro strain for plain concrete and 1.5% FF fibrous concrete by nonlinear relationship.

**Table 4.6**: Drying shrinkage of 1.0%FF and Plain Concrete

| Time (days) | Strain plain concrete (Micro strain) | Strain FF 1.0% (Micro strain) |
|---|---|---|
| 1 | 40 | 10 |
| 3 | 144 | 70 |
| 7 | 195 | 111 |
| 10 | 220 | 141 |
| 14 | 235 | 162 |
| 20 | 245 | 171 |
| 25 | 250 | 178 |
| 28 | 253 | 182 |
| 29 | 124 | 111 |
| 32 | 23 | 32 |
| 35 | -89 | -43 |
| 38 | -169 | -102 |
| 42 | -241 | -145 |
| 45 | -305 | -176 |
| 50 | -342 | -207 |
| 57 | -368 | -220 |
| 62 | -389 | -235 |
| 75 | -401 | -246 |
| 90 | -408 | -250 |
| 105 | -412 | -253 |
| 120 | -415 | -256 |

It can be seen from the results in **Table 4.6** that the 1.0% fibrous concrete samples minimized the drying shrinkage 28.0% at lime water stage and 38.3% at drying stage because the interfacial bond strength between fibers and concrete component is greater than bond strength between the component in the concrete.

The above mention finding agree well with finding several studies such as **Kao (2005)** that's found that drying shrinkage was greatly reduced by the addition of fibers. Each fiber described a curve, the shrinkage decreased with increasing dosage of polypropylene fibers up to a point, and then increased as more fibers were added**. Zollo (1984))** that's reported in his study a 75% reduction in shrinkage of polypropylene reinforced concrete. **And Al-tayyib et al (1988)** reported that's the drying shrinkage of the polypropylene reinforced concrete with w/c ratio 0.45, 0.55 and 0.65 decreases 2%, 5% and 11% respectively, lower than its corresponding plain concrete mixes at the age of 70 days.

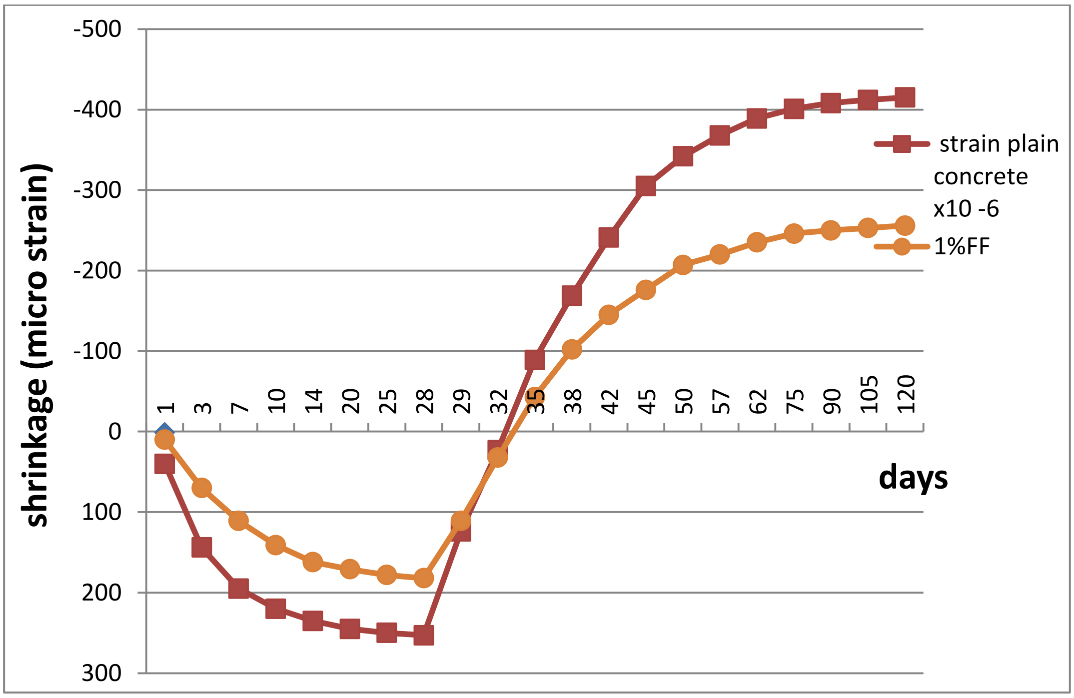


**Figure 4.6 :** The effect of 1.0%FF on Drying shrinkage of concrete .

### 4.2.3 1.5% of Forta Ferro Fibers Samples

The result of shrinkage in term of axial strain are presents in **Table 4.7. Table 4.7** includes the shrinkage of plain concrete and 1.5% FF fibrous concrete. These results are also drawn in **Figure 4.7**

The result of shrinkage of plain concrete and 1.0 % forta ferro fibrous concrete showed the following stages:

1- At the stage that the samples immerged in the limewater, the shrinkage of concrete started as concrete solidities and reached 253 and 208 micro strain for plain concrete and 1.0% forta ferro fibrous concrete respectively. The rate of expansion was increasing with time as shown in **Figure 4.7**
2- After 28 days the samples removed from the water and storage in drying room, a recovery of the shrinkage of concrete commenced with a linear relationship until reaching -250and -100 micro strain for both plain concrete and 1.5% FF fibrous concrete respectively.
3- The rate of shrinkage increased with nonlinear relationship until reaching a permanent level of -415 and -291 micro strain for plain concrete and 1.5% FF fibrous concrete.

Its can be seen from the results in **Table 4.7** that the 1.5% fibrous concrete samples minimized the drying shrinkage 17.7% at lime water stage and 29.8% at drying stage because the interfacial bond strength between fibers and concrete component is greater than bond strength between the component in the concrete.

The above mention finding agree well with finding several studies such as **Kao (2005)** that's found that drying shrinkage was greatly reduced by the addition of fibers. Each fiber described a curve, the shrinkage decreased with increasing dosage of polypropylene fibers up to a point, and then increased as more fibers were added**. Zollo (1984))** that's reported in his study a 75% reduction in shrinkage of polypropylene reinforced concrete. **And Al-tayyib et al (1988)** reported that's the drying shrinkage of the polypropylene reinforced concrete with w/c ratio 0.45, 0.55 and 0.65 decreases 2%, 5% and 11% respectively, lower than its corresponding plain concrete mixes at the age of 70 days.

**Table 4.7**: Drying shrinkage of 1.5%FF and Plain Concrete

| Time (days) | Strain plain concrete (Micro strain) | Strain FF 1.5% (Micro strain) |
|---|---|---|
| 1 | 40 | 21 |
| 3 | 144 | 95 |
| 17 | 195 | 132 |
| 10 | 220 | 165 |
| 14 | 235 | 184 |
| 20 | 245 | 195 |
| 25 | 250 | 202 |
| 28 | 253 | 208 |
| 29 | 124 | 132 |
| 32 | 23 | 41 |
| 35 | -89 | -51 |
| 38 | -169 | -122 |
| 42 | -241 | -173 |
| 45 | -305 | -213 |
| 50 | -342 | -244 |
| 57 | -368 | -264 |
| 62 | -389 | -275 |
| 75 | -401 | -282 |
| 90 | -408 | -286 |
| 105 | -412 | -289 |
| 120 | -415 | -291 |

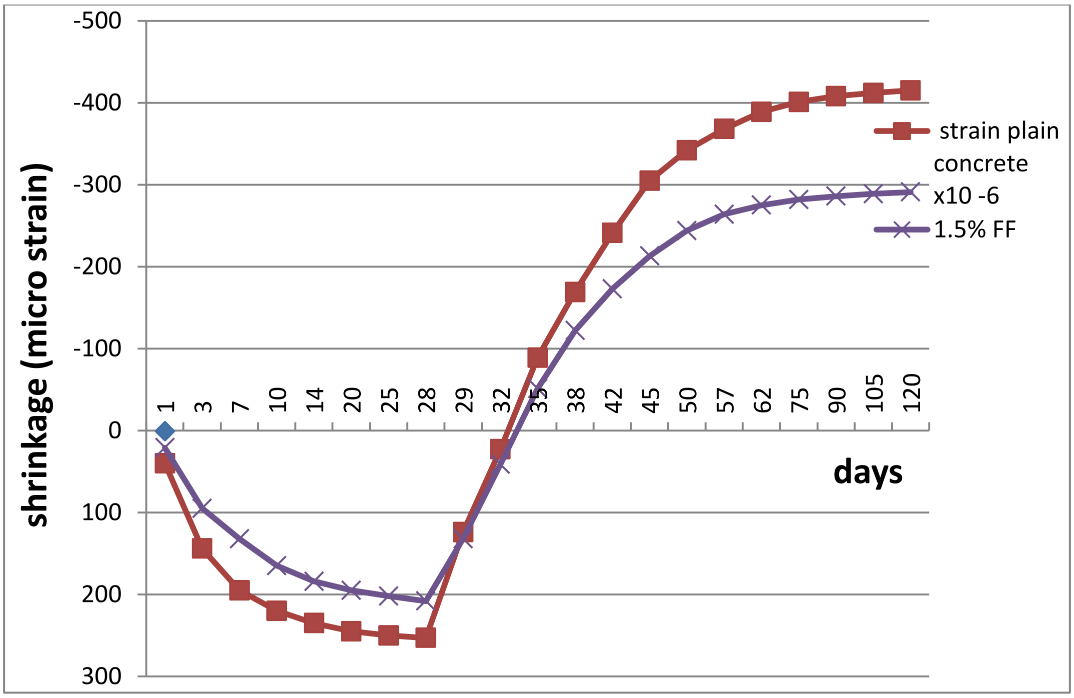


**Figure 4.7:** The effect of 1.5%FF on Drying shrinkage of concrete

### 4.2.4 Comparison between shrinkage of plain concrete and forta ferro fibrous concrete samples

A comparison between the drying shrinkage of plain concrete and 0.5%, 1.0% and 1.5% steel fibrous concrete sample is shown in **Table 4.8** and **Figure 4.8**, The result in **Table (4.8)** show that FF with 0.5%,1.0% and 1.5% decrease the drying shrinkage 19.2% ,38.31 and 29.8% respectively the result in **Figure (4.8)** show that the drying shrinkage decrease with increase the FF in Concrete.

At 1.0% FF content, the drying shrinkage decrease 38.31% in comparison with the control concrete mix. This finding agrees with the observation made by other researchers such as (**Kao (2005), Al-Tayyib et al , (1988) and Zollo (1984)**).

**Table 4.8:** Maximum drying shrinkage of FF

| *Beams Type* | *Maximum Shrinkage (-) ( Micro Strain )* | *Maximum Shrinkage (+) (Micro Strain)* | *Increase in Strain (%)* | *Decrease in strain (%)* |
|---|---|---|---|---|
| **Plain concrete** | -415 | 253 | | |
| **FF 0.5%** | -335 | 228 | 9.88% | 19.2% |
| **FF 1.0%** | -256 | 182 | 28% | 38.31% |
| **FF 1.5%** | -291 | 208 | 17.7% | 29.8% |

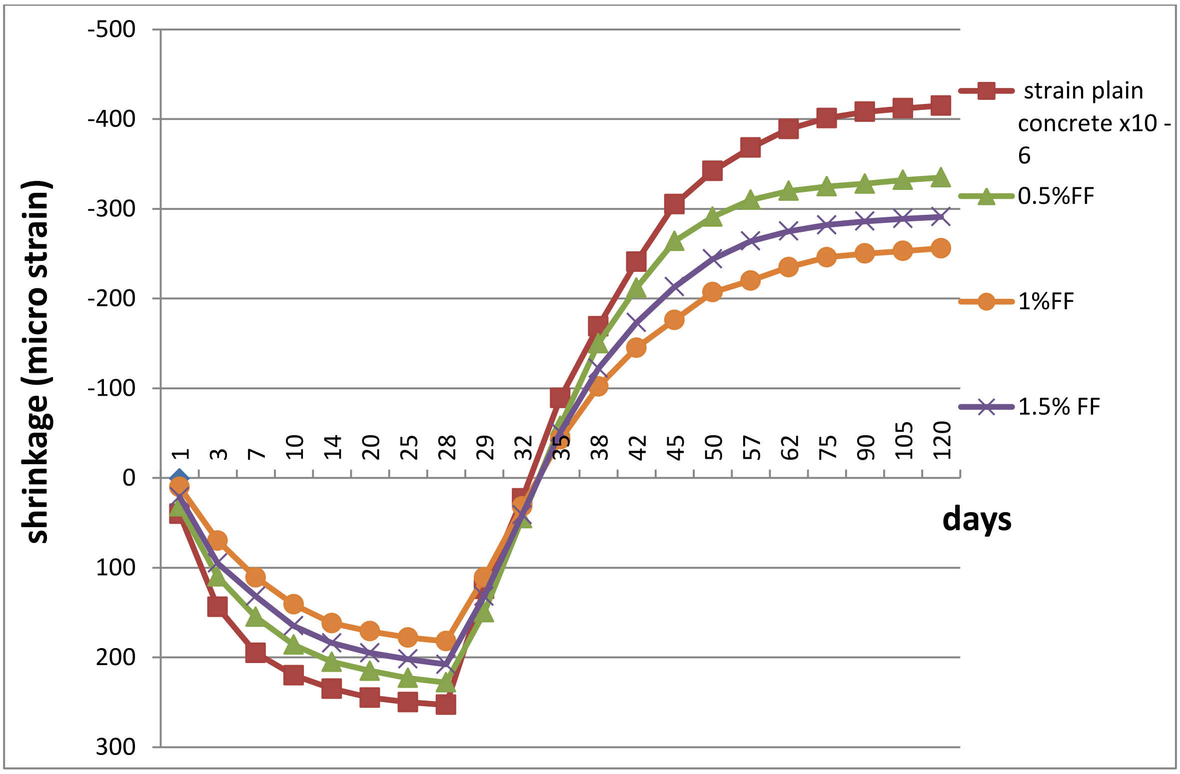


**Figure 4.8** : The effect of FF on drying shrinkage properties of concrete

## 4.3 Maximum Shrinkage of Forta Ferro and Steel Fibers

From the above test of drying shrinkage. Certain percentages of FF and SF that reduce the drying shrinkage far better than the plain concrete. Three dosage of SF and FF are added 0.5%,1%and 1.5% by total volume of concrete have been used to study drying shrinkage properties of concrete according ASTM C 157 Standard, **Table(4.9)** Shows that 1.5% is the optimum percentage of SF in concrete , it decreases the drying shrinkage about 16.4% , Also 1% is the optimum percentage of FF , it decreases the drying shrinkage about 38.31%

**Table 4.9:** Maximum drying shrinkage of FF and SF

| ***Beams Type*** | ***Maximum Shrinkage (-) ( Micro Strain )*** | ***Maximum Shrinkage (+) (Micro Strain)*** | ***Increase in Strain (%)*** | ***Decrease in strain (%)*** |
|---|---|---|---|---|
| **Plain concrete** | -415 | 253 | | |
| **SF 0.5%** | -395 | 239 | 5.5% | 4.8% |
| **SF 1.0%** | -369 | 228 | 9.8% | 11.0% |
| **SF 1.5%** | -347 | 213 | 15.8% | 16.4% |
| **FF 0.5%** | -335 | 228 | 9.88% | 19.2% |
| **FF 1.0%** | -256 | 182 | 28% | 38.31% |
| **FF 1.5%** | -291 | 208 | 17.7% | 29.8% |

**Table(4.9)** Shows that 1.5% is the optimum percentage of SF in concrete , it decreases the drying shrinkage about 16.4% , Also 1% is the optimum percentage of FF , it decreases the drying shrinkage about 38.91%

The result observe that FF is better than SF for reducing the drying shrinkage of concrete , This finding agrees with the observation made by other researchers such as (**Kao (2005), Al-**

**Tayyib et al, (1988), Zollo (1984) Chern and Young (2000), Ramseyer (2006), litvin (1985) and Victor et al. (2009))**

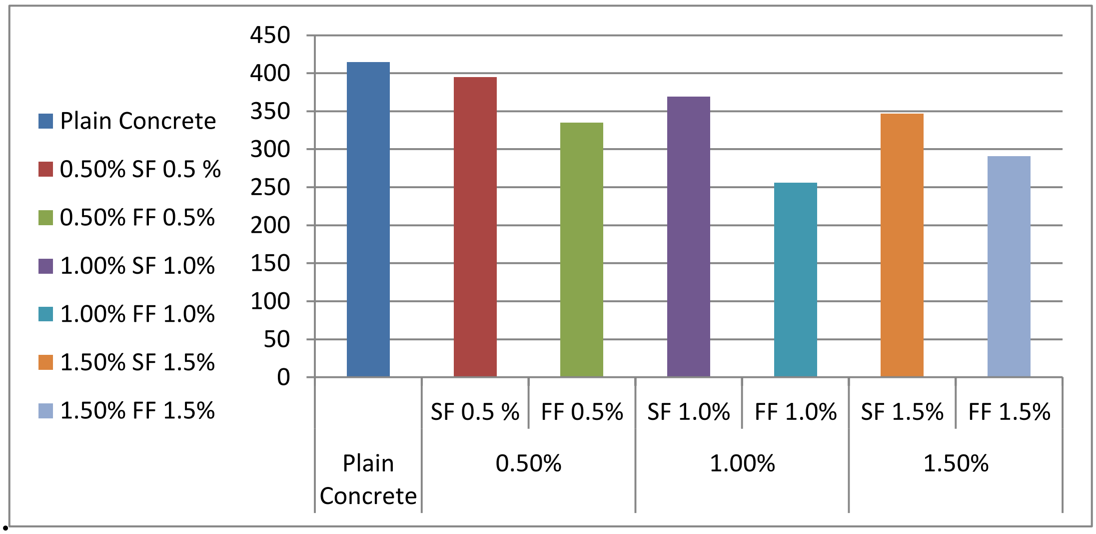


**Figure 4.9** : Maximum drying shrinkage of FF and SF

## 4.4 Fresh properties

### 4.4.1 Slump Results

The Slump result for different contents of steel fibers and forta ferro fibers were tested according ASTM C143.The steel fibers and forta ferro fibers ratios were taken as 0%, 0.5%, 1% and1.5% (by total volume).

In addition, the slump values for the different contents of steel fibers and forta ferro are recorded as shown in **Table (4.10)**. The relationship between slump values and Steel and forta ferro fibers contents are shown in **Figure (4.10)**. It is noticed that with the addition of Steel fibers slump values are reduced. However, the mixes used are still workable. For SF 0.5% samples, the slump is reduced by 16% and at SF 1.5% the slump is reduced by 35% compared with plain concrete slump. In addition, It is noticed that with the addition of forta ferro fibers slump values are reduced. However, the mixes used are still workable for 0.5% and 1% but it's not workable at 1.5% .For FF 0.5% and FF 1.0%, the slump is reduced by

20%, 36% respectively and at FF 1.5 the slump is reduced by 46 % compared with plain concrete slump.

**Table 4.10:** Slump test of plain concrete and fibrous concrete.

| ***% OF (F)*** | ***SLUMP (cm)*** |
|---|---|
| SF 0.0 | 12 |
| SF 0.5 | 10.1 |
| SF 1.0 | 8.6 |
| SF 1.5 | 7.8 |
| FF 0.5 | 9.5 |
| FF 1.0 | 7.6 |
| FF 1.5 | 6.5 |

This reduction could be associated to the friction development between steel fiber surface and concrete constituent. This finding agrees with previous research work, such as **(Hannat,(1978), Swamy (1974), Ramakrishanan (1988), Faisal (1990) and Kao(2005)).**

Also this reduction could be associated to the friction development between FF fiber surface and concrete constituent and irregular shape of FF fibers. This finding agrees with previous research work, such as **(Knapton (2003),Balaguru and Khajuria (1996)).** From **Figure (4.10)** The result show that SF is more workable than FF

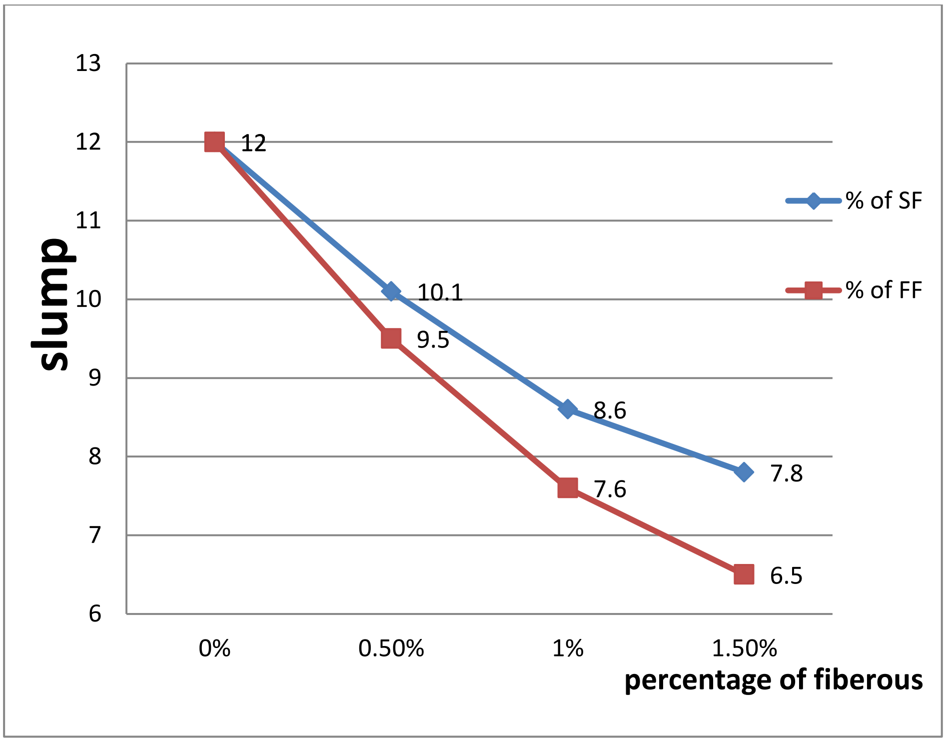


**Figure 4.10:** Effect of percentage of fibrous content on Slump

## 4.5 Hardened properties

### 4.5.1 Compressive Strength Results

The compressive strength for different contents of steel fibers and forta ferro fibers were tested at the end of 28 days using compressive strength testing machine. The Steel Fibers and Forta Ferro Fibers ratios were taken as 0%, 0.5%, 1% and1.5%. Three cubes of each Fibers ratio are casted and the average of three test results is taken for more accurate results. The values of the compressive strength of concrete samples with steel fiber and forta ferro fibers are presented in **Table (4.11)**.Also, the relationship between compressive strength, steel fiber and forta ferro fibers content is shown in **Figure (4.11)**.

It is observed from **Figure (4.11)** that the addition of steel fibers has a positive impact on compressive strength of concrete, with the increasing of the Steel Fibers content. When the steel fibers content increases, the compressive strength increases also. Compressive strength increase at the 28 days by about 2.1%, 6.6% and 13% at steel fiber content (by the total volume) 0.5%, 1.0% and 1.5 % with respect plain concrete. At SF 1.5% content, the compressive strength increase 13% in comparison with the control concrete mix.

Also it is observed from **Figure (4.11)** that the addition of forta ferro fibers have positive impact on compressive strength of concrete, with the increasing of forta Ferro fibers content. When the forta Ferro fibers content increases, the compressive strength increases also. Compressive strength increases at the 28 days by about 2.1%, 4.3% and 5.9% at FF fibers content (by total volume) 0.5%, 1.0% and 1.5% with respect plain concrete. At 1.5% FF content, the compressive strength increase 5.9% in comparison with the control concrete mix.

Steel fibers play an important role in enhancing compressive strength of concrete. This rising of compressive strength is related to the increase in the adhesive strength between SF and the cement paste. This finding agrees with the observation made by other researchers such **(Amir et al (2002), Shendet et al (2012)**

This rising of compressive strength is related to the increase in the adhesive strength between FF and the cement paste. Forta ferro fibers play an important role in enhancing strength of concrete. This finding agrees with the observation made by other researchers such as **(Aulia (2002), knapton, (2003), Al Massri et al (2012)).**

Its observe from **Figure (4.11)** the Steel fiber is more effect than forta ferro fibers at the compressive strength of concrete. This finding agree with previous researches such as **(Aulia (2002), Knapton(2003), Al Massri et al (2012), Amir et al (2002), Shendet et al (2012))**.

**Table 4.11**: Compressive strength of plain concrete and fibrous concrete

| % of Fibers | No. of Samples | Compressive Stress ( $kg/cm^2$ ) | Average Compressive Stress ($kg/cm^2$) |
|---|---|---|---|
| **F 0.0** | 1 | 255.6 | 258.3 |
| | 2 | 261.2 | |
| | 3 | 258.8 | |
| SF 0.5 | 1 | 267.4 | 267.1 |
| | 2 | 270.4 | |
| | 3 | 263.7 | |
| **SF 1.0** | 1 | 278.5 | 275.4 |
| | 2 | 270.4 | |
| | 3 | 277.5 | |
| **SF 1.5** | 1 | 291.7 | 291.9 |
| | 2 | 288.4 | |
| | 3 | 295.6 | |
| **FF 0.5** | 1 | 265.2 | 263.73 |
| | 2 | 295.3 | |
| | 3 | 266.7 | |
| **FF 1.0** | 1 | 269.5 | 269.53 |
| | 2 | 273.4 | |
| | 3 | 265.7 | |
| **FF 1.5** | 1 | 273.1 | 273.73 |
| | 2 | 276.5 | |
| | 3 | 271.6 | |

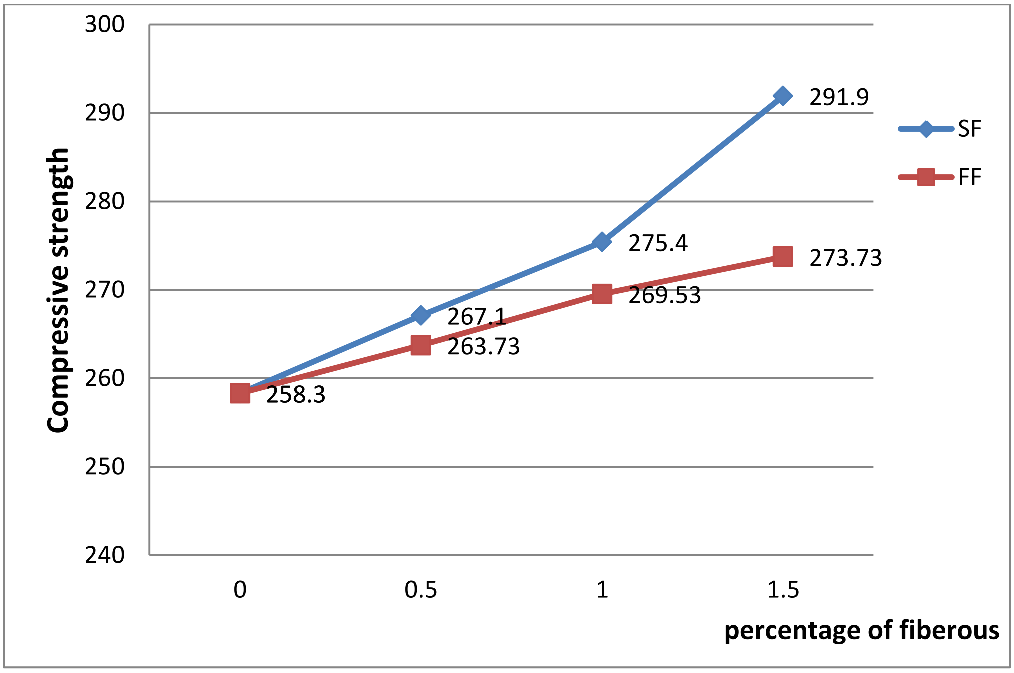


**Figure 4.11:** The effect of fibrous on Compressive Strength of Concrete

### 4.5.2 Spiltting Strength Results

The splitting strength for different contents of steel fibers and forta ferro fibers were tested at the end of 28 days cylinders split tensile test machine. The steel fibers and forta ferro Fibers ratios were taken as 0%, 0.5%, 1% and1.5%. Three cylindrical specimens of each Fibers ratio are casted and the average of three test results is taken for more accurate results.

The values of the splitting strength are presented in **Table (4.12).** In addition, the relationship between splitting strength, Steel and forta ferro fiber content is shown in **Figure (4.12)**. It is observed from **Figure (4.12)** that the addition of steel fibers has a positive impact on splitting strength of concrete, with the increasing of the steel fibers content. When the steel fibers content increases, the splitting strength increases also. Splitting strength increase at the 28 days by about 6%, 20.8% and 35.5 % at steel fiber content (by the total volume) 0.5%, 1.0% and 1.5 % with respect plain concrete, also it is observed from **Figure (4.12)** that the addition of forta ferro fibers has a positive impact on splitting strength of concrete, with the increasing of the forta ferro fibers content. When the forta ferro fibers content increases, the compressive strength increases also. Compressive strength increase at the 28 days by about 3.9%, 10.4% and 19.9% at FF fiber content (by the total volume) 0.5%, 1.0% and 1.5 % with respect plain.

**Table 4.12:** Splitting Strength of plain and fibrous concretes specimens.

| % of Fibers | No. of Sample | Tensile Stress (kg/cm$^2$) | Average Tensile Stress (kg/cm$^2$) |
|---|---|---|---|
| SF 0.0% | 1 | 27.4 | 25.86 |
| | 2 | 26.7 | |
| | 3 | 23.5 | |
| SF 0.5 | 1 | 28.42 | 27.42 |
| | 2 | 26.51 | |
| | 3 | 27.35 | |
| SF 1.0 | 1 | 31.56 | 31.25 |
| | 2 | 32.24 | |
| | 3 | 29.96 | |
| SF 1.5 | 1 | 36.83 | 35.12 |
| | 2 | 34.25 | |
| | 3 | 34.28 | |
| FF 0.5 | 1 | 26.7 | 26.89 |
| | 2 | 27.1 | |
| | 3 | 26.87 | |
| FF 1.0 | 1 | 27.95 | 28.56 |
| | 2 | 27.83 | |
| | 3 | 29.89 | |
| FF 1.5 | 1 | 31.73 | 31.02 |
| | 2 | 30.57 | |
| | 3 | 30.77 | |

At 1.5% SF content, the splitting strength increase 36% in comparison with the control concrete mix. This finding agrees with the observation made by other researchers such as **(Shedat et al( 2012), Faisal (1990) and Amir et al (2002)).**

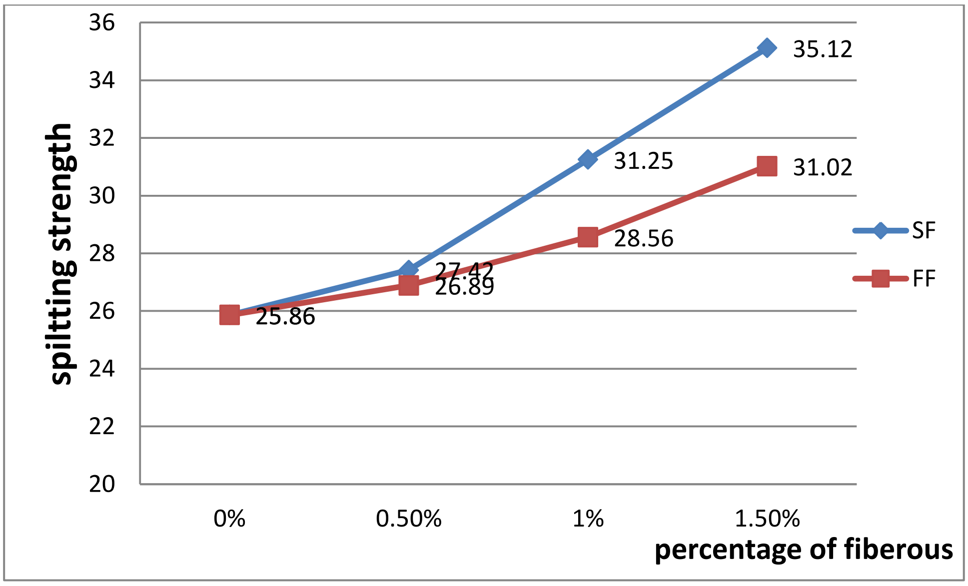


**Figure 4.12:** The effect of fibrous on splitting strength of concrete

At 1.5% FF content, the splitting strength increase 20% in comparison with the control concrete mix. This finding agrees with the observation made by other researchers such as **(Al Massri et al,. (2012) and Li (2002)).**

Also its observe from **Figure (4.12)** the Steel fiber is more effect than Forta Ferro Fibers at the splitting strength of concrete. This finding agree with previous research's such as **(Al Massri et al., (2012), Faisal (1990), Li (2002), Shedat et al. (2012) and Amir (2002).**

# Chapter (5)

# Conclusions and Recommendations

## 5.1.1 Generals

In addition to the effect of the fibers on the drying shrinkage properties of concrete mixes, the workability and hardened properties compressive strength and splitting strength were studied. Two types of fibers steel fibers and polypropylene fibers with different contents were added to the concrete and compared with the control mix. Based on the limited experimental work carried out in this study,

### 5.1.1 Drying Shrinkage of concrete

1- Steel Fibers with 0.5% ,1% and 1.5% (by total volume ) decreases the drying shrinkage 5.5% ,11%and 16.4% respectively. The result show that the drying shrinkage decrease with increase the SF in Concrete because bond interaction between fibers and cement base.

2- Forta Ferro Fibers with 0.5%,1% and1.5%(by total volume) decreases the drying shrinkage 19.2% ,38.31% and 29.8% respectively. The result show that the drying shrinkage decrease 38.31 % at 1.0% FF dosage because the friction bond between cement base and FF. However, at 1.5 % drying shrinkage increase from 38.31% to 29.8%.

## 5.1.2 Fresh properties

1) Increasing Forta Ferro content will slightly decrease the slump value of the reference concrete , the slump value decrease about 21% ,36% and 46% at 0.5% , 1% and 1.5% at 0.5 w/c ratio.

2) Increasing steel fiber content will slightly decrease the slump value of the reference concrete , the slump value decrease about 16% ,28 % and35% at 0.5% , 1% and 1.5% at 0.5 w/c ratio , at 1.5% of FF the slump value indicate that the mix are not good workable (6.5 mm)

### 5.1.3 Hardened properties

- **Compressive strength of concrete**

1) When the steel fibers content increases, the compressive strength increases also. compressive strength increase at the 28 days by about 3.4%, 6.6% and 13% at steel fiber content (by the total volume) 0.5%, 1.0% and 1.5 % with respect plain concrete
2) When the Forta Ferro fibers content increases, the compressive strength increases also. compressive strength increase at the 28 days by about 2.1%, 4.3% and 5.9% at FF fiber content (by the total volume) 0.5%, 1.0% and 1.5 % with respect plain concrete

- **Splitting tensile strength of concrete**

1- When the steel fibers content increases, the splitting strength increases also. Splitting strength increase at the 28 days by about 6%, 20.8% and 35.5 % at steel fiber content (by the total volume) 0.5%, 1.0% and 1.5 % with respect plain concrete

**2-** When the Forta Ferro fibers content increases, the compressive strength increases also. Compressive strength increase at the 28 days by about 3.9%, 10.4% and 19.9% at FF fiber content (by the total volume) 0.5%, 1.0% and 1.5 % with respect plain concrete.

## 5.2 Recommendations for future research

Having carrying out this study several suggested for further research can be summarized as follows:

1) The effect of FF and SF on the durability of concrete.
2) The effect of FF and SF on the drying shrinkage properties on UHPC and RPC with different temperature condition.
3) The effect of FF and SF on the permeability of normal concrete , UHPC and RPC
4) The effect of FF and SF on drying shrinkage of normal concrete , UHPC and RPC at the site with thermal effect

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