تأثير بعض المضافات المعدنية الدقيقة التجزئة على انكماش الجفاف للجسور الخرسانية

المقيدة النهايات

كجزء من متطلبات نيل درجة

الماجستير في علوم الهندسة المدنية

من قبل

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EFFECT OF *some finely divided mineral admixtures on drying shrinkage of end restrained*

concrete beams

Submitted to the College of Engineering of the University of Babylon in Partial   Fulfillment of the Requirements   for the Degree of Master   of Science in Civil   Engineering

By

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

((هُوَ الَّذِي بَعَثَ فِي الْأُمِّيِّينَ رَسُولًا مِنْهُمْ يَتْلُو عَلَيْهِمْ آيَاتِهِ وَيُزَكِّيهِمْ وَيُعَلِّمُهُمُ الْكِتَابَ وَالْحِكْمَةَ وَإِنْ كَانُوا مِنْ قَبْلُ لَفِي ضَلَالٍ مُبِينٍ))

صدق الله العظيم

سورة الجمعة (الآية ٢)

Abstract

This investigation is conducted to study the effects of adding finely divided mineral admixtures on drying shrinkage strain of free and end restrained concrete beams.

End restrained steel moulds having a channel section were used to study restrained shrinkage cracking, these moulds concrete specimens with different mixes were cast and exposed to laboratory drying conditions to measure the free and restrained shrinkage strain. Specimens of compressive strength, splitting tensile strength, flexural strength, density, rebound number and static modulus of elasticity measurement were cast and tested.

Three local admixtures of finely divided mineral admixtures (FDMA) were used which are lime stone dust (LSD), Silica flour (SF) and bentonite (Bt). Three levels of addition were used for each type, (١.٥٪, ٣٪ and ٤٪ by weight of cement) for (LSD), (٢.٥٪, ٥٪ and ٨٪ by weight of cement) for (SF) admixture and (٢.٥٪, ٤.٥٪ and ٦٪ by weight of cement) for bentonite admixture .

The experimental results illustrate that the development of free shrinkage is affected by the type and amount of admixture addition.

For concrete specimens with different levels of (LSD), the free shrinkage strain decreased at early and later ages. The higher reduction was about (٢٢٪) at level (٣٪) at (١٣٠) days drying period, while no noticeable effect was observed in free shrinkage strain with (SF) at all

ages but it increased significantly with (Bt) addition, especially with level (٦٪) at later ages. The increment was about

(٢٧%) at (١٣٠) days drying period , while no evident effect was observed in the early ages.

It was observed that the increase of content of any admixture used leads to a decrease in cracking time, crack width and creep strain at (cracking time). The tensile strain capacity and elastic tensile strain at (cracking time) were decreased except that with bentonite of the level (٦٪) .

Based on the results obtained, it can be concluded that the increase of content of adding admixtures leads to increase in compressive strength , especially with bentonite (Bt) at level (٢.٥٪). The increment was about (١٦%) , but beyond this level (٢.٥٪) it starts to decrease until it becomes lower than that of the control mix by about (٤٪) with (٦٪) level. Other concrete properties including splitting tensile, flexural strength , modulus of elasticity, density and rebound number show trends similar to that observed in compressive strength.

Mathematical models for the prediction of some properties before and after addition some of finely divided mineral admixtures were developed in this study. Non-linear regression estimation is used to

evaluate good coefficient correlation with less difference between the observed value and predicted value (df) and with fewer variables introduced in them.

ACKNOWLEDGEMENT

I

الخلاصة

هذه الدراسة تهدف إلى دراسة تأثير إضافة المضافات المعدنية الدقيقة التجزئة على انكماش الجفاف للجسور الخرسانية المقيدة النهايات.

في هذه الدراسة تم استخدام قوالب تقييد حديدية ذات مقطع على شكل (حديد ساقية) لدراسة تشققات الانكماش المقيد، هذه القوالب تم صب نماذج كونكريتية مختلفة فيها (تشمل كل الخلطات المستخدمة وقد تعرضت للظروف المختبرية) لغرض تحديد أو قياس انفعال انكماش الجفاف الحر والمقيد، كما تم أيضا صب نماذج لتعيين مقاومة الانضغاط ومقاومة شد الانشطار ومقاومة الانثناء ومعامل المرونة والكثافة ورقم الارتداد.

تم استخدام ثلاثة أنواع محلية من المضافات المعدنية الدقيقة التجزئة (FDMA) والتي هي احد أنواع المواد المانعة لنفاذ الماء وهي (غبار الجير الحي LSD، مطحون السيليكا SF ، والبنتونايت Bt) ، لكل نوع من هذه الأنواع استخدمت ثلاث نسب مئوية من وزن السمنت (٪١.٥ ٪٤ , ٪٣ ,) للمضاف غبار الجير الحي (LSD)، وبنسب (٪٨ , ٪٥ , ٪٢.٥) للمضاف مطحون السيليكا (SF) والنسب المئوية (٪٦ , ٪٤.٥ , ٪٢.٥) للبنتونايت (Bt) .

أوضحت النتائج العملية ان تطور الانكماش الحر يتأثر بنوع وكمية المضاف المستخدم.

وأوضحت النتائج ان زيادة محتويات المضاف غبار الجير الحي (LSD) يقلل انفعال انكماش الجفاف الحر للخرسانة في الأعمار المبكرة والمتأخرة، وان أعلى نسبة انخفاض تقدر بحوالي (٪٢٢) عند نسبة إضافة (٪٣) وفترة جفاف (١٣٠) يوم، بينما لا تأثير واضح في انكماش

الجفاف الحر للخرسانة عند استخدام المضاف مطحون السيليكا (SF) وعند كل الأعمار. ولكنه يزداد بشكل فعال عند استخدام المضاف البنتونايت (Bt) وخصوصا عند نسبة إضافة (٦%) في الأعمار المتأخرة وان مقدار الزيادة هي حوالي (٢٧%) عند فترة الجفاف (١٣٠) يوم بينما لا تأثير واضح لانكماش الجفاف الحر في الأعمار المبكرة.

كما أوضحت النتائج، انّ زيادة محتوى أي مضاف يقلل من زمن حدوث التشقق، عرض الشق وانفعال الزحف عند (زمن حدوث التشقق)، كذلك إن سعة انفعال الشد وانفعال الشد المرن عند (زمن حدوث التشقق) ينقص باستثناء نسبة إضافة البنتونايت (٦%) .

كما انه واعتمادا على النتائج ، يمكن ان الاستنتاج ان زيادة محتوى أي مضاف يزيد من مقاومة انضغاط الخرسانة ، خصوصا عند نسبة إضافة البنتونايت (٢.٥%) ، وحيث ان مقدار الزيادة كان (١٥.٩%) ولكن عند تجاوز النسبة المئوية (٢.٥%) تبدأ مقاومة الانضغاط بالانخفاض حتى تصل عند النسبة المئوية (٦%) إلى اقل من مقاومة الانضغاط للخرسانة المرجعية بنقصان مقداره (٤%). وقد حذت الخواص الأخرى من مقاومة الشد ومقاومة الانثناء ومعامل المرونة والكثافة ورقم الارتداد نفس ما حذته خاصية مقاومة الانضغاط.

تم استخدام موديلات رياضية لغرض استخراج بعض الخواص الميكانيكية للخرسانة قبل وبعد إضافة بعض المضافات المعدنية الدقيقة التجزئة (FDMA)، تعتمد على معادلات غير خطية متعددة المتغيرات للحصول على قيم تخمينية استخدمت لايجاد معامل ارتباط جيد (R) بين هذه الخواص باستخدام بعض المعلومات عن الخواص الميكانيكية للخرسانة قبل إضافة المضافات المعدنية الدقيقة التجزئة (FDMA) إليها ومع اقل اختلاف بين القيم الحقيقة والقيم المخمنة (df) لهذه الخواص وأقل متغيرات.

Certificate

We certify that the thesis entitled "**Effect of Some Finely Divided Mineral Admixtures on Drying Shrinkage of End Restrained Concrete Beams**" , was prepared by "*Basim Thabit Hamza*", under

our supervision at Babylon University in fulfillment of partial requirements for the degree of Master of Science in Civil Engineering .

Signature :

Name : Assist Prof. Dr. Mahdi S. Essa

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(Supervisor)

Certificate

      We certify that we have read the thesis entitled " **Effect of Some Finely Divided Mineral Admixtures on Drying Shrinkage of End Restrained Concrete Beams** " and as an examining committee, examined the student "*Basim Thabit Hamza*" in its content and in what is connected with it, and that in our opinion it meets the standard of thesis for the degree of Master of Science in Civil Engineering (Construction Materials)

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Date :

Approval of the Civil Engineering Department

Head of the Civil Engineering Department

Signature :

Name : Assist Prof. Dr. Ammar Y. Ali

Date :

Approval of the Deanery of college of Engineering

Dean of College of Engineering.

Signature :

Name : Assist Prof. Dr. Abdul Wahid K. Rajeh

Date :

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NOTATIONS

Most commonly symbols used are listed below. These and others are defined where they appear in the research.

Symbol	Description
Ac	Air content
Bt	Bentonite admixture
$BM_{2.5}$	Mix with Bentonite admixture (٢.٥٪ by weight of cement)
$BM_{4.5}$	Mix with Bentonite admixture (٤.٥٪ by weight of cement)
BM_6	Mix with Bentonite admixture (٦٪ by weight of cement)
CKD	Cement klin dust
CSH	Calcium silicate hydrate gel
Cc	Cement content
D_p	Drying period
D_f	Range of the difference between the actual and predicted shrinkage
E	Modulus of elasticity
FDMA	Finely divided mineral admixture
Frb	Flexural strength before addition of admixture
I.R	Insoluble residue
L.O.I.	Loss on Ignition
LSD	Limestone dust admixture
LSF	Lime saturation factor
$LM_{1.5}$	Mix with lime stone dust (١.٥٪ by weight of cement)
LM_3	Mix with lime stone dust (٣٪ by weight of cement)

Symbol	Description
LM$_\xi$	Mix with lime stone dust (ξ٪ by weight of cement)
OPC	Ordinary portland cement
R	Correlation coefficient
R.H.&H	Relative humidity
Ra	Percentage of admixture (by weight of cement)
Rn	Rebound number
Sha	Free drying shrinkage strain after addition admixture
Shb	Free drying shrinkage strain before addition admixture
S	Slump of fresh concrete
SF	Silica fume
SM$_{\Upsilon.\circ}$	Mix with silica fume ($\Upsilon.\circ$٪ by weight of cement)
SM$_\circ$	Mix with silica fume ($\circ$٪ by weight of cement)
SM$_\wedge$	Mix with silica fume ($\wedge$٪ by weight of cement)
SRA	Shrinkage reducing admixture
V/S	Volume to surface ratio
w/c	Water to cement ratio
p	Density of hardened concrete
μ	Micron

Experimental Data

Appendix ((A))

Table (A-١) : Physical Properties of the OPC Used

Physical Properties	Test Result	I.O.S.٥:١٩٨٤ [٧٦] Limits
Fineness, blaine , m²/kg	٣٣٣.٨٣	≥ ٢٣٠
Setting time, Vicat's method Initial hrs:min Final hrs:min	١:٣٠ ٢ : ٤٥	≥ ٠٠:٤٥ ≤ ١٠ : ٠٠
Compressive strength of ٧٠.٠ mm cube , MPa . ٣ days ٧ days	١٦.٨ ٢٧	≥ ١٥ ≥ ٢٣
Soundness % (Auto Clave) Method	٠.٥	≤ ٠.٨

Table (A-٢) : Chemical Composition of the OPC Used

Oxide	(%)	I.O.S.٥ : ١٩٨٤ [٧٦] limits
CaO	٦٠.٩	-
SiO₂	٢٠.٨٨	-
Al₂O₃	٥.٥٦	-
Fe₂O₃	٣.٣٦	-
MgO	٣.٧٥	≤ ٥ %
SO₃	٢.٦٣	≤ ٢.٨ %
Free lime	٠.٦٥	≤ ٤.٠ %
L.O.I	١.٨٦	≤ ٤ %
I.R (Insoluble Residue)	٠.٩٧	≤ ١.٥ %
Compound composition	(%)	I.O.S.٥ :١٩٨٤ [٧٦] limits
C₃S	٣٧.٧٢	-
C₂S	٣١.٧٢	-
C₃A	٩.٠٤	-
C₄AF	١٠.٢٢	-
L.S.F.	٠.٨٧	٠.٦٦ – ١.٠٢

Table (A-٣) : Properties of the Sand

Sieve size (mm)	Percent passing %	I.O.S.٤٥ : ١٩٨٤ [٧٧] limits
٩.٥	١٠٠	١٠٠
٤.٧٥	١٠٠	٩٠-١٠٠
٢.٣٦	٩٩.٨	٨٥-١٠٠
١.١٨	٨٢.٨	٧٥-١٠٠
٠.٦	٥٥.٤	٦٠-٧٤
٠.٣	١٤	١٢-٤٠
٠.١٥	٤	٠-١٠
Properties	**Test Results**	**I.O.S.٤٥:١٩٨٤ [٧٧] limits**
Sulphate content, SO$_3$ specific gravity Absorption (%)	% ٠.٤٣ ٢.٥٣ ١.٦١	≤ % ٠.٥ - -
Fineness modulus Impurities content	٢.٤ % ٢.٣	- ≤ % ٣

Table (A-٤) : Properties of Gravel

Sieve size (mm)	Percent passing %	I.O.S.٤٥:١٩٨٤ [٧٧] limits
٣٧.٥	١٠٠	
٢٠	١٠٠	١٠٠
١٢.٥	٩٧.٥	٩٠-١٠٠
٩.٥	٥٨	٥٠-٨٥
٤.٧٥	٤.٧١	٠-١٠
Properties	**Test results**	**I.O.S.٤٥:١٩٨٤ [٧٧] limits**
Sulphate content, SO$_3$, %	٠.٠٩	≤ ٠.١

Specific gravity	٢.٦١	-
Absorption	٠.٥٥	-
Impurities content %	٠.٦	$\leq ٪١$

CHAPTER ONE

INTRODUCTION

١.١ General

Concrete is generally used as a construction material because it can be formed into any shape man desires and it provides at sensible cost a material that can be designed to ensure high compressive strength. Its low tensile strain capacity in the main disadvantage of concrete, where concrete is considered as a brittle material and lacks ductility [١] .

In general, concrete cracks when there are tensile stresses exceeding in their magnitude its tensile strength. An understanding of the properties of concrete and its behaviors under field conditions, which resemble them, is necessary and important to analyze its drawbacks.

One of the major problems facing the engineers in Iraq and other countries in the Middle East is the higher drying shrinkage of concrete due to the weather conditions. This high drying shrinkage is considered as the main reason of concrete cracks. Concrete also exhibits certain undesirable properties such as relatively low tensile strength, reinforced concrete design methods generally do not consider concrete taking tensile stresses, cracking within certain limits belongs to the natural

behavior of concrete structure, and has no effect on the serviceability of the structure. However, when the cracks form a nucleus for progressive deterioration of the structure that impairs performance cracking prevention , control or repair becomes necessary [٢].

Reduction in moisture content of concrete cause drying shrinkage which is considered to be the principal volume change that may occur in concrete. This movement results in contraction of the concrete mass.

Restrained concrete movement usually leads to microcracks, especially in countries having hot weather. The restrained contraction (which is commonly present in practice) will induce tensile stresses in concrete, and when these stresses exceed the tensile strength or after alternatively the tensile strain capacity of concrete is exceeded, cracking will take place [٢].

Besides cement, aggregate and water(main concrete ingredients) , there is a trend to incorporate additional materials in concrete e.g. chemical admixtures, fibers and pozzolans to improve specific features and or to facilitate placing , conveying , compacting , finishing operations of concreting or to obtain desirable properties [٢].

The use of admixture has been growing up very rapidly through the previous years , and nowadays . Admixtures are used for different purposes all over the world .

Admixtures can be defined according to ACI committee ٢١٢ [٣] as materials other than cement, aggregate and water, added to concrete or

to cement paste before or after the mixing, to give the concrete mixes or past other features in their liquid, plastic state , setting , curing and hardened state . The British concrete code as reported by Berkovitch [٤] stated that admixtures may be used to produce a good mixture with economy.

١.٢ Objective of the Work

In the present work , an attempt is made to study the effect of some finely divided mineral admixture on free drying shrinkage and cracking of restrained concrete under natural weather conditions.

Furthermore, compressive strength, splitting tensile strength, flexural strength static modulus of elasticity , density and rebound number are determined.

The main variables used in this study are :

١- Type of admixture (there are three admixtures of finely divided mineral materials, (the first is Lime Stone Dust (LSD), the second is Silica Flour (SF), the third is Bentonite (Bt).

٢- The levels of additions are as follows[*] :

- Three levels of (LSD) admixture (١.٥٪, ٣٪, ٤٪ by weight of cement).

- Three levels of (SF) admixture (٢.٥٪, ٥٪, ٨٪ by weight of cement).

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[*] Previous researchers used this levels of admixtures to study its effects on concrete durability, so its were selected in this work to investigate of its effects on drying shrinkage of concrete.

- Three levels of (Bt) admixture (٢.٥٪, ٤.٥٪, ٦٪) by weight of cement).

١.٣ Research Layout :

The research work presented in this thesis is given through five chapters :

Chapter one provides a general introduction .

Chapter two "Literatures Review" introduces a definition of shrinkage, and the main factors influencing it. The previous literature including works on shrinkage, creep, tensile strain capacity and other important properties of concrete were discussed.

Chapter three consists the details of experimental work which includes a description of the moulds used to achieve shrinkage crack. Mixing , casting, curing and testing the specimens for shrinkage, compressive strength, modulus of elasticity, flexural strength, splitting tensile strength, density and rebound number are explained.

In chapter four the analysis and discussion of experimental work are presented.

Chapter five contains the conclusions and recommendations for further work.

CHAPTER TWO

LITERATURES REVIEW

٢.١ Shrinkage :

٢.١.١ General :

Shrinkage is one of the harmful property of concrete, especially in tropical region climates, because of most environmental conditions accelerate water evaporation from concrete, needless hydration concrete water, that is to say, free quantity of it evaporates through time. Concrete shrinks when it dries as a result of capillary tension which develops in the water remaining in concrete. Shrinkage may lead to detrimental stresses and often deleterious cracks in concrete when it is not controlled. That impairs concrete strength and durability and its designed function as well as the negative esthetic effects [٢].

Shrinkage cracking occurs when the tensile stresses due to restrained volume contraction exceed the tensile strength of concrete. Cracking in service depends on many factors, including shrinkage potential, degree of restraint , construction methods, and environmental conditions. Many researchers have performed laboratory studies to evaluate the shrinkage and cracking potential of concrete and cement – based materials [٥].

٢.١.٢ Mechanism of Concrete Shrinkage :

Concrete shrinks as it dries under normal atmospheric conditions. Tensile stresses develop when the concrete is prevented from shrinkage freely. The combination of high tensile stresses with the low fracture resistance of concrete often results in cracking. Cracks reduce load carrying capacity and accelerate deterioration, which reflects adversity on the maintenance costs and service life. Although free shrinkage measurements are useful in comparing different mixture compositions, they do not provide sufficient information to determine if the concrete will crack in service.

Cracking is a complex phenomenon, which is dependent on several factors including free shrinkage , age − dependent material property development, creep relaxation, shrinkage rate , and degree of restraint. Shrinkage can be divided into plastic shrinkage, drying shrinkage, carbonation shrinkage and autogenous shrinkage [١].

Water-related shrinkage is a volumetric change caused by the movement and the loss of water (i.e, change in the internal pore pressure caused by drying or self − desiccation). Drying is driven by the environmental conditions in which the relative humidity of the concrete structure strives to bring into balance with the humidity of the surrounding environment. Water is squeezed out from the capillary pores resulting in tensile stresses till humidity balance is occurred with lower environmental humidity. The cause of compressing the concrete matrix is the tensile stress that explains partially water − related shrinkage is the most significant in thinner structures (with large surface area to volume ratio) due to the more rapid loss of water. Pavements, Bridge decks, and

slabs are examples of thin structures that may be susceptible to drying shrinkage cracking [٧,٨,٩] .

٢.١.٢.١ Plastic Shrinkage :

Plastic shrinkage is a term reserved for freshly poured concrete. Plastic shrinkage occurs when water is allowed to evaporate from the fresh concrete surface. Environmental considerations including solar effects, wind speed, high temperature and low relative humidity drastically influence the potential of plastic shrinkage cracking [١٠]. Generally, plastic shrinkage cracking can be prevented by limiting early – age evaporation through the use of plastic sheeting , monomolecular films, water fogging , or wind breaker in conjunction with properly designed concrete mixtures. Results of several studies suggest the benefits of using short fibers as a possible alternative solution to this problem [١١, ١٢ , ١٣].

Cracks of plastic shrinkage develops when a large horizontal area of concrete makes contraction in the horizontal direction more difficult than vertically. Deep cracks of an irregular pattern are formed [١٤].

٢.١.٢.٢ Carbonation Shrinkage :

Carbonation occurs as a result of a reaction that occurs between hydrated cement and carbon dioxide in the atmosphere which causes the concrete to shrink. Carbonation shrinkage occurs along the surface of concrete and as such it is usually not a main cause for concern in structural concrete [٦]. Carbonation shrinkage is not to be effective in the conditions which have no carbon dioxide.

٢.١.٢.٣ Drying Shrinkage :

Drying shrinkage is by far the most common reason of shrinkage. Drying shrinkage occurs in hardened concrete as a result of water evaporation. The reaction of cement and water results in the formation of calcium silicate hydrate gel (CSH) with water-filled space. The size of the pores in the water-filled space varies from large capillary pores (> ٥ micron) to smaller voids in the (CSH) gel that are filled with adsorbed water (٠.٥-٢.٥). Drying occurs, disjoining pressure removes adsorbed water from these pores and hydrostatic forces (capillary stresses) form a meniscus that exerts stresses on the (CSH) skeleton causing the cement paste to shrink.

One of the most substantial factors which affects influencing free shrinkage is (w/c) ratio. W/C ratio required for complete hydration is about ٠.٤٢ depending on the amount of gel porosity that is assumed. The amount of mix water has a direct influence on the amount size of the porosity (i.e, higher w/c ratio pastes have higher porosity). Specimens with a lower w/c ratio have a lower a mount of pore water and

consequently exhibit lower drying shrinkage. It should be noted that recently the use of high – range water reducing admixtures has led to increased workability for lower w/c mixtures. Another factors that influences shrinkage is the degree of hydration, chemical and mineral admixtures, and cement composition. They typically alter reaction products, porosity, and mechanical stiffness [١٥]. Hobbs [١٦] showed that the successive loss of water from cement paste develops, capillary tension in the residual water accompanied with stresses and shrinkage in concrete. Neville [١] reported that hydrated C_3A and calcium sulfoaluminate show to undergo a change in lattice spacing from (١.٤) to (٠.٩) on drying.

٢.١.٢.٤ Autogenous Shrinkage :

Autogenous shrinkage occurs under sealed concrete (i.e., no moisture loss) without temperature change. Autogenous shrinkage occurs primarily as a result of chemical shrinkage (i.e., volume reduction due to the hydration reaction) and self-desiccation (i.e., the internal consumption of water by the hydration reaction). Consequently , concrete can be made with significantly lower water demands (٠.٢ < w/c < ٠.٤٢) resulting in concrete which may be susceptible to self-desiccation shrinkage. Self desiccation describes a process where the internal water is consumed by hydration and the internal surfaces of pores can no longer be saturated. Self-desiccation occurs even in specimens that are sealed

during curing and can lead to incomplete hydration. Although autogenous shrinkage was described as early as at ١٩٣٠'s [١٧].

Tazawa and Miyazaw [١٨] also reported that inclusion of aggregate leads to a reduction in autogenous shrinkage as in the case of drying shrinkage. This is due to the reduction in the cement paste contents and the elastic deformation of aggregate.

Hua et al [١٩] studied the phenomenum linked to hydration and self-desiccation, they noted that capillary depression is the main origin of the autogenous shrinkage of hardening cement paste.

٢.٢ Factors Influencing Shrinkage :

٢.٢.١ Aggregates :

Aggregates affect concrete deformation through water demand, aggregate stiffness and volumetric concentration, and paste aggregate interaction [٢٠]. The primary source of shrinkage is the cement paste. Aggregates that require a lower water demand for workability therefore will produce concretes with a lower cement content, which will result in lower shrinkage. Shape and texture of coarse aggregate play a role on the behavior of fresh concrete and hardened concrete. Shape and texture affect the demand for sand. Flaky, elongated, angular and rough particles

have high voids and require more sand to fill the voids and to providing a workable concrete, thus increasing the demand for water and thereby increase the shrinkage. Spherical or cubical aggregates require less paste and less water for workability [٢١].

Aggregates with higher stiffness give greater restraining effects to shrinkage stresses and result in lower shrinkage in concrete [١]. Aggregates that shrink considerably upon drying usually have a low stiffness. This type of aggregate may also have a large water absorption value, which will result in a concrete with higher shrinkage [٢٢]. Aggregates with low absorption tend to reduce shrinkage and creep [٢٣].

Concrete containing a well-graded aggregate with large maximum aggregate size requires less cement paste, thus, decreasing bleeding, creep, and shrinkage [٢١,٢٢]. However, it is to be noted that although an excess of coarse aggregate could decrease drying shrinkage it will increase the amount of micro-cracks within the paste [٢٤].

٢.٢.٢ Cement :

Tazawa and Miyazawa [٢٥] found that cement composition has a greater influence on autogenous shrinkage than drying shrinkage. As compared with ordinary Portland cement, larger autogenous shrinkage was observed for high early strength cement at an early age , and blast furnace slag cement at later ages. Less autogenous shrinkage was observed for moderate heat cement paste, and low heat Portland cement

with a high C_3S content. Autogenous shrinkage depends on the hydration of C_3A and C_4AF it increases with the increase in these compounds. The use of an expansive cement was found to produce a large shrinkage reduction in the cement mortar, but negligible effect in the concrete as showed by Saito and et-al. [٢٦]. The aggregate was found to play an important role in the shrinkage of the concrete. It was found that at the beginning of shrinkage, some cracks had already existed around coarse aggregate particles used in the expansive cement concretes. The formation of these cracks was found to lead a partial loss of restraint of coarse aggregate particles against drying shrinkage.

٢.٢.٣ Water Content :

The water content has a large influence on the drying shrinkage of cement paste and concrete for a given w/c ratio, concretes of a wet consistency have a higher paste content and have a greater amount of shrinkage than a stiffer mixture [٢٢]. For a given proportion of cement and aggregate, concretes of wet consistency have a higher water content and thus have a greater amount of shrinkage than a stiffer mixture.

Carlson et al [٢٧] showed that the shrinkage decreases about (٣٠) percent when water content is reduced (١٥) percent. A similar tendency was given by ACI committee ٢٢٤ [٢٨] for (١٠) percent reduction of water content, the one year drying shrinkage was lowered by about (١٥) percent.

Brooks [٢٩] concluded that the shrinkage of hydrated cement paste is directly proportional to the w/c ratio between the values of about (٠.٢ – ٠.٦) , at higher (w/c) ratios, the additional water is removed upon drying without resulting in shrinkage as explained in Figure (٢.١)
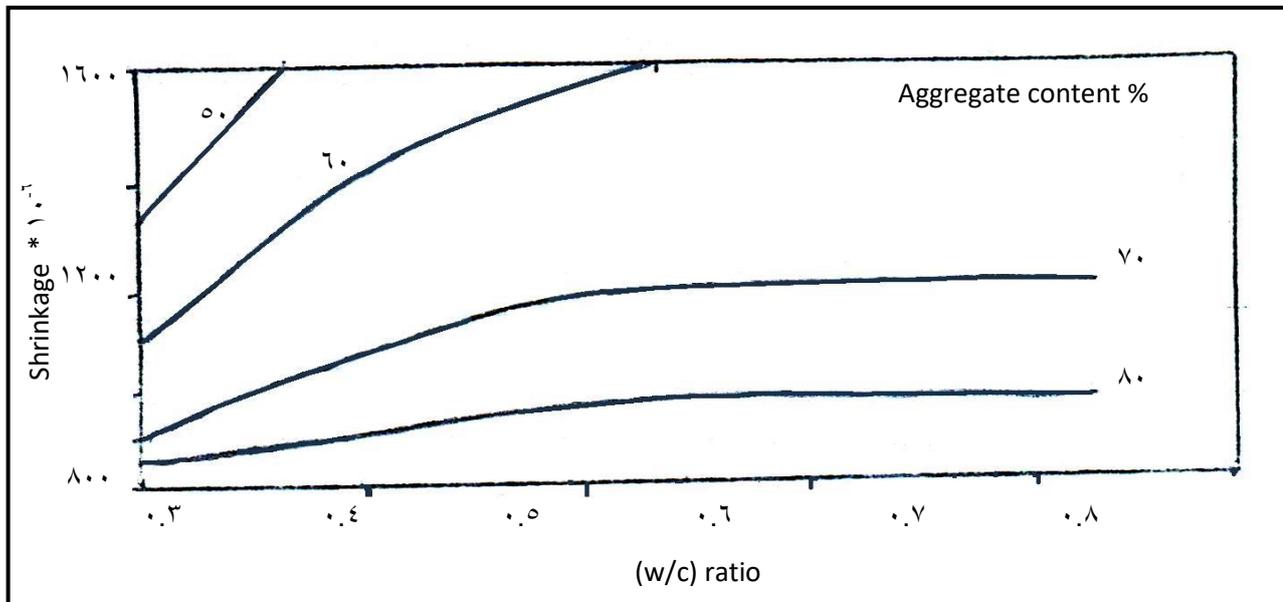
The drying shrinkage is the main shrinkage, which is related to

Figure (٢.١) : Influence of (w/c) Ratio on the Shrinkage for Different Volume Content of Aggregate [٢٩]

The drying shrinkage is the main shrinkage, which is related to The water content in mixture, because the water content determines the amount and rate of evaporation of water from the cement paste.

Generally , the water content of a mix will indicate the expected shrinkage, the following Figure (٢.٢) is showing the general relation between the water content with the drying shrinkage for different types of aggregates [١].
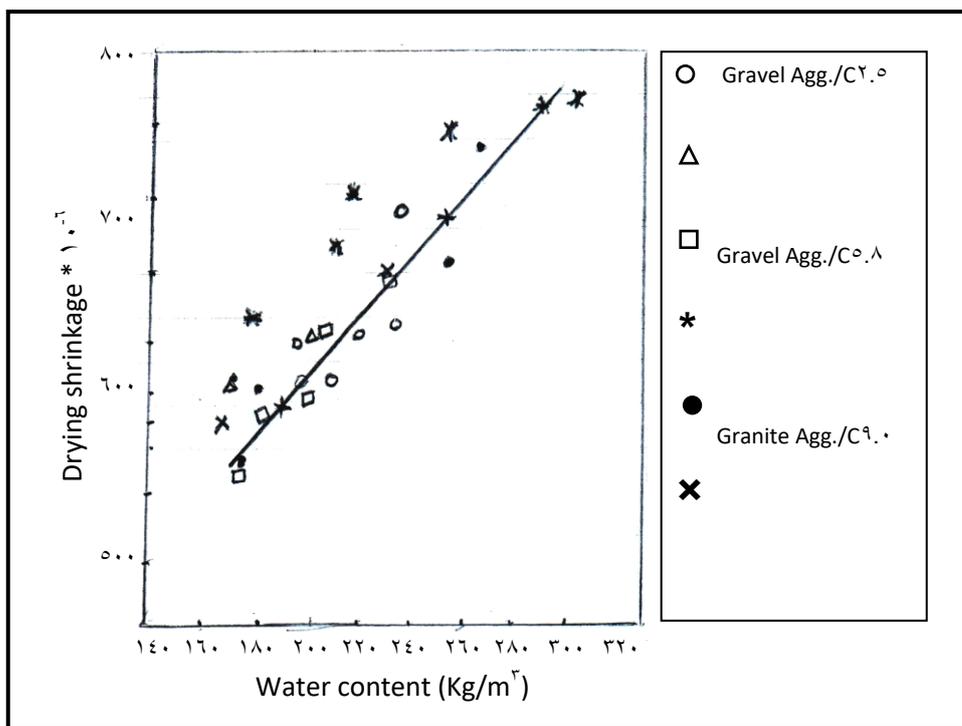
Figure (٢.٢) : Relation Between The Water Content of Fresh Concrete and Drying Shrinkage [١]

٢.٥.٤ Effect of Size and Shape of Concrete Specimens on Shrinkage :

The size and shape of concrete specimen definitely influence the rate of moisture loss under a given storage condition, and this can affect the rate of volume change as well as total expansion or contraction.

Al-Mudaiheem and Hansen [٣٠] measured the shrinkage of concrete specimens of various sizes over a one – year period dryness. The shrinkage decreased with increasing specimen size. The ultimate shrinkage of paste, mortar , and concrete is found to be independent of specimen size and shape according to the dynamic shrinkage/ weight loss curves. They concluded that the ultimate drying shrinkage may be estimated from the shrinkage versus drying time curves for small laboratory specimens of ١x١x١١ in. (٢٥ x ٢٥ x ٢٧٩ mm) with the same mixture proportions as the larger structural members.

٢.٢.٥ Shrinkage – Reducing Admixtures :

Shrinkage – reducing admixtures can be divided into two types namely , mineral and chemical admixtures. They typically reduce the shrinkage strain in concrete specimens.

٢.٢.٥.١ Mineral Admixtures :

Fly ash used in mortar samples reduces the drying shrinkage by about (٣٠ to ٤٠٪) when compared with pure Portland cement mortar. Mortar samples containing ٤٠٪ fly ash were expanded instead of contraction. Based on the strength and shrinkage measurement results, it was concluded that the nonstandard Afsin-Elbistan fly ash (from Afsin-Elbistan power plant, Turkey) could be utilized in cement based material additive particularly in concrete pavement, large industrial concrete floors, parking lot applications or rock bolt applications of rock engineering where shrinkage should be a voided. However, further studies are needed to investigate long-term properties of the concrete made with this fly ash before it can be used as a mineral additive or in production of a shrinkage compensating cement [٣١].

Tangtermsirikul and et-al. [٣٢] tested (١٥ x ٤٠ x ١٦٠)mm prism specimens to measure length changes due to drying shrinkage. The drying shrinkage test were conducted in a controlled environment of ٧٧ F (٢٥ c) and ٦٠٪ relative humidity. Three types of class C fly ash and one type of class F fly ash were used in the experiment. The class C fly ash had a

smaller drying shrinkage than the ordinary cement paste mixtures, the addition of fly ash reduced the water requirement of the mixtures, thus, reducing the shrinkage. The class C fly ash also reduced the autogenous shrinkage due to chemical expansion of the concrete mixture.

The morphology, particle size distribution and surface characteristics of fly ash used as a mineral admixture have a considerable influence on the water requirement, workability, and rate of strength development of concrete (Mehta [٣٣]).

Molhotra [٣٤] studied the effect of additional various percentages of limestone dust as a partial replacement for fine aggregate on concrete properties. The results showed that there is a significant increase in strength with increasing the amount of limestone dust in lean concrete mixes. However, this is not evident in concrete mixes which are relatively rich in cement.

Silica fume is an industrial by product with a particle size about ١٠٠ times finer than Portland cement Malhotra [٣٤]. Tazawa and Yonekura [٣٥] examined shrinkage and creep of mortar and concrete. Drying shrinkage of concrete was tested using (١٠٠ x ١٠٠ x ٤٠٠ mm) prism specimens. The specimens stored in a controlled environment of ٦٨ F (٢٠ C) , ٥٠٪ relative humidity. The drying shrinkage of the concrete mixtures

with the silica fume was lower than that of the same type mixtures without the silica fume.

Haque [٣٦] measured the drying shrinkage on (٨٥ x ٨٥ x ٢٨٥ mm) prism specimen. The addition of both ٥ and ١٠٪ silica fume of cement weight leads to a substantial reduction of drying shrinkage of their concrete.

Silane is an aqueous admixture, called aqueous amino vinyl silane. Silane treatment of silica fume and or carbon fiber is highly effective for decreasing the drying shrinkage of cement paste. The increase of the hydrophilic character of fibers and particles after the treatment and the formation of chemical bonds between fibers cement and particles are believed to be the main reasons for the observed decrease of the drying shrinkage. By adding Silane-treated carbon fibers and replacing as-received silica fume by Silane-treated silica fume, the shrinkage at ٢٨ days is decreased by ٣٢٪ (Yunsheng [٣٧]).

Tazawa and Miyzawa [١٨], showed that is an expansive additive currently used in Japan for concrete. This admixture expands when it is hydrated, without loss in strength. It uses calcium silicate and glass interstitial substitute rather than CaO. This material is stable but it must be moist cured and requires longer mixing.

٢.٢.٥.٢ Chemical Admixtures :

The use of chemical shrinkage reducing admixture in high – performance concrete was found to be significantly reduce drying shrinkage and restrained shrinkage cracking in laboratory ring specimens.

The following effects were observed when an organic admixture (shrinkage reducing admixture) was added [٣٨] :

١- Comparing to distilled water, there is a significant reduction in the surface tension of a solution containing the shrinkage reducing admixture.

٢- The drying rate of the cement pastes is reduced.

٣- A significant decrease in autogenous shrinkage in low w/c ratio mortars cured under sealed conditions.

There was no significant change in ٢٨ days compressive strength of mortar specimens with the addition of a shrinkage reducing admixture for (w/c=٠.٣٥) (٨٪ silica fume) and cured with sealed conditions at ٨٦ F (٣٠ C).

A shrinkage reducing admixture has been suggested for use in reducing the rate of shrinkage in concrete at early-ages when concrete is most vulnerable, even though reductions in overall shrinkage have also been observed [٣٩].

Berk [١٣] , tested the specimens that were stored at (١٣ C) (٣٧.٤ F) and ٥٠٪ relative humidity and having ٢٪ shrinkage reducing admixtures by weight of cement. The results showed that the drying shrinkage of

concrete increased as the w/c ratio increased for all the mixtures tested. The drying shrinkage was greatly reduced with the addition of the shrinkage reducing admixture and curing time. The longer curing periods reduced the sensitivity to changes in the w/c ratio with respect to shrinkage reduction.

Shah, and et-al. [٣٩], used prism specimens of (١٠٠ x ١٠٠ x ٢٨٥ mm) placed in controlled environmental of ٦٨ F (٢٠ C) and ٤٠٪ relative humidity. They found that the shrinkage reducing admixture (SRA) decreased compressive strength. The addition of the (SRA) reduced the amount of shrinkage. As the amount of (SRA) added increases, the shrinkage further decreases. The addition of (SRA) reduced the restrained shrinkage crack width. Free shrinkage was also reduced, and caused a delay in the restrained shrinkage cracking.

٢.٢.٦ Another Factors Affects Drying Shrinkage :

٢.٢.٦.١ Relative Humidity :

The shrinkage in concrete is proportional inversely with the relative humidity due to the reduction of water evaporated from the surface of

concrete. Figure (٢.٣) showed that, drying shrinkage of concrete in an atmosphere of (٧٠٪) relative humidity is about one-third lower than in (٥٠٪) relative humidity [٢٣]. The reduction in the shrinkage is propertied to the increase of relative humidity because of the reduction of water evaporation from the surface of concrete.
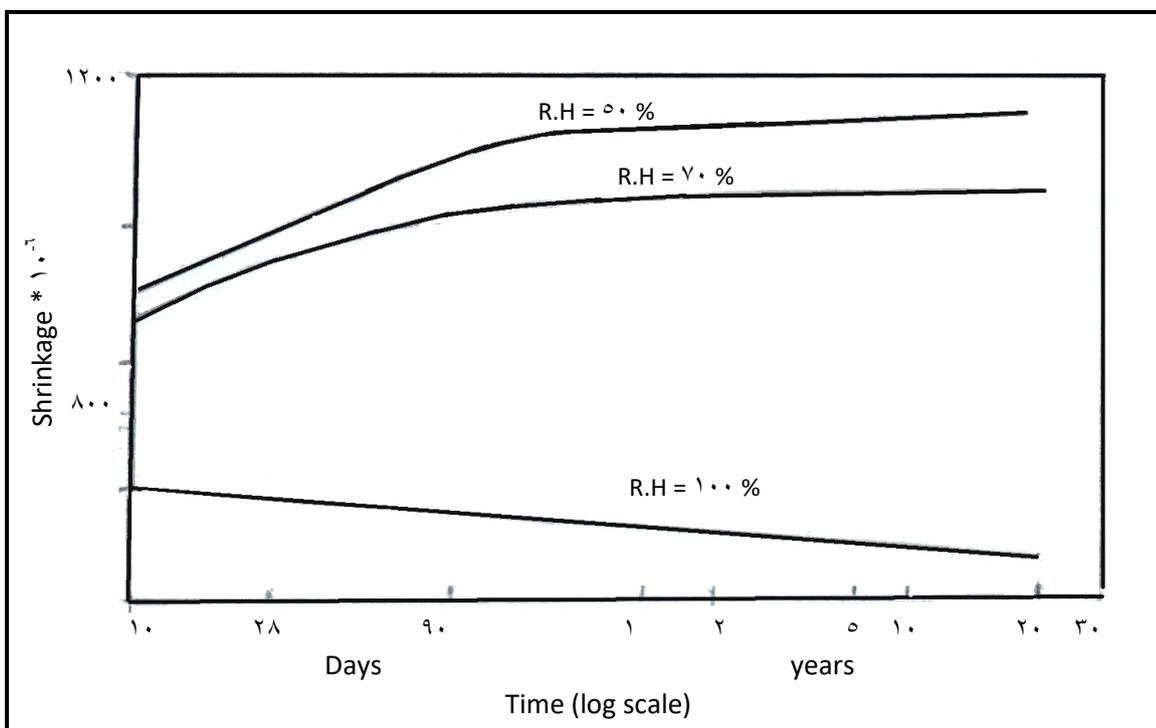
Figure (٢.٣) : Relation Between Shrinkage and Time for Concrete Stored at Different Relative Humidities [١]

٢.٢.٦.٢ Ambient Temperature :

The shrinkage is proportional with the increase of ambient temperature because of the increase of evaporation of water from concrete surfaces.

٢.٢.٦.٣ Drying Time and Rate of Drying :

When the drying time is long, the shrinkage will increase. The rapid drying out does not increased allow a relief of stress by creep or relaxation and may lead to shrinkage cracking. The magnitude of shrinkage is largely independent of the drying rate but transferring concrete directly from water to a very low humidity can lead to fracture [١] .

٢.٢.٦.٤ Curing Period :

There is some contradictions about the curing period effect on shrinkage of concrete are reported by some researchers. Tremper and Spellman [٢٨] , showed that moist curing duration of concrete does not seem to have effect on drying shrinkage, Hanson [٤٠], reported that, concrete at (٢٨) days curing instead of (٧) days before drying was started gave about, (٢٠٪) reduction in free shrinkage strain. The longer the curing time , concrete was the less shrinkage occurrence.

Al-Sayed and Amjad [٤١] tested twelve of concrete slab specimens (١٠٠٠ x ١٠٠٠ x ٢٠٠ mm) in dimensions and twelve (١٥٠ mm x ٣٠٠ mm) cylinders. All specimens were placed to examine the effects of curing conditions on shrinkage. Shrinkage measurements began on the eighth day after specimen placement. Watering twice a day, burlap, polyethylene, and air curing were all found to result in high shrinkage rates. Other methods were recommended to reduce the shrinkage rate. Sealing the concrete with resin modified wax or watering the concrete four or five times on a day may decrease the shrinkage rate of concrete.

٢.٣ Moisture Diffusion in Concrete :

Moisture diffusion in concrete is important factor that is needed to determine the drying shrinkage and creep. Two types of moisture diffusion were discussed, macrodiffusion and micro diffusion [٤٢]. Macrodiffusion is the movement of water through the path of least resistance. This movement occurs in larger pores and has no measurable effect on the concrete deformation. Micro diffusion is the movement of water between the capillary pores and gel pores. These are the smallest pores in the concrete and thus the movement of water in these pores has a significant effect on the concrete deformation. The movement of water in the gel pores or micropores allows for the breakage of bonds which are the source of creep. Therefore, the movement of water in the gel pores intensifies creep.

There are three components of the moisture in concrete which are hardened cement paste moisture, aggregate moisture, and aggregate/ cement paste interface moisture . The hardened cement paste consists of capillary and gel pores. Aggregate is dispersed in the cement paste matrix in a manner that does not provide for a continuous porous path for moisture to travel. The pores are arranged as a buffer zone, which can either store or release moisture to the surrounding cement paste matrix. At the aggregate/cement paste interface, channels may be present. These channels can be the result of insufficient compaction bleeding , or aggregate contact. This situation can lead to rapid bulk movement of moisture [٤٣].

٢.٤ Shrinkage Cracking in Concrete :

The permanent situation of concrete in structure is that it is under some degree of restraint, either externally or internally.

The shrinkage in concrete is time dependent and when it is restrained , it will induce stresses. These stresses are increasing with time so is the tensile strength. Relaxation in concrete prevent the development of cracking when the shrinkage develops slowly, but when shrinkage occurs rapidly , it may induce restrained strain which exceeds the tensile strain capacity of concrete and cracking takes place sequentially when the developed stress exceeds the tensile strength of concrete , cracking occurs as shown in Fig. (٢.٤). The advent or absence of cracking depends on the rate and quantity of shrinkage, creep, degree of restraint to deformation [٤٤].
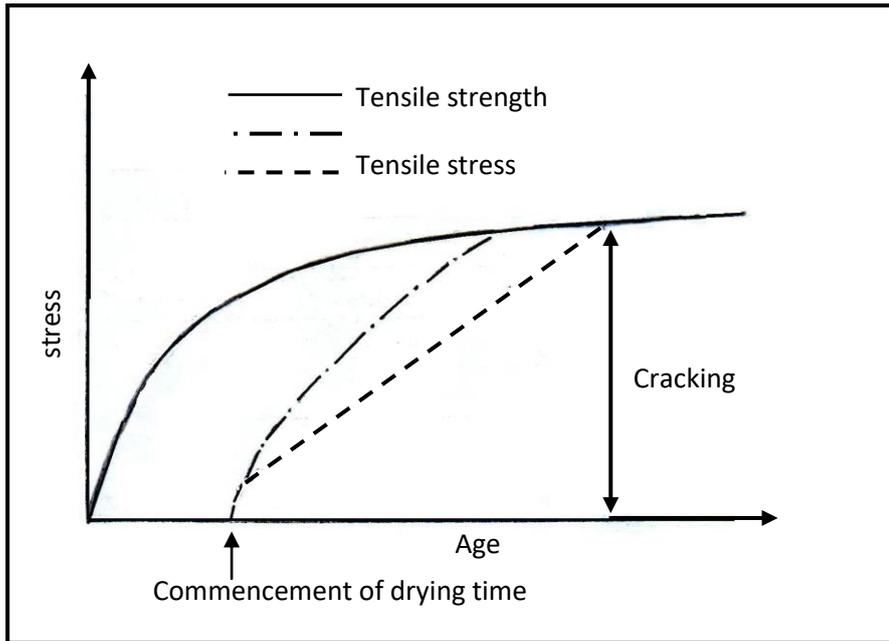
Figure (٢.٤) : Sketch of Crack Development (Stress Wise) [٤٤]

٢.٤.١ Restrained Shrinkage Cracking :

The restraint tries to prevent the dimensions changes due to volume change, so the elastic strain within a concrete member will produce. Normally, restraint conditions that will induce compressive stresses in concrete are not considered in design because of the ability of concrete to withstand compression. On the other hand, restraint conditions that induce tensile stresses are of the main concern because due to the low tensile strength of concrete. The degree of restraint depends largely on strength, creep, relative dimension and modulus of elasticity of concrete. The induced stresses in concrete due to restraint

lead to a decrease in-direct proportion with decrease of restraining part stiffness [٤٥].

ACI committee ٢٠٧ [٤٥] shows that there is no difference in its effects between the type of restrained with respect to base or end occurrence.

Al-Rawi [٤٦], used (I – shaped) moulds having a channel section to study crack width and shrinkage crack spacing .

The crack width rate increases for high strength concrete as a result of the high free shrinkage.

There are two types of restraint :

١- Base-Restraint : for example , walls cast on continuous base. The restraint varies throughout the wall height.

٢- End-Restraint : for example, the restraining edges exist only at the member ends (I shaped) beams, beams in concrete frame. The restraint in these members is uniform.

٢.٤.٢ Factors Influencing Cracking Resistance :

١- Creep (Relaxation) of concrete.

٢- Tensile strain capacity.

٣- Elastic tensile strain capacity.

٤- Cracking age.

٢.٤.٢.١ Creep (Relaxation) of Concrete :

Creep is generally defined as the deformation of concrete under sustained stress [٢٨]. However if the restraints are such that a stressed concrete specimens is subjected to a constant strain (such as the case of restrained shrinkage movement), creep will be expressed as a progressive decrease in stress with time now as "relaxation [١]. It includes the amount of strain that is in excess of the elastic strain capacity and the loss of restraint. Al-Rawi [٤٧] considered the creep strain as a significant concrete property which must not be ignored. Creep strain of concrete subjected to restrained shrinkage is the difference between tensile strain capacity and elastic tensile strain capacity. He reported very high values of creep in tensile to up ($٢٢٠*١٠^{-٦}$).

٢.٤.٢.٢ Tensile Strain Capacity :

Cracking of concrete depends partly upon the maximum strain that the concrete can sustain in tension before cracking occurs. This maximum strain is termed the " tensile strain capacity ".

The tensile strain capacity is measured in the ACI committee ٣٠٤ [٤٨] by dividing the flexural strength of concrete by the modulus of elasticity for concrete [٤٤]. Probably the reason is the non-linearity of stress distribution across the member which causes the modulus of

rupture to be (٢٠-٤٠٪) higher than the true tensile strength of concrete [٢٧].

٢.٤.٢.٣ Elastic Tensile Strain Capacity :

The elastic tensile strain capacity is the amount of strain that is instantly relieved due to the elastic recovery of restrained concrete upon cracking . It is defined by Al-Rawi [٤٤] as the observed free contraction of concrete at the onset of cracking. He also developed a method for measuring the elastic tensile strain capacity.

Elastic tensile strain capacity does not include creep strain ,which was lost during tension build up, before the occurrence of cracking. It is naturally less than tensile strain capacity. It is considered as a basic concrete property that may be used for calculation of shrinkage crack width [٤٦].

Blakey et-al. [٥٠], carried out restrained shrinkage tests on mortar bars, their results showed that an elastic strain capacity ranging between ١٠٠-٤٠٠*١٠⁻⁶ (cement paste) and ١٠٠-٢٠٠*١٠⁻⁶ (mortar) achieved (for various curing age and exposure conditions).

٢.٤.٢.٤ Cracking Age :

It is the time required for the progressive shrinkage strain exceeding the tensile strain capacity of concrete. It depends on these factors : (shrinkage, creep, degree of restraint, tensile strain capacity …

etc.). Their effects on concrete are complex. Many factors reduce the shrinkage, but at the same time reduce strength and the tensile strain capacity. The final effect may be positive or negative. These factors will limit the index of comparing various mixes about the first cracking time.

Neville [٤٩] , showed that it is not necessary that the weakest or the strongest concrete that cracks most severely. He related the occurrence of cracking to the balance of the opposing factors of concrete strength and stiffness.

Blackey and et-al. [٥٠], stated that the cracking age increases with the increase in duration of curing. Specimens did not crack when the curing treatment was (٢٨) days in fog followed by air curing.

Al-Nassar [٢] studied the effect of admixtures, super plasticizer , plasticizer , BVD and waterproofing on the shrinkage of concrete. He used I-shaped moulds having a channel section to study restrained shrinkage cracking in concrete. He found that the development of shrinkage is affected by the type and amount of admixture. For restrained shrinkage test at the first three days, super plasticizer, plasticizer and waterproofing admixtures decrease the shrinkage, except BVD. Cracking time increases when using superplasticizer and plasticizer, while it decreases with BVD and there was no change with waterproofing admixture.

٢.٥ Another Studies About Concrete Shrinkage :

Folliard and Berk [٥١], used silica fume slurry and super plasticizer along with a shrinkage reducing admixture (SRA) to produce a high strength concrete. The concrete was kept at a slump of ١٥٠ to ٢٠٠ mm. Concrete prisms of ٧٥ x ٧٥ x ٢٨٥ mm were cast to measure free drying shrinkage. The use of a (SRA) reduced the drying shrinkage of the high strength concretes both with and without silica fume.

The ring test was used to determine the restrained shrinkage. The steel ring used had an inner diameter of ٢٥٠ mm and an outer diameter of (٣٠٠ mm). The concrete was placed ٥٠ mm thick and ١٥٠ mm high around the steel ring. The restrained shrinkage was significantly reduced when the (SRA) was used. The shrinkage reduction was more significant with the silica fume mixtures [٥١].

Tritsch and Darwin [٥], used the free shrinkage and restrained ring tests to evaluate concrete mixes designed for use in bridge decks. Their study consists of a series of preliminary tests and three test programs. In each program, the concrete is exposed to drying conditions of about ٢١ C (٧٠ F) and ٥٠٪ relative humidity. The preliminary test include one basic concrete mix and two mixes designed to have a high cracking tendency, one mix is a concrete and the other is a mortar. For each mix, two (٧٦ x ٧٦ x ٢٨٦ mm). Free shrinkage prisms and one restrained ring specimen are cast, the concrete is (٧٦ mm) tall, (٧٦mm) thick, and is cast around a (١٣ mm) thick steel ring with an outside diameter of (٣٢٤ mm).

They found that:

1- The restrained ring tests are inconclusive in terms of cracking tendency since only one out of ٣٩ concrete rings cracks during testing. The ring that cracked, however, was made from the mortor mix, which had the highest paste content and highest shrinkage rate of all the mixes in programs ١ and ٢.

2- Free shrinkage and restrained shrinkage rate decrease as the surface to volume ratio of the concrete specimens decreases.

3- Restrained shrinkage rate generally increases with increase free shrinkage although free shrinkage is found to be a weak predictor for rate of actual restrained shrinkage.

4- Replacing type I Portland cement in the control mix with type II coarse-ground cement results in a slightly lower free shrinkage and a lower restrained shrinkage rate.

5- Adding (SRA) to the concrete reduces the free shrinkage and restrained shrinkage rate.

Kovler [٥٢], in his study found advanced methods of concrete curing to mitigate autogenous shrinkage and cracking at early age. He used cement modification, mineral additives, chemical admixtures, fibers, mix proportions and proper curing. These methods have been reviewed by Tazawa and Miyazawa, Kovler and Zhutivsky, Ito et-al. Some of them are accepted by professionals as really effective methods for mitigating both shrinkage and cracking of early age concrete. Some others do not help much in reducing shrinkage, but still are rather effective in mitigating cracking (for example, using steel fibers).

Al-Husseini M. Sh. [٥٣] , used different levels of cement klin dust as a partial replacement of cement and sand, the results showed that there is no significant effect on shrinkage strain when the cement kline dust (CKD) is used as cement replacement. At level of cement replacement (٤٠٪ of CKD by weight of cement), the shrinkage after (١٨٠ days) is only ١٥٪ more than that of the control mix. When using CKD as a sand replacement the shrinkage effect is more pronounced. This effect is particular significant for mortars containing more than ١٠٪ of CKD by weight of sand.

Morkarem [٥٤], used five models to assess the development specifications of cement shrinkage performance. These models are the ACI ٢٠٩ code model, Bazant B٣ model, CEB ٩٠ code model, Gardener/Lockman model, and the Sakata model. This performance specification limits the amount of drying shrinkage for concrete mixtures used by the Virginia department of transportation (VDOT). The results stated that, the percentage length change limits for the Portland cement concrete mixtures were ٠.٠٣ at ٢٨ days, and ٠.٠٤ at ٩٠ days. For the supplemental cementation materials mixtures, the percentage length change limits were ٠.٠٤ at ٢٨ days, and ٠.٠٥ at ٩٠ days, the CEB ٩٠ code model performed best for the Portland cement mixtures, while the Cardener/Lockman model performed best for the supplemental cementation materials mixtures.

Weiss and Shah [٥٥], compared different geometries of the restrained ring test and used it to evaluate shrinkage reducing admixtures (SRA). The authors performed two series of ring tests, a long ring series and short ring series. In both series, concrete rings were cast around a ١٥٠ mm (٦ in) diameter solid steel core. In the long ring series, the height of the specimen was held at ١٥٠ mm (٦ in) while thickness of ٢٥, ٧٥ , and ١٥٠ mm were used to simulate varying slab thickness. These rings were exposed to drying from outer circumstance, causing a moisture gradient between the inner and outer edges of the concrete ring for short ring series. Specimens were (٣٠ mm) tall with concrete wall thickness of ٣٠ , ٧٥ and ١٥٠ mm. The results of the long ring series showed that time to cracking is delayed as ring thickness increases. In the mixes without (SRA), cracking occurred between ٧ and ٢٣ days. Two mixes with (SRA) in the (٢٥ mm) thick rings cracked between ٧٠ and ٧٧ days, while the residual of (SRA) mixes did not crack during the ١٥٠ days test period in the long ring series. The short ring series showed that cracking potential decreased with increased ring thickness and that the (SRA) delayed or prevented cracking for mixes without the SRA, cracking occurred at ٨ days for the ٢٥ mm thick rings , and ١٠ days for the ٧٥ mm thick rings. The ١٥٠ mm thick rings did not crack with ٧٠ days.

The mixes with (SRA) had no cracks in the two thicker rings, while the (٢٥ mm) thick ring cracked at ١٧.٣ days. They concluded that thicker concrete rings are more resistant to cracking with or without a uniform moisture profile.

٢.٦ Admixtures for Concrete :

٢.٦.١ General :

The reason for the growth in the use of admixtures is that they are capable of giving the desirable physical mechanical properties and economic benefits with respect to concrete. These benefits include the use of concrete under conditions where previously there existed considerable, or even insuperable difficulties. Admixture make possible of using of a wider range of factors in the mix. The effectiveness of any admixture may vary depending on its dosage in the concrete and also on the constituents of the mix, especially the properties of the cement with some admixtures. The relevant dosage is the solids content and not the total mass of the admixture in liquid form [١].

Usually admixtures are classified according to their major purpose of use. They are used to modify the properties of concrete or mortar and make them more suitable for the work by hand , economy or such other purposes as saving energy. In many instances, very high strength , resistance to freezing and thawing , retarding and accelerating, an admixture may be the only feasible mean of achieving the desired result. The specific effects of an admixture depend on many factors such as; type, amount and the chemical composition of the admixture, the chemical composition and gypsum content in cement, time of adding the admixture, period of mixing mix proportions of the mix and the quality of compaction for the mix … etc. [٥٦]

Generally , the admixtures are classified to their action on the properties of concrete or the characteristic effects of their use. The American concrete Institute (ASTM C٤٩٤-٨٢) provides a broad classification [٥٧] as follows :

١- Accelerating admixtures.

٢- Air – entraining admixtures.

٣- Water reducing and set – controlling admixtures.

٤- Admixtures for flowing concrete.

٥- Reducing shrinkage cracks.

٦- Miscellaneous admixtures.

٢.٦.٢ Miscellaneous Admixtures

In addition to the previous admixtures, there exist also other admixtures used for other purposes, such as air detrainment, anti-bacterial action, and waterproofing (including the finely divided mineral materials which are studied in this work). These admixtures are not sufficiently standardized to make reliable generalizations possible. Moreover, some of the names under which certain admixtures are sold give an exaggerated impression of their performance. This is not to say that these admixtures are not beneficial : under many circumstances.

They serve a very useful purpose, but their performance needs to be carefully established prior to use [١].

٢.٧ Waterproofing Admixtures :

٢.٧.١ General :

Concrete absorbs water because the surface tension in the capillary pores in the hydrated cement paste pulls in water by capillary suction. Waterproofing admixtures are used to eliminate the penetration of water into concrete. Water penetrates through concrete by two ways [٥٨]:

١- In case of the water-retaining structures or structures such as basements in waterlogged ground. The hydrostatic pressure is exposed on one side of concrete surface, and water can be penetrates through any continual canal between two sides of concrete.

٢- In the case of rain (other than driven by wind) or capillary rise. Low-water pressure is exposed on one side of concrete body, water can be penetrate by capillary property and transfers through concrete to the surface wherever it is able for evaporating because the surrounded air of this surface is unsaturated .

The performance of these admixtures is related with the way of water penetration through concrete. The effectiveness of waterproofing in the first case is much more effective than in the other case. Water-

repellant admixtures reduce the influence of action mechanism of the second case , whereas it is not efficient for preventing passing of the water under the influence of the hydrostatic pressure [٥٨].

One of the best of the impingements to reduce the canals and capillary bypasses in concrete , is controlling (w/c) in mixture. During process of cement hydration , some of capillary bypasses are closed by sequent of hydration that is formation of gel of cement (٣ CaO. ٢SiO٢ . ٣H٢O) that are called " Tobermorite". If (w/c) ratio is more than (٠.٧) in Portland cement concrete, the amount of gel product is not enough to close the capillary bypasses, thus bypasses stay present and they can transfer water through concrete. The hydraulic permeability for cement gel is very small (٧*١٠$^{-١٤}$ cm/sec). The following Figure (٢.٥) shows capillary continuance and discontinuous of cement gel [٥٨].
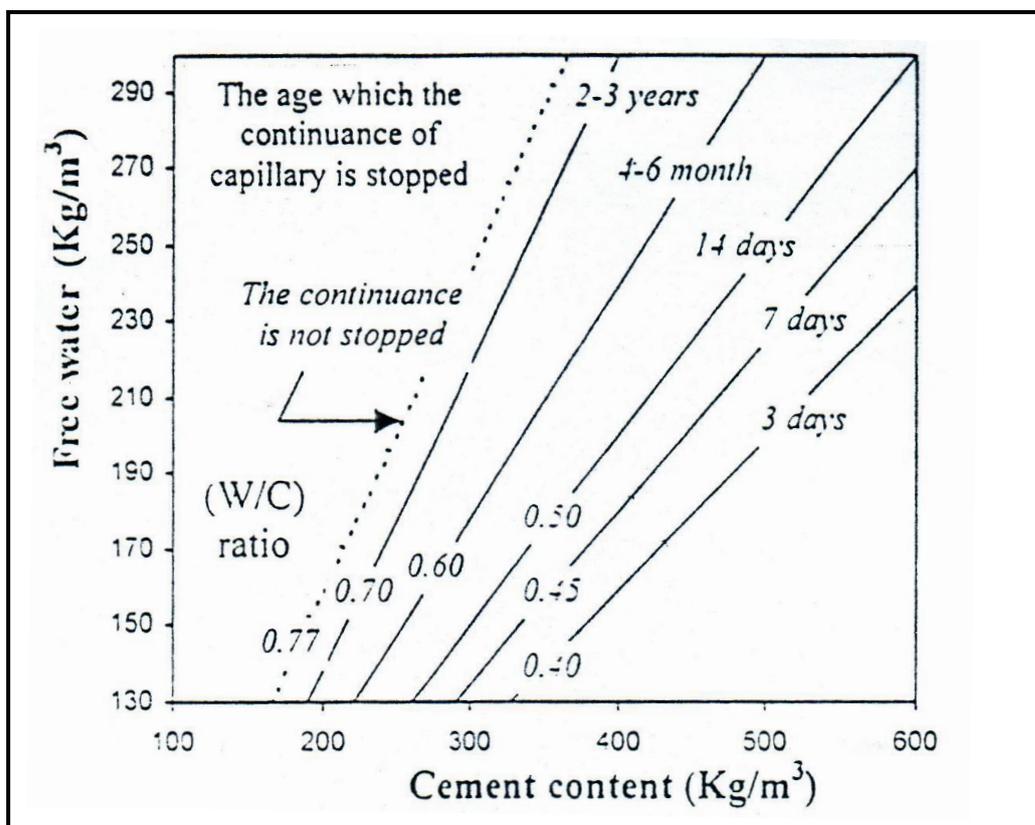
Figure (٢.٥) : The Continuance and Discontinuance of Capillary Pores for Cement Paste [٥٨]

٢.٧.٢ Influence of Waterproofing Admixtures on Capillary System for the Hardened Cement Paste

Both sizes and continuity of capillary pores in the hardened cement paste depend on actual (w/c) ratio and degree of the maturity of cement paste. Diameters of the capillary pores are usually varying between (٠.٠٥-٠.١ μ) , and through these pores, water can be transferred under the effect of the exposed pressure or by capillary property, as in Figure (٢.٦.a). It is believed that by the presence of the waterproof admixtures, the outside surface for concrete and the inside superficies pores become closed either by a layer of molecules (as in the cases that stearic acid and other fatty acids are used Figure (٢.٦ b)) or by a corporating layer of

admixture (as in the case that waxy materials and bituminous materials are used Figure (٢.٦ c)). Thus, the final result for the two cases is to produce water repelling surfaces [٥٨].
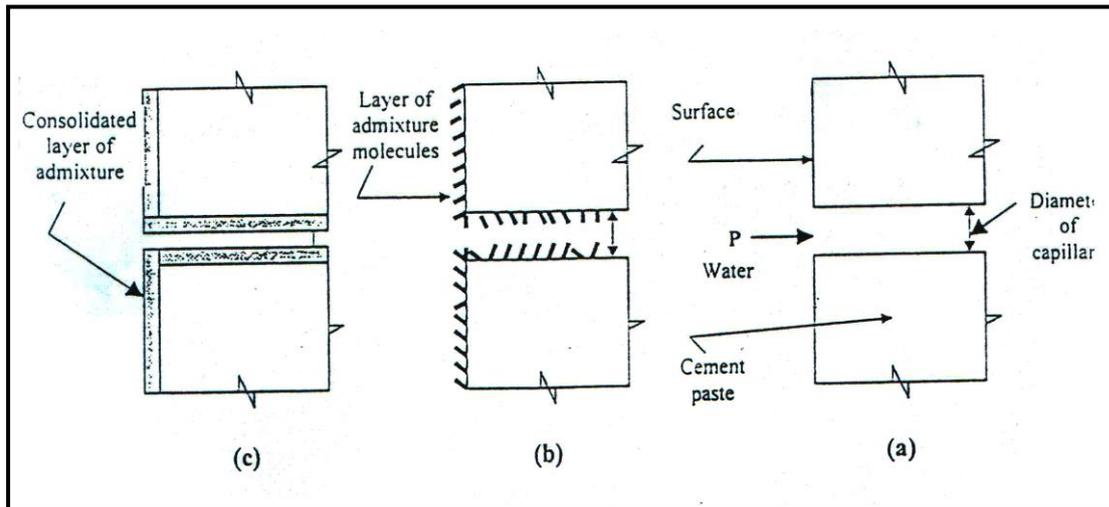
Figure (٢.٦) : Surface of Capillary Pores Become Closed by   a Layer of Molecules of Admixture [٥٨]

٢.٧.٣ Influence of Waterproof Admixtures on Concrete Properties:

Waterproof admixture improve the properties of hardened concrete with no evident effect on the properties of fresh concrete. Employment of the materials, containing calcium stearate, alumina stearate, stearic acid as solid form or emulsifier, bituminous materials or hydrocarbon resins, do not affect fresh concrete properties that include

the air content, workability, changes of the mixture design and others. Some waterproofing admixtures used to improve the workability of the mix owing to the presence of finely divided wax or bituminous emulsion [١,٥٨]. They also improve cohesion of the concrete then may result in a sticky mix. Waterproofing admixtures from the class of waxy emulsifier are characterized by features modifying the durability of concrete and allowing to reduce (w/c) ratio [٥٨].

٢.٨ Finely Divided Mineral Admixtures :

Finely divided mineral admixtures are material other than of aggregate and Portland cement , add to the concrete mixture before mixing process or during it as separate components. There is another type of these admixtures which called "mixtures". They are grinned and mixed with ordinary Portland cement to make blended hydraulic cement (ASTM ٥٩٥) [٥٩].

These admixtures may be contained cementations or pozzolanic properties or both or may be contained another properties. The fineness of these admixtures exceeds fineness of Portland cement, so the physical properties of fresh cement paste is affected. They can be classified into three types:

a- Cementitious materials.

b- Relative chemically inert materials.

c- Pozzolans.

The class (B) includes materials such as Bentonite, clays, ground quartz, ground lime stone, hydrated lime, chalk and talc. These materials are defined as fillers [٥٨].

٢.٨.١ Advantages of Finely Divided Mineral Admixtures :

The finely divided mineral admixtures are used in any type of concrete and are used normally for on or more for following properties [٥٨].

١-To correct the lackness in the amount of fine materials in the mixture when fine aggregate not available with suitable levels or when the required cement contents for proper workability are less than the required for certain strength.

٢-To improve one or more of concrete properties i.e to increase the resistance to sulphates, to reduce the expansion resulting from reaction the alkalies available in cement with parts of active silica in aggregate, to reduce permeability and to reduce the librated heat.

٣-To reduce the cost of materials consisting concrete or the cost of producing concrete or both.

٢.٨.٢ Applications of (FDMA) :

In fact, it rarely , to use natural cement and Hydraulic limes and the ground slag, inert finely divided mineral as admixtures to hydraulic cement concrete for purpose constructions.

Higginson [٦٠] referred to these applications for these admixtures. High furnace slag was used as an admixture in mass concrete [٦١], as a raw material to produce Portland cement with high furnace slag.

Fly ash is used when it is available with high quality, as an admixture in mass concrete [٦٢]. Constructive concrete , paves , concrete productions. Natural pozzolans were used for constructive purposes (concrete productions) [٦٣, ٦٤] while the ash of rice husk was used in producing hydraulic cement [٦٥] and in making bricks [٦٦]. The condensed vapors of silica may be used now a days to produce concrete with high strength.

٢.٨.٣ Performance of Finely Divided Mineral Admixtures (FDMA) :

The machinery leads to improve workability of fresh concrete by using (FDMA) lie in improving the ability of leveling of cement paste in concrete and in increasing the adhesiveness of mixture. The fineness of grains added, their shape took a great importance while the chemical properties of admixture takes a minor importance. In spite of this, the

carbon contents in fly ash has a clear role in reducing the amount of intended air in the fresh mixture because of its ability to absorb intended air factors [٦٧]. The main source for influence of the pozzolans in hardened concrete is the chemical reaction between the silican components of pozzolans and calcium hydroxide releasing from hydrated Portland cement leading to form stable physical and chemical cement materials. This process is slow to a certain extent but it continues for a long time when the required water for reaction is available this reaction. That does not only explain the reason of reduction in strength in early ages and its increase in later ages but also it explains the reason of improvement the strength of concrete containing pozzolans for chemical influence, that's because the free hydrated limes represent a lack point in hardened cement past [٦٨].

٢.٨.٤ The Influence of (FDMA) on the Fresh Concrete Properties :

When available concrete aggregate, concrete lacks in size of fine particles specially those that are passing from sieve (٧٥ mm), so the usage of (FDMA) will compensate of losing fine particles in aggregate, this action leads to reduce the bleeding and segregation and increasing of concrete strength. When using a suitable amount of mineral admixture to correct the lack of aggregate grading that doesn't need to increase the total amount of water in concrete, also the properties of drying shrinkage and absorption of hardened concrete doesn't affect largely. Despite of

particles shape and the fineness of mineral admixtures regard from necessary for properties to get a low water content. Example rough and bad grindings pozzolans may cause in the shape of powdered volcanic glass which may cause increasing in water content of concrete in a certain slump and by this it leads to increase in bleeding and segregation of fresh concrete [٦٠].

The surface area of solid materials to the unit of water volume is specified important factors limited to properties of bleeding and degree of fresh concrete plastic and in concrete mixture of the concrete when the ratio of surface area for solid materials to the volume of water is low, the cement paste is field with water and by so this the aggregate particles will be segregated from each other with very fine layer from cement paste, so the mixture needs plastic and tends to segregation [٦٩]. When the surface area ratio for solid materials to volume of water is low the rate of bleeding speed increases. During the bleeding process, some of the water block under the rough aggregate particles consisting voids inside of concrete and leads to weakness the adhesion between the aggregate particles and cement paste. These voids cause increasing horizontal permeability of concrete, then, they decrease its durability and strength. They can decrease the undesirable properties by increasing the surface area of solid materials comparing with the volume of water in cement paste. In general This may increase the rigidity of cement paste [٦٩].

٢.٨.٥ The Influence of (FDMA) on the Properties of Hardened Concrete :

Mineral admixtures are used in general as replacement of a Portland cement in concrete for economical consideration as well as to those of the durability of concrete. When using fly ash which have low calcium with known amount of natural pozzolans, it decreases the early strength until (٢٨ days) but it improves the later strength [٧٠].

Concrete containing ground slag's of blast furnace or of fly ash of a high content calcium shows a reduction in strength at one and three days age. The acquisition at strength will be great after seven days of curing , while the pozzolan materials with a high activity like the rice husk and the condensed silica fume may lead to increase strength of concrete at early and later ages specially when used with water reducing admixtures to reduce the water demand in the mixture [٧١]. On the other hand when mineral admixtures are used as a partial replacement of fine aggregate in a mixture it will lead to an increasing in the strength of concrete at early and later ages. The acquired strength in early ages belongs partially to slight speeding of cement hydration. As the acquired strength in later ages (which is normally big), it belongs basically to the interaction of pozzolans which lead to decrease the volume of pores in concrete structure. Replacing the weak compound of calcium hydroxide with a stronger compound of secondary cement get [٦٠].

The influence of mineral admixtures in concrete strength changes in a clear form according to the properties of admixture used and the

properties of concrete mixture. In general, lean mix needs to cement for a long time to acquire strength when replacing a part of cement with pozzolans admixture [٧٢].

٢.٨.٦ Thermal – Cracks Resistance :

The usage of cement and pozzolan admixtures in concrete reduces the effects of high temperatures of concrete comparing with control concrete which contain only Portland cement. The reduction causing in temperature is proportional directly with admixture amount used as a compensated for the weight of cement in the mixture. The influence of using of concrete temperature for a certain content of cement simply or may be zero [٧٣].

Moreover, there is another benefit produces from using mineral admixtures, when the concrete faces high temperatures comparing with normal temperatures, either because of hydration thermal or for any reason, it is shown that the site concrete pure of any mineral admixtures faces of losing resistance due to micro cracks caused by cooling comparing with the samples cured in the laboratory, but the concrete that has mineral admixtures acquires almost resistance, while the Portland cement concrete faces damage during exposes to high temperatures.

CHAPTER THREE

EXPERIMENTAL WORKS

٣.١ Introduction

This chapter describes the materials used in the production of the specimens , mix proportions and the methods of testing.

٣.٢ Program of the Work and Mixes :

In the present work , a study of the effects of adding some of finely divided mineral admixtures on drying shrinkage of end restrained concrete beams is investigated.

Three levels of each admixture were investigated , there are three admixtures which are limestone dust , Bentonite and Silica flour. These levels are (١.٥٪, ٣ % and ٤٪ by weight of cement limestone dust), (٢.٥٪ , ٥٪ , ٨٪ , by weight of cement silica flour), and (٢.٥٪, ٤.٥٪, ٦٪ by weight of cement bentonite), are investigated.

Each set of the mixes was cast at the same time to ensure similar drying conditions.

Concrete mix characteristics are summarized in Table (٣.١) .

High slump mixes (١٥٠ – ١٨٠) mm were chosen to ensure workable , compactable and a higher tendency to drying shrinkage concrete.

Table (٣.١) Concrete Mix Characteristics

Mix Symbol	Type of admixture	Admixture content (% by weight of cement)	Curing time (days)
M٠	No Admixture	٠	٣
LM١.٥	Lime stone dust	١.٥	٣
LM٣	Lime stone dust	٣	٣
LM٤	Lime stone dust	٤	٣
SM٢.٥	Silica flour	٢.٥	٣
SM٥	Silica flour	٥	٣
SM٨	Silica flour	٨	٣
BM٢.٥	Bentonite	٢.٥	٣
BM٤.٥	Bentonite	٤.٥	٣
BM٦	Bentonite	٦	٣

For each shrinkage test, specimens of (٦) concrete cubes of (١٥٠ x ١٥٠ x ١٥٠) mm are cast for compressive strength determination at ages (٧, ٢٨ days), specimens of (٢) concrete cylinders of (١٠٠ x ٢٠٠ mm) were

cast for splitting tensile strength determination at (٢٨ days) age ,
specimens of (٣) concrete prism of (١٠٠ x ١٠٠ x ٤٠٠ mm) were cast for
flexural strength determination at (٢٨ days) age and specimens of (٢)
concrete cylinders (١٥٠ x ٣٠٠ mm) for modulus of elasticity
determination at ٢٨ days.

٣.٣ Materials , Moulds and Mix Design:

٣.٣.١ Cement :

Ordinary Portland cement from Al-Kuffa cement factory used for
concrete mixes. The cement was properly stored in the laboratory. All the
required quantity of cement was delivered at one time from the same
batch to avoid any variation in physical and chemical properties. This
cement conformed to the Iraqi specification (IOS ٥-١٩٨٤) [٧٤]. The
physical and chemical properties are given in appendix (A), Table (A١) and
Table (A٢) .

٣.٣.٢ Fine Aggregate :

Natural sand from Al-Akhaidur used . Its grading and other characteristics conformed to the Iraqi specification No. ٤٥/١٩٨٤ [٧٥] as shown in appendix (A) Table (A٣) .

٣.٣.٣ Coarse Aggregate (Gravel) :

The coarse aggregate from Al-Nibaee quarry used with a maximum size of (١٢.٥) mm. It was washed, then stored in air to dryness , the gravel used conforms to the Iraqi specification No. ٤٥ ١٩٨٤ . The grading and other properties of this aggregate are listed in Appendix (A) Table (A٤).

٣.٣.٤ Water :

Tap water used throughout this work for both mixing and curing of concrete .

٣.٣.٥ Finely Divided Mineral Admixtures

٣.٣.٥.١ Lime Stone Dust :

The lime stone dust used in the experimental work supplied by lime factory which is delivered the local materials from Al-Kadak region in western desert. It stored in a dry place and added to the concrete mixes as a dry powder. The physical and chemical analysis of this dust are given in Tables (٣.٢) and (٣.٣) .

٣.٣.٥.٢ Silica Flour :

The silica flour used throughout the research brought from General Company of Geological Mining and Survey in Baghdad which is delivered the local materials from Al-Sufra in western desert. It stored in a dry place and added to the concrete mixes as a dry powder. The physical and chemical analysis of this silica flour are given in Tables (٣.٤) and (٣.٥)

٣.٣.٥.٣ Bentonite :

Bentonite used through the research brought from General Company of Geological Mining and Survey in Baghdad which is delivered the local materials from Al-Sufra in western desert. This Bentonite is yellowish – brown in color. It stored in a dry place and added to the concrete mixes as a dry powder the physical and chemical analysis of this Bentonite are given in Tables (٣.٦) and (٣.٧).

Table (٣.٢) : Chemical Properties of Lime Stone Dust[*]

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[*] Chemical properties tests of (LSD , SF and Bt) are achieved by general company of geological mining and survey.

Chemical compound	Percent of total weight
CaO	٥٤.٦٨
SiO_2	١.٢
Fe_2O_3	٠.٠٧
Al_2O_3	٠.٢٥
TiO_2	٠.٠٠٦
MgO	٠.٢٦
Na_2O	٠.١٣
K_2O	٠.٠٥
L.O.I	٤٢.٦٥
SO_3	-

Table (٣.٣) : Hydrometer Analysis of Limestone Dust

Diameter of particles (μ^{**})	Percent of finer particles
٧٣	١٠٠
٥١	٩٢.٥
٣٤	٩١.٤
٢٢	٩١.٢
١٥	٩٠.٥
١١	٨٨.١
٦.٠	٨٢.٣
٤.٩	٥٩.٨
٣.٥	٣٢.٥
١.٩	٣٠
١.٠	١٩.٧٧

Table (٣.٤) : Chemical Properties of Silica Flour

** μ : Micron

Chemical compound	Percent of total weight
SiO_2	٩٨.٦
Al_2O_3	٠.٦٦
Fe_2O_3	٠.٠٩٢
CaO	٠.٥٤
MgO	٠.٠٤
So_3	-
K_2O	٠.٠٣
Na_2O	٠.٠٤

Table (٣.٥) : Hydrometer Analysis of Silica Flour

Diameter of particles (μ)	Percent of finer particles
٦٩	١٠٠
٤٩	٩٨.١٨
٣٥	٩٧.٧٤
٢٤	٩٧.٧٤
١٥	٩٧.٧٤
٩.٠	٩٥.٩٣
٦.٥	٩٠.٥٠
٥.٠	٧٧.٨٣
٤.٠	٥٧.٩٢
٣.٠	٤١.٦٣
١.٠	٢١.٧٢

Table (٣.٦) : Chemical Properties of Bentonite

Chemical compound	Percent of total weight
SiO_2	٥١.٩٦
Fe_2O_3	٤.٩٢
Al_2O_3	١٤.٦٩
TiO_2	٠.٩
CaO	٥.٨٩
MgO	٣.٣٨
Na_2O	١.١
K_2O	٠.٤٣
L.O.I	١٣.٠٢

Table (٣.٧) : Hydrometer Analysis of Bentonite

Diameter of particles (μ)	Percent of finer particles
٦٧	١٠٠
٤٧	٩٧.٨
٣٣	٩٦.٢
٢١	٩٦.٠
١٦	٩١.٠

١٠	٩٠.٨
٨.٠	٨٧.٩
٤.٥	٧٥.١
٣.٠	٥٥.٩
٢.٥	٤٠.٣
١.٠	٢٥.١

٣.٣.٦ Moulds :

The moulds used in this study are as follows :

١- Channel shape moulds having a channel section with the dimensions shown in Figure (٣.١) used to offer an end – restraining frame. This frame used to study free shrinkage and shrinkage cracking of end – restrained concrete members.

Side view

Concrete

Restraining steel base

Sec A - A

١٢٠ mm

٥٠ mm

١٠٠ mm

٢٨٠٠ mm

١٠٠ mm
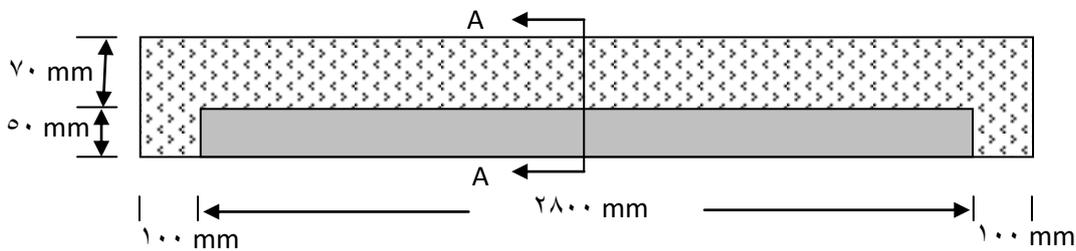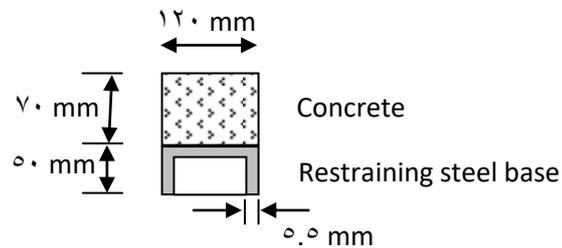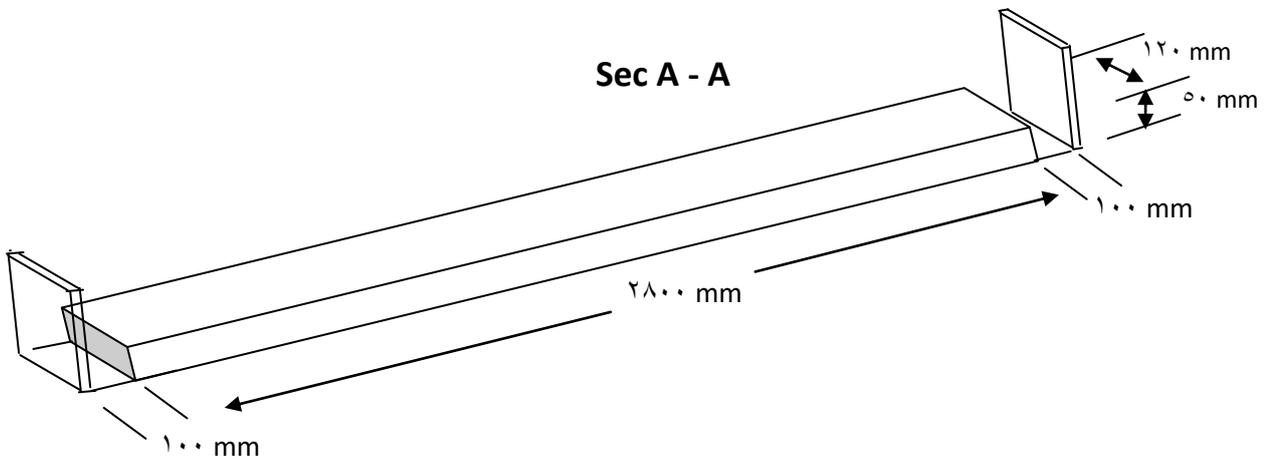
Isometric Drawing of the Steel Mould

Fig (٣.١) Schematic Diagram of the Restraining Steel Mould

٢- (١٥٠ x ١٥٠ x ١٥٠ mm) cube moulds of concrete specimens for compressive strength test .

٣- (١٠٠ x ٢٠٠) mm cylinder moulds of concrete specimens for splitting tensile strength test.

٤- (١٥٠ x ٣٠٠) mm cylinder moulds of concrete specimens for static modulus of elasticity test.

٥- (١٠٠ x ١٠٠ x ٤٠٠ mm) prism moulds of concrete specimens for flexural strength test.

The cube and cylinder moulds were cleaned and rigidly tightened. They were oiled in order to facilitate the demoulding process.

For the channel shape mould , a layer of polyethylene sheets was put over the channel base and oiled to minimize base friction.

٣.٣.٧ Mix Design and Proportions :

The concrete mix designed according to ACI mix design method (ACI ٢١١.١. ٧٧). This mix designed to obtain a target compressive strength of (٣٠ MPa) at ٢٨ days age and a slump range of (١٥٠ – ١٨٠) mm. The maximum size of coarse aggregate chosen to be (١٢.٥ mm) in order to enhance the compatibility of concrete in the restraining mould. The quantities of the materials for the concrete mix were as follows :

Cement (kg/m^٣)	Sand (kg/m^٣)	Gravel (kg/m^٣)	Water (kg/m^٣)	W/C ratio
٤٧٩.٢	٦٦٢	٩٤٤	٢٣٠	٠.٤٨

The mix proportions are (١:١.٣٨:١.٩٧)

٣.٤ Mixing, Casting and Compaction :

The following method adopted for mixing the materials. The concrete mixed using an electrical drum type mixer with a capacity of (٠.١ m^٣) . The interior surface of the mixer cleaned and moistened before placing to prevent water absorption from the mixture.

Materials put in the pan of the mixer , firstly the coarse and fine aggregates mixed together with small amount of mixing water . Cement and the residual of mixing water added in succession as mixing proceeded, then mixing continued until a homogeneous mix was obtained. The total mixing period from the time of adding water was about ٤ minutes. The slump was measured according to ASTM (C١٤٣.٨٩ a : ١٩٨٩) [٧٦].

Then the concrete mixes cast and well compacted in the moulds by a tamping rod in three layers for cubes and four layers for cylinders and two layers for the restraining steel frame and prism moulds. Finally , the moulds leveled by hand trawling.

٣.٥ Curing and Drying Conditions :

Wett Hessian sheets and polyethylene sheets were used to cover the surface of shrinkage beams after casting to prevent plastic shrinkage cracking due to rapid evaporation from the upper surface of concrete specimens. The chosen period of curing (٣ days) by sprinkling of water for drying shrinkage specimens. The remaining compressive, splitting and flexural specimens demoulded after they covered with polyethylene sheets and then put in water at (٢٢ C) for (٢٨ days) .

The drying shrinkage beam specimens subjected to drying in uncontrolled laboratory conditions. Temperature and relative humidity variation in the laboratory measured and recorded.

All the specimens cast in September. The measurements continued until January for drying shrinkage specimens. In this period the relative humidity and temperature given in Table (٣.٨).

Table (٣.٨) : Temperature and Relative Humidity During Measurement Period

Month	Temperature (av.) C	Relative humidity (av.) %
September	٣٩.٠	٣١.٠
October	٢٩.٠	٣٣.٥
November	٢٢.٤	٤٣.٦٣
December	٢١.٥٤	٤٨.٧٩
January	١٨.٣٢	٥٤.٩٢
Total Average	٢٦.٠	٤٢.٣٦

٣.٦ Testing of the Concrete Specimens :

٣.٦.١ Restrained – Shrinkage Test :

Concrete beams were tested for restrained shrinkage. The shrinkage cracking model was based on the model devised by Al-Rawi [٤٤] , where the beams were left in the moulds (to achieve end restraint by the moulds). For each mix, two restrained shrinkage mould were used, the first was supplied with artificial crack, (opening) in the web for free shrinkage determination as can be seen in plate (٣.١) and the other for restrained shrinkage cracking test.

The small depth of the beam (٧٠ mm) would enable a fast rate of drying shrinkage without significant differential shrinkage.

The end of the mould offers an end-restraint to the web which would be formed as a result of the stresses induced from concrete shrinkage.

The contraction at the surface of the drying concrete web was measured by the distance between the demec points using a mechanical extensometer with (٢٠ cm) gauge length and an accuracy of (٠.٠٠٢ mm/division) as in plate (٣.٢). The demec points were fixed (during the first stage of curing period) a long the center line of the web at (٢٠ cm) apart using an adhesive epoxy resin.
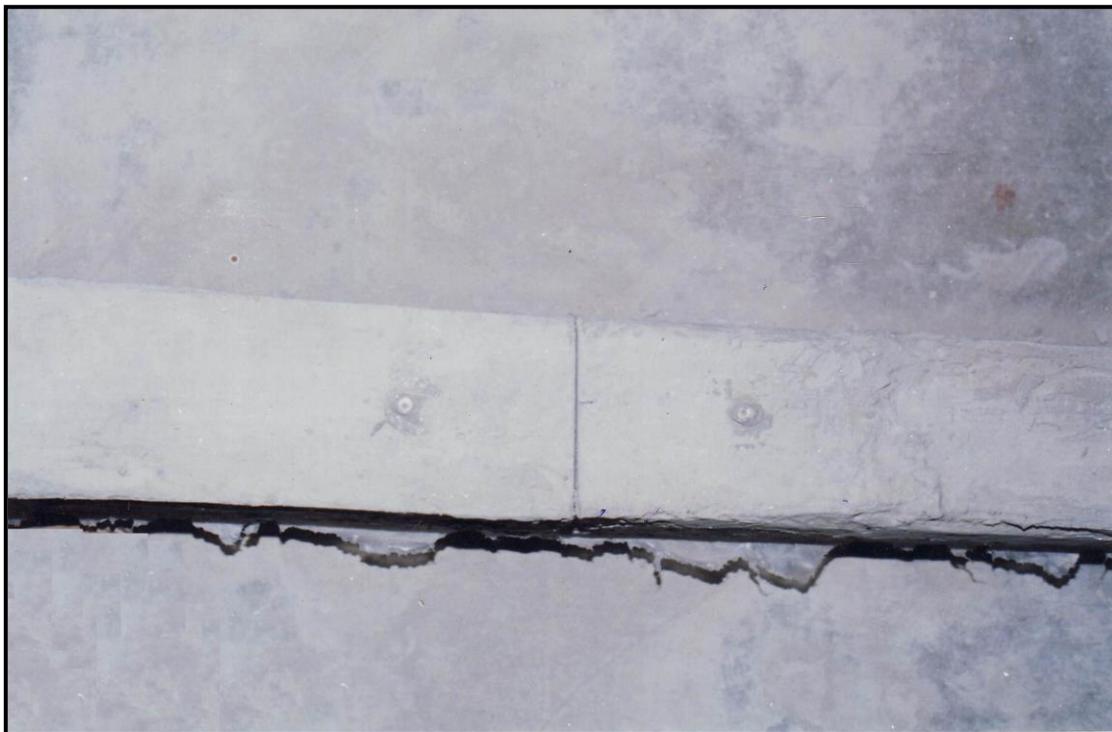
Plate (٣.١) : The Artificial Gap and Two Demecs on The Sides of The Gap
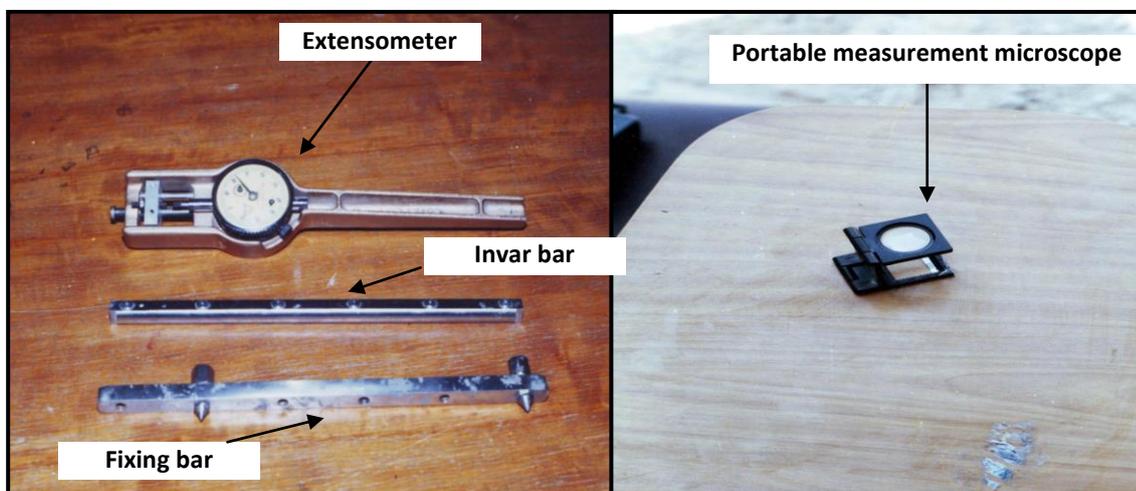
Plate (٣.٢) : Devices of Measurement of Concrete Shrinkage

After the occurrence of crack, the strain measurement was repeated so as to record the free contraction recovery of concrete (the elastic tensile strain capacity) at the onset of the crack. The elastic tensile strain capacity is taken as the splitting tensile strength divided by the modulus of elasticity. Further demec points were fixed at the side of the

restraining steel mould in order to measure the amount of loss of restraint, which is due to shortening of the steel mould prior to cracking.

The free shrinkage was determined by fixing demec points at both sides of the gap for the moulds with artificial crack (opening) in the web and by different periods measuring the widening of the artificial crack in the middle of the beam, see plates (٣.٣a , ٣.٣b).

Plate (٣.٣a) : Some of Specimens for Free and Restrained Shrinkage Of Concrete

Plate (٣.٣b) : Free Drying Shrinkage Measurement

Readings were taken from the next day after curing period till (١٣٠ days) or when no movement could be recorded.

The tensile strain capacity represent, the free shrinkage strain resisted by the specimen due to drying from the moment of casting until the occurrence of cracking taking into account the loss in restraint during this period.

Creep strain was calculated by subtraction the elastic tensile strain capacity from the tensile strain capacity. The crack width was measured by a crack dial microscope. Equations mentioned below explain the above experimental measurements :

Creep strain = tensile strain capacity – elastic tensile strain capacity

Tensile strain capacity=Free drying shrinkage strain–loss in restraint

٣.٦.٢ Compressive Strength Test :

This test was done according to British Standards (B.S ١٨٨١ part ١١٦:١٩٨٣) [٧٧] for ages (٧ & ٢٨) days. The capacity of the compression machine used for this purpose was (٢٠٠٠ KN). For each test age three cubes of concrete tested for each mix used.

Before the cube specimens tested, they taken out from the water tank. Their surfaces dried of the excess water and kept in the laboratory for a few minutes to obtain saturated dry surface specimens.

٣.٦.٣ Splitting Tensile Strength Test :

This test was done according to the procedure outlined in ASTM-C٤٩٦ [٧٨]. Each splitting tensile strength value was the average of two specimens.

٣.٦.٤ Flexural Strength Test :

The two point loading method was used in making flexure strength test. This test was done according to (B.S ١٨٨١.١٩٧٠) [٧٩], using a machine of (١٠٠٠ KN) maximum capacity. Each flexural strength value was the average of three specimens.

٣.٦.٥ Static Modulus of Elasticity Test :

The static modulus of elasticity was determined according to ASTM-C٤٦٩ [٨٠] specification. The specimens were cured as for cubes. The top surface of cylinders was well – finished and capped with cement paste to a void any loss of strength, the load was applied gradually and increased continuously at a constant rate until ٤٠٪ of the ultimate load . The compress meter used has a gauge length of ١٥٠ mm and a dial gauge with an accuracy of ٠.٠١ mm. The recorded values are the average readings for two cylinders.

٣.٦.٦ Density Test :

This test was done in order to get information about the variation of voids contents due to the difference in percentages of the (FDMA)

used in this work. It was carried out on the same specimens which are used in the compressive strength test. The concrete specimens were weighted to the nearest (٠.٠٥ gm). Each density value was the average of three specimens.

٣.٦.٧ Surface Hardness Test :

Schmidt rebound hammer used to test of surface hardness of concrete specimens. This test was done with the cub concrete specimens. Each rebound number value was the average of three specimens.

CHAPTER FOUR

RESULTS AND DISCUSSION

٤.١ Introduction :

In this chapter , the results of the tests described in chapter three are presented and discussed. To condense the data , only the average values of test results are provided in form of tables and figures.

٤.٢ Free Shrinkage Test :

By using the steel mould described in chapter three (concrete beam with a gap at its middle to ensure free movement) free shrinkage was measured for all concrete specimens and recorded in Table (٤.١).

Curves showing free drying shrinkage strain development of concrete beams made with and without finely divided mineral admixtures are shown in Figures (٤.١ to ٤.٦).

From these Figures it can be seen that the free drying shrinkage increases with the age progress for all mixes , the rate of shrinkage varies depending with respect to the evaporation intensity. The initial rate of drying shrinkage at early ages was very high because of the diffusion theory of drying that the shrinkage is influenced powerfully by the moisture loss. The moisture will be evaporated initially from surface and near the surface with a high rate. This is due to the high diffusion coefficient of the moisture from the surface as a vapor.

It can be noticed from Figure (٤.١), Figure (٤.٤) and Table (٤.١) that concrete mixes of (LM₁.₅, LMᵣ, LM₄), had free drying shrinkage strains is lower than that of the control mix. This reduction in free drying shrinkage strain for these mixes is nearly constant for all drying periods.

It can be noticed from the Figure (٤.٢) and Figure (٤.٥) that concrete mix (SM₈) containing silica flour of (٨٪) the free drying shrinkage strain increased about (١١٪ , ٩%) for drying periods (٦٣ & ١٣٠) days respectively compared with their control mix, while mixes (SMᵣ.₅ and SM₅) have no significant effect on free drying shrinkage strain compared with control mix for all drying periods.

It can be noticed from the Figure (٤.٣) and Figure (٤.٦) Bentonite admixture has a great influence on free drying shrinkage strain of concrete mixes. The mixes containing bentonite gave high increase in free drying shrinkage strain compared with the control mix, except for the (٢٨ days) age.

Concrete mix (BM٢.٥) containing bentonite of (٢.٥٪), the free drying shrinkage strain increased about (١٥٪, ٢١٪) for drying periods (٦٣ & ١٣٠) days respectively compared with control mix. The second concrete mix containing bentonite (BM٤.٥), the free drying shrinkage strain increased about (٢٤٪ , ٢٢٪) for drying periods (٦٣ & ١٣٠) days respectively compared with their control mixes. The third concrete mix containing bentonite (BM٦), the free drying shrinkage strain increased about (١٦% , ٢٧%) with drying periods (٦٣ & ١٣٠) days respectively compared with control mix.

These differences in free drying shrinkage strain for different admixtures used depend on :

١- fineness of admixture

٢- Its ability of mixing with water

٣- Its ability to create air voids, gel pores and gel particles.

Another measurements of cracking time and free drying shrinkage strain at that time and other drying shrinkage data are listed in Table (٤.٢). it can be seen that the free drying shrinkage strain (at cracking time) depends on the type of the admixture and its content.

It can be noticed that the free drying shrinkage strain at the cracking time decreased about (٢١%) for all mixes with lime stone dust (LM₁.₅, LM₃ and LM₄) compared with the control mix, (SM₂.₅) silica flour admixture (٢.٥٪), the free drying shrinkage strain at the cracking time decreased about (١٥%) compared with the control mix. Mixes with silica flour of level (SM₅ and SM₈), the free drying shrinkage strain at the cracking time decreased about (١٨%).

It can be noticed that for the Bentonite admixture, the free drying shrinkage strain at cracking time is lower than that of the control mix except the mix (BM₆) (٦٪ by weight of cement), it had greater free drying shrinkage strain than that of the control mix about (١١٪), where as (BM₂.₅) of (٢.٥٪) was about (١٢%) lower than that of the control mix and the mix (BM₅) of (٥٪) was about (٨٪) lower than that of the control mix.
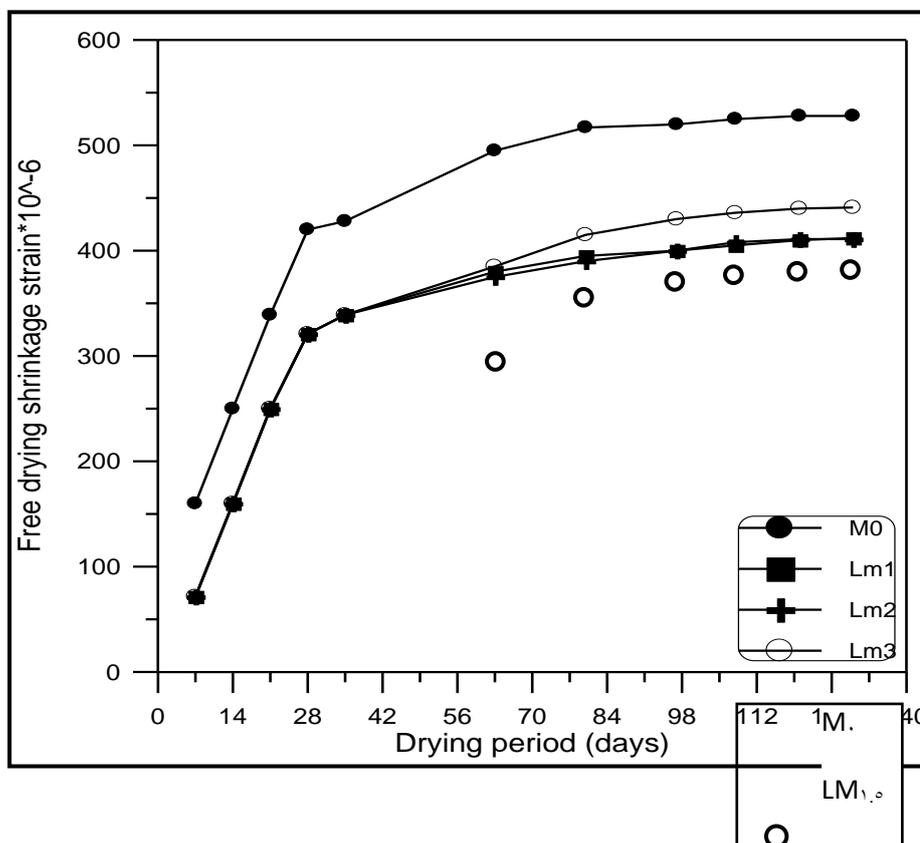
Figure (٤.١) : Free Drying Shrinkage Versus Drying Periods for Concrete Mixes with Different Levels of (LSD)
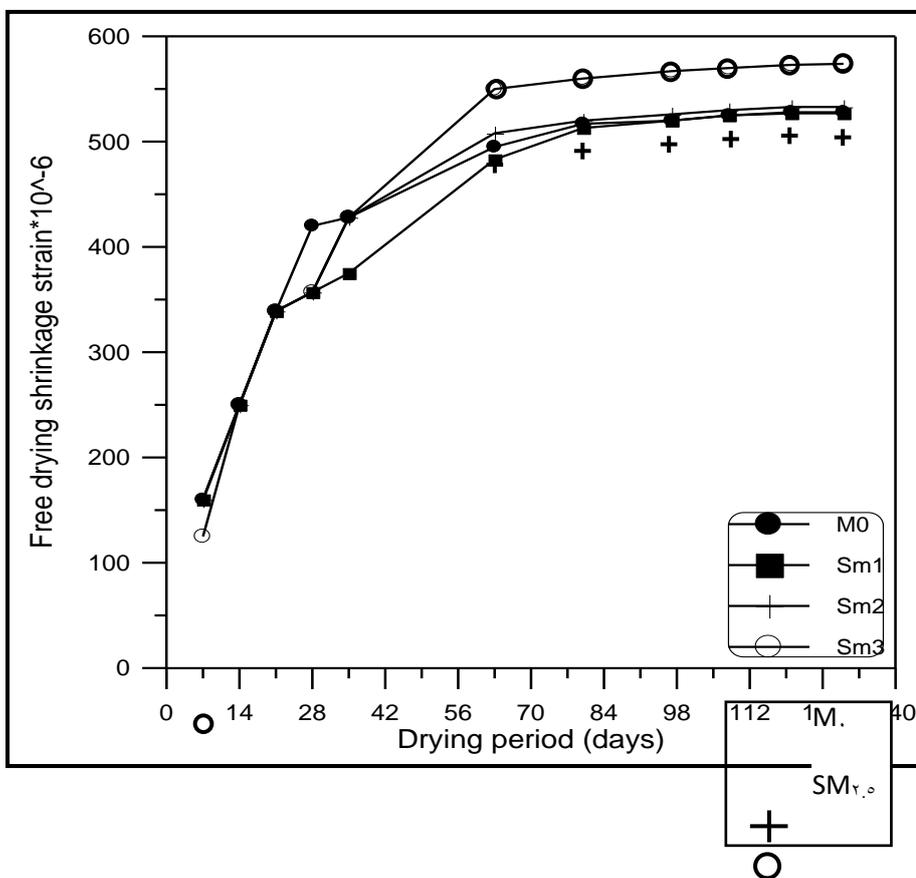
Figure (٤.٢) : Free Drying Shrinkage Versus Drying Periods for Concrete Mixes with Different Levels of (SF)
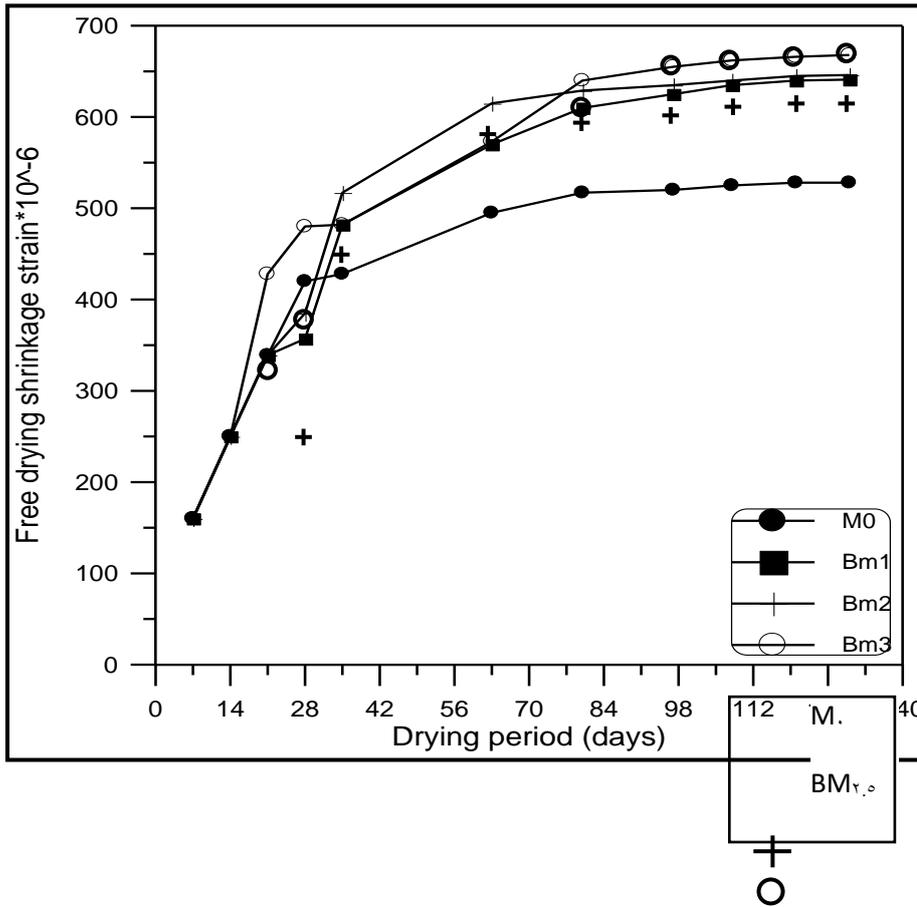
Figure (٤.٣) : Free Drying Shrinkage Versus Drying Periods for Concrete
Mixes with Different Levels of (Bt)
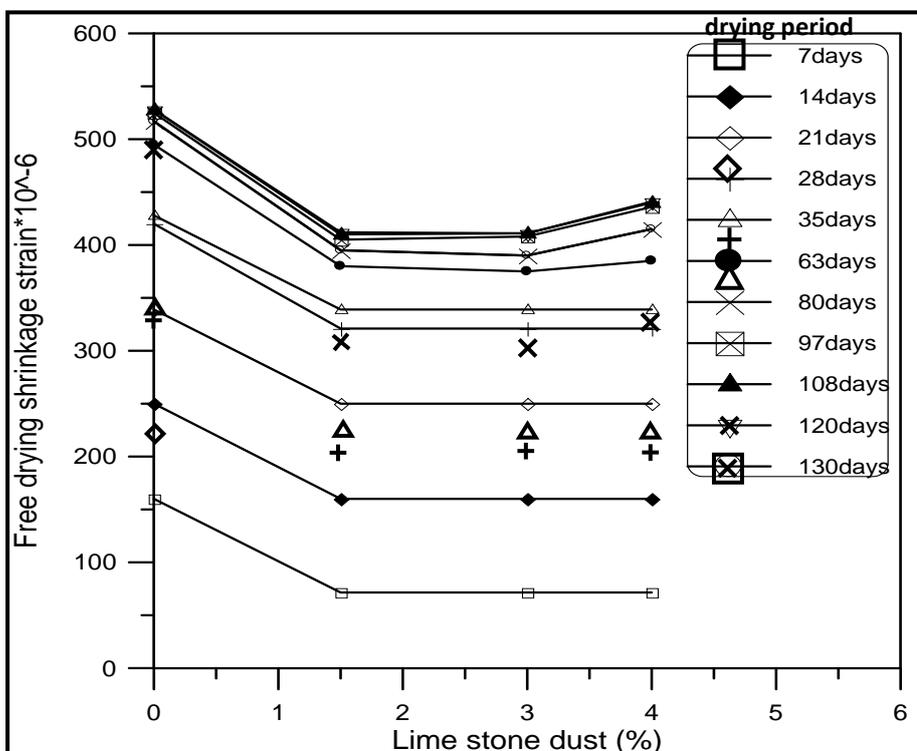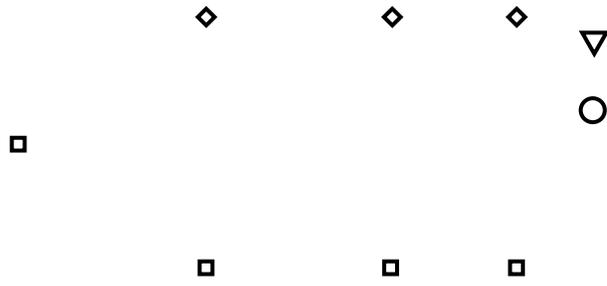
Figure (٤.٤) : Free Drying Shrinkage Versus Various Lime Stone Dust Contents with Different Periods
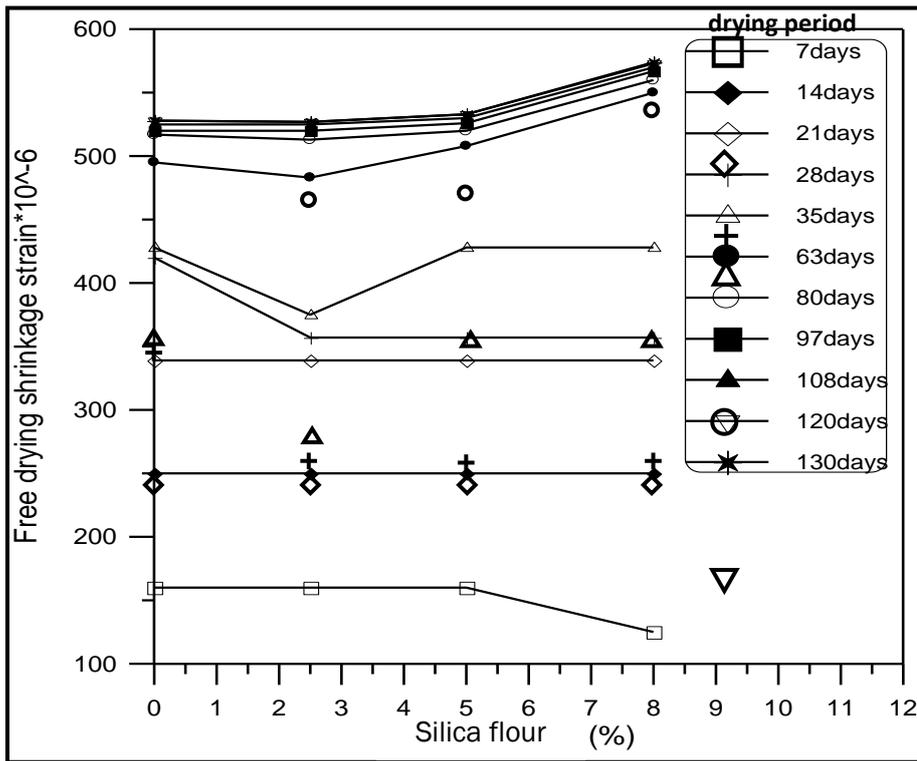
Figure (٤.٥) : Free Drying Shrinkage Versus Various Silica Flour Contents with Different Periods
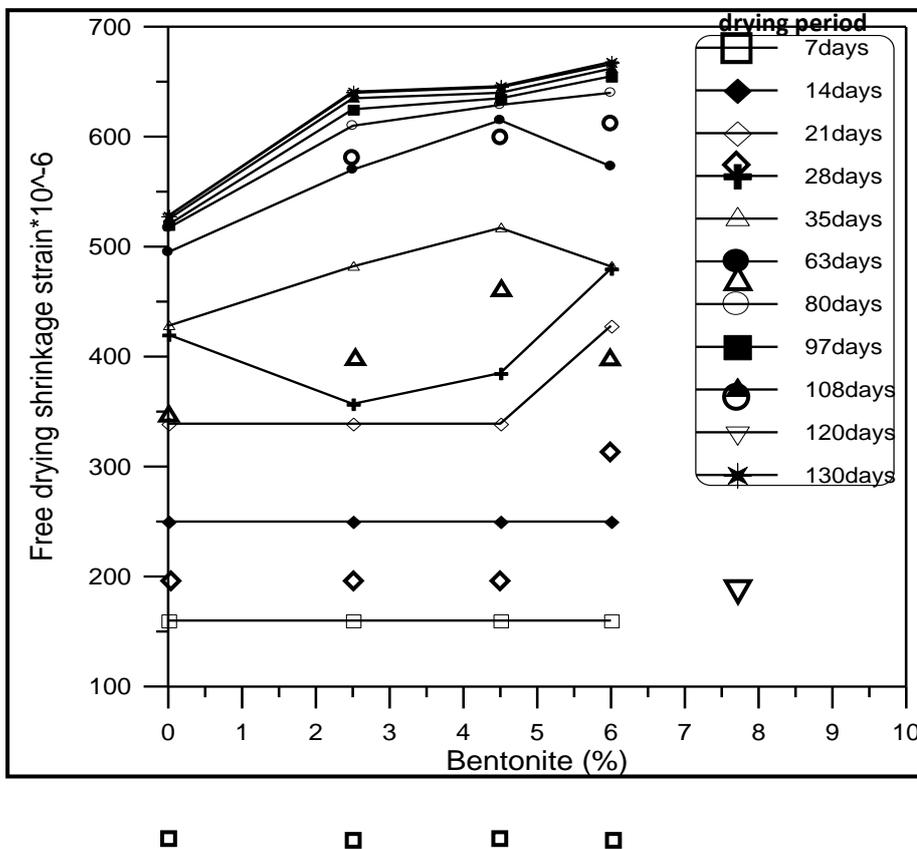
Figure (٤.٦) : Free Drying Shrinkage Versus Various Bentonite Contents with Different Periods

٤.٣ Restrained Shrinkage test :

When the concrete is stored in mould and exposed to dryness process, the web shrinks while the restrained edge tends to hinder this action. Some loss of restraint will be occurred and net web shortening takes place. It follows that the loss of restraint of the concrete beam prior

to cracking can be estimated as the compression (shortening) in the mould web [٨١]. Such movement was measured by taking strain gauge readings at the both sides of the steel channel web (demec points were fixed on the two beam sides to measure the amount of loss of restraint due to shortening of the web steel mould during the time prior to cracking).

To predict the improvement in concrete shrinkage cracking properties, the first cracking time was recorded.

Loss of restraint measurement and the first cracking time are given in Table (٤.٢).

٤.٣.١ Tensile Strain Capacity :

The determination of tensile strain capacity was based on the restrained shrinkage model presented by Al-Rawi [٦٤]. The tensile strain capacity is shown in Table (٤.٢) and Figures (٤.٨ and ٤.٩).

Indicating of Table (٤.٢) and Figures (٤.٧ and ٤.٨) it can be seen that the effect of the three finely divided mineral admixtures on tensile strain capacity. It can be seen that , an addition of the percentage of these admixtures to concrete mixes causes an evident reduction in tensile strain capacity at cracking time for these concrete mixes compared with the control mix, except the mix containing Bentonite (BM₆) of (٦٪) it increases about (١٤%). The difference in tensile strain capacity for concrete mixes containing the admixtures compared with the control mix is given in Table (٤.٣).
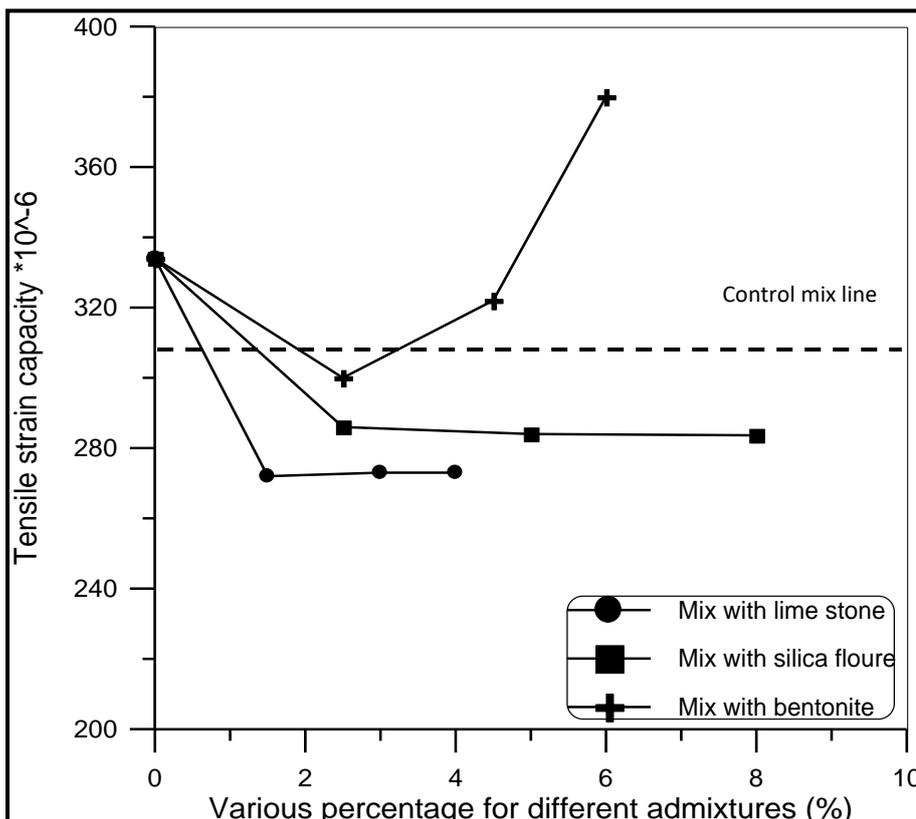
dust

flour

% Admixture content

Figure (٤.٨) : Effect of The Admixture Type on The Tensile Strain Capacity of Concrete
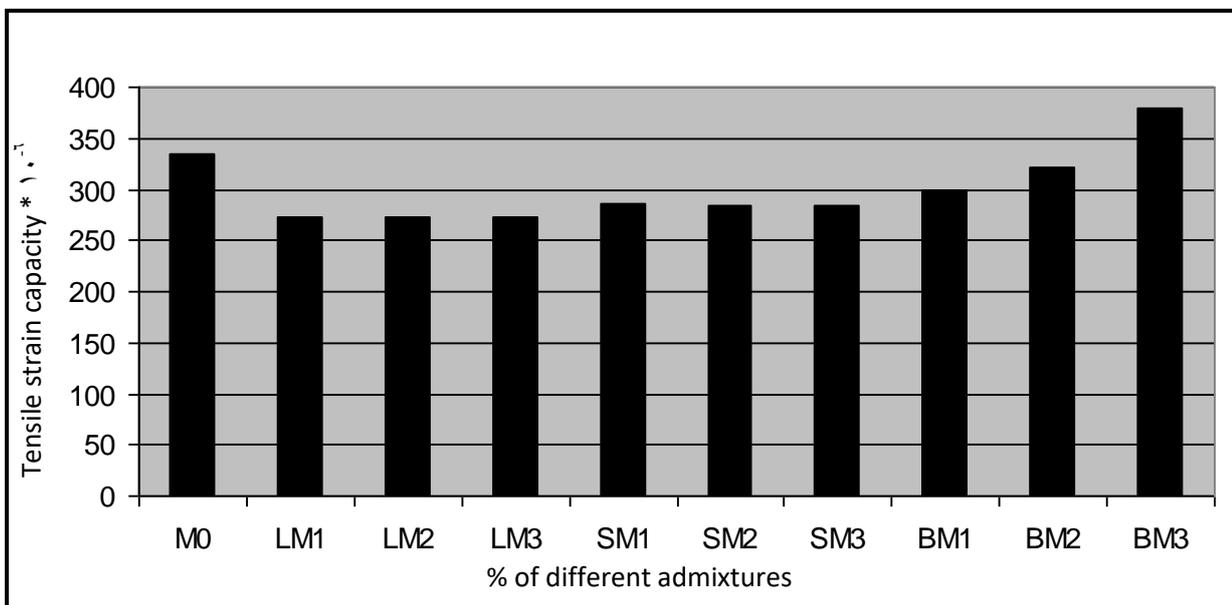
Figure (٤.٨) : Effect of Various Contents of (FDMA) on Tensile Strain Capacity of Concrete

Table (٤.٣) : The Difference in Tensile Strain Capacity for Concrete Mixes Containing The Admixtures Compared with The Control Mix

Mix symbol	Tensile strain capacity *١٠$^{-6}$	The difference % in tensile strain capacity
M.	٣٣٤	٠
LM١.٥	٢٧٢	-١٨.٥
LM٣	٢٧٣	-١٨.٢
LM٤	٢٧٣	-١٨.٢
SM٢.٥	٢٨٦	-١٤.٣
SM٥	٢٨٤	-١٤.٩
SM٨	٢٨٣.٦	-١٥
BM٢.٥	٣٠٠	-١٠.١
BM٤.٥	٣٢٢	-٣.٦
BM٦	٣٨٠	+١٣.٧

The main reasons for this behavior are due to the admixture type, the free drying shrinkage strain value and the loss extent in end restraint of the steel mould.

The above behavior may be attributed to the fact that drying shrinkage increases with the presence of fine particle admixtures which make cracks to appear at early time. At this time the free drying shrinkage is lower than the control mix. This leads to reduce the tensile strain capacity.

٤.٣.٢ Elastic Tensile Strain Capacity :

The test results of elastic tensile strain capacity are given in Table (٤.٢). When the crack takes place in the concrete specimen, the tensile strain capacity is measured as the immediate reversible movement after cracking.

Table (٤.٤) shows the effect of the three finely divided mineral admixtures on the elastic tensile strain capacity and its differences compared with control mix.

It can be seen that, the addition of these admixtures to concrete mixes causes a clear reduction in elastic tensile strain capacity at cracking time for compared with the control mix, except with the concrete mix (BM₁) containing Bentonite of level (٦٪), it increases about (٤٣%).

Table (٤.٤) : The Difference in Elastic Tensile Strain Capacity for Concrete Mixes Containing the Admixtures Compared with the Control Mix

Mix symbol	Elastic tensile strain capacity * 10^{-6}	The difference % in elastic tensile strain	Calculating elastic tensile strain capacity

		capacity	$*10^{-6}$
M.	١٢٥	.	١٠٦
LM١.٥	١١٤	-٨.٨	١٠٩
LM٣	١٠٤	-١٦.٨	١٠١
LM٤	١٠٠	-٢٠	١٠٤.٥
SM٢.٥	١١٤	-٨.٨	١٠٥.١
SM٥	١٠٧	-١٤.٤	١٠٣.٥
SM٨	١١٤	-٨.٨	١١٧.٣
BM٢.٥	١٠٧	-١٤.٤	١١٧.٧
BM٤.٥	١٢٥	.	١١٧.٨
BM٦	١٧٨.٥	+٤٢.٨	١١٤.٦

From this table, it can be noticed that, the calculated values of the tensile strain capacity are under estimated than those measured directly. This is in line with Al-Rawi [٦٢] who found that the elastic tensile strain capacity obtained using the direct method was greater than that calculated.

٤.٣.٣ Creep :

Creep strain of the specimens subjected to restrained drying shrinkage was determined as the difference between the tensile strain capacity and the elastic tensile strain capacity [٦٢].

Table (٤.٥) and Figure (٤.٩) shows the effect of the admixture on creep strain of concrete, it can be seen that the creep strain (at cracking

time) decreases with the addition of any percentage of these finely divided mineral admixtures.

The reduction of creep strain at cracking time was at different rates because of the difference in tensile strain capacity values.

The reduction in creep strain at cracking time for mixes containing the admixtures compared with control mix is given in Table (٤.٥).
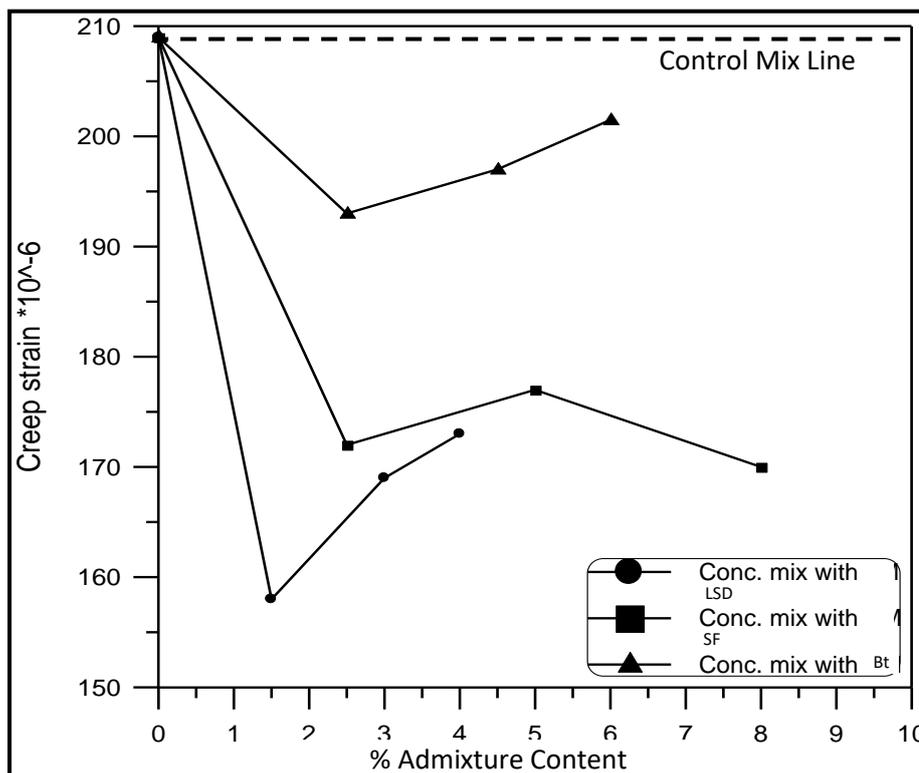
Figure (٤.٩) : Effect of The Admixture Type on The Creep Strain of Concrete

Table (٤.٥) : The Reduction in Creep Strain for Concrete Mixes Containing Different Admixtures of (FDMA) Compared with Control Mix.

Mix symbol	Creep strain $*10^{-6}$	Creep strain reduction %
M٠	٢٠٩	٠
LM١.٥	١٥٨	٢٤.٤
LM٣	١٦٩	١٩.١
LM٤	١٧٣	١٧.٢
SM٢.٥	١٧٢	١٧.٧
SM٥	١٧٧	١٥.٣
SM٨	١٧٠	١٨.٦
BM٢.٥	١٩٣	٧
BM٤.٥	١٩٧	٥.٧
BM٦	٢٠١.٥	٣.٥

This behavior of creep strain may be attributed to the elongation of cracking time and the restrained shrinkage tensile stress due to drying conditions [٦٢,٨٢].

٤.٤ First Cracking Time :

From Table (٤.٦) and Figures (٤.١٠) to (٤.١٢) it can be seen that the influence of admixtures on drying shrinkage cracking is not equal, some of the admixtures decreased the first crack time and the others showed the same of that of the control mix.

To evaluate the improvement in concrete shrinkage cracking properties, the first crack time was recorded.

High difference in cracking time was caused for silica flour (٥٪ , ٨٪ by weight of cement) and bentonite admixture at level (٦٪ by weight of cement) Compared with control mix. That is may be due to the ability of these admixture to leads cracks to appear earlier because the strength of concrete is still in a weak stage.

In general, cracking time increases when admixtures are used, but in other side, these admixtures have a property that they have a high surfactant effect, forming air voids in concrete during the mixing process, and thus the strength of concrete is reduced [٥٨].

٤.٥ Crack Width :

The restrained shrinkage crack width test results of the concrete beams made with admixtures of (FDMA) and without it, are given in Table (٤.٦) and plotted in Figure (٤.١٠) to Figure (٤.١٢).
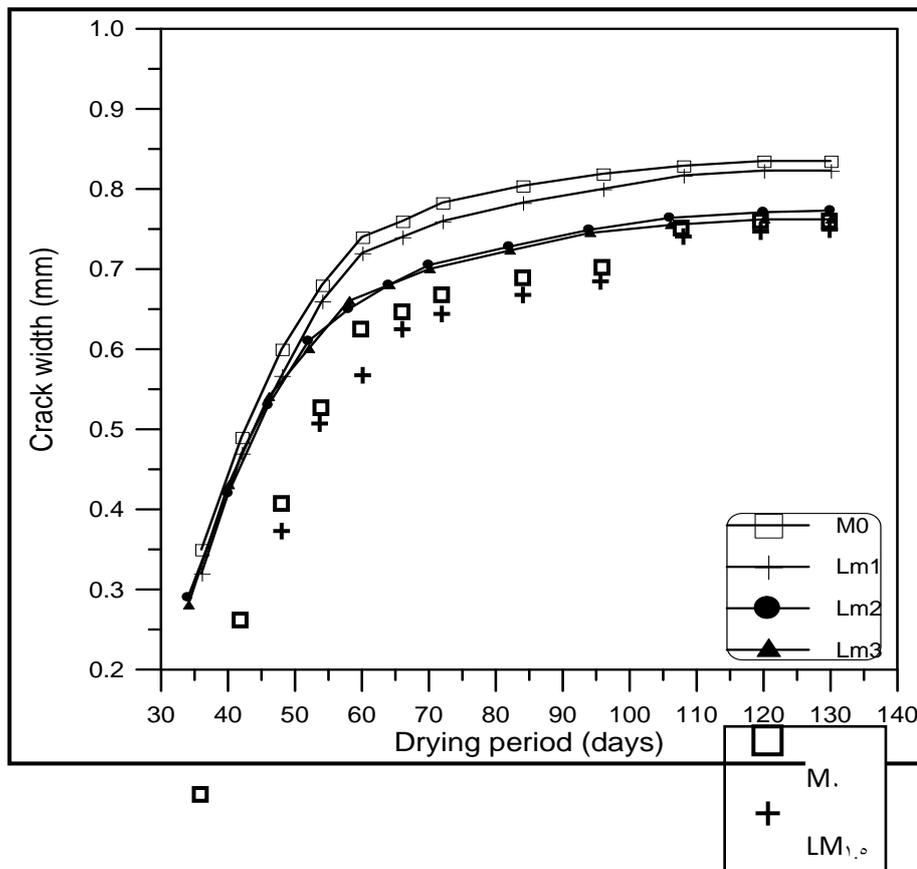
Figure (٤.١٠) : Crack Development of Concrete Made With Different Levels of Limestone Dust Admixture And Without It
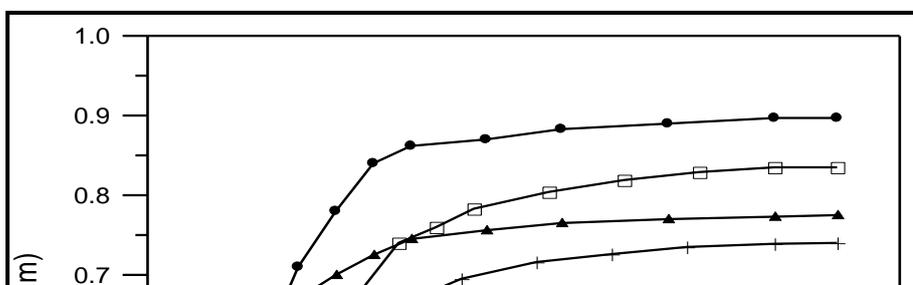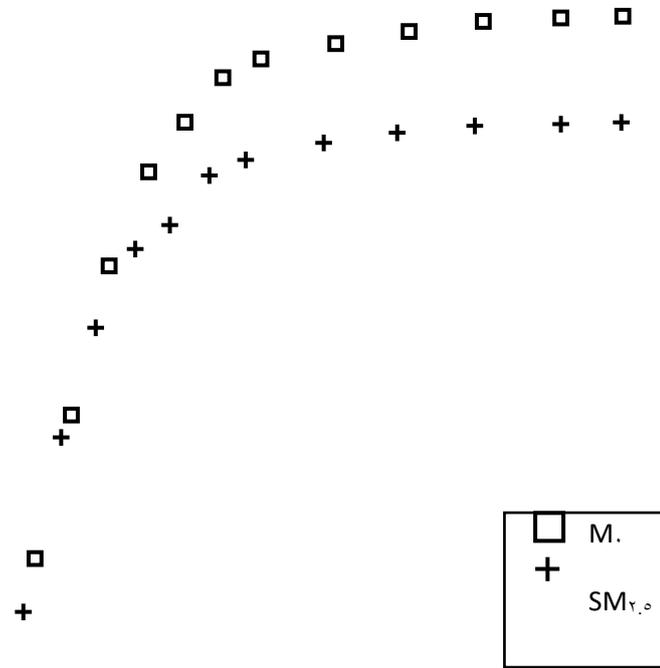
Figure (٤.١١) : Crack Development of Concrete Made With Different Levels of Silica Flour Admixture And Without It
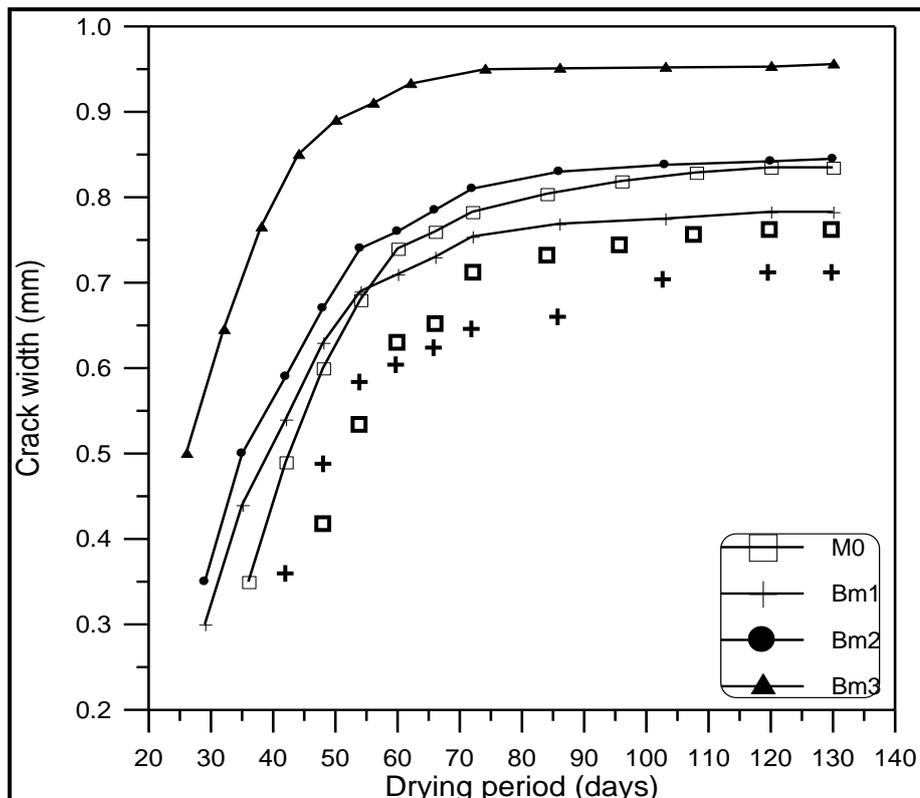
Figure (٤.١٢) : Crack Development of Concrete Made with Different Levels of Bentonite Admixture and without It

From these tables and figures, it can be seen that the crack width of the mixes made with admixtures was the same and lower than the crack width of control mix, except those (BM٦) and (SM٥) for the mix with (٦٪) Bentonite (BM٣), the crack width was higher about (٤٣%) compared with the control mix, contrary the (LM٤) lime stone dust (٤٪) which crack width is lower about (٢٠٪).

The measurement of crack width for all specimens was achieved by portable dialed microscope, every (٦) days at early ages and every (١٢) days at later ages.

Generally , the crack width development is slower with age progress when admixtures were added compared with control mix. This can be considered as an advantage reflection of using some admixtures,

as reducing crack width is very important from durability point of view [٢].

At later ages, it is obvious that there is effect on crack width when the Bentonite (٦٪) was used, it was changed from (٠.٨٣ mm) for control mix to (٠.٩٥ mm) at (١٣٠ days) age.

٤.٦ Position of The Crack :

A combination of shrinkage and restraint develops tensile strain. When the induced strain exceeds the allowable tensile strain of concrete, cracking takes place. Alternatively, when the developed stress exceeds the tensile strength of concrete , cracking occurs [٤٤] .

Plates (٤.١) to (٤.٥) show the position of crack for some concrete specimens. It can be noticed that the cracks occurred within the middle third of the concrete specimen rather than at the side thirds. This means that the higher restrained shrinkage strain is at the middle of the specimen rather than at the sides. This behavior is attributed to the growth of a strain gradient at the end which increases the restraint loss and reduces the possibility of cracking, while at interior regions, higher strain would be developed due to the build up of friction forces and the absence of strain gradient, so cracks would be expected to initiate at the interior regions of member [٤٤].

Plate (٤.١) : The Crack Location in Specimen (LM٢)

Plate (٤.٢) : The Crack Location in Specimen (SM٢.٥)

Plate (٤.٣) : The Crack Location in Specimen (SM₈)
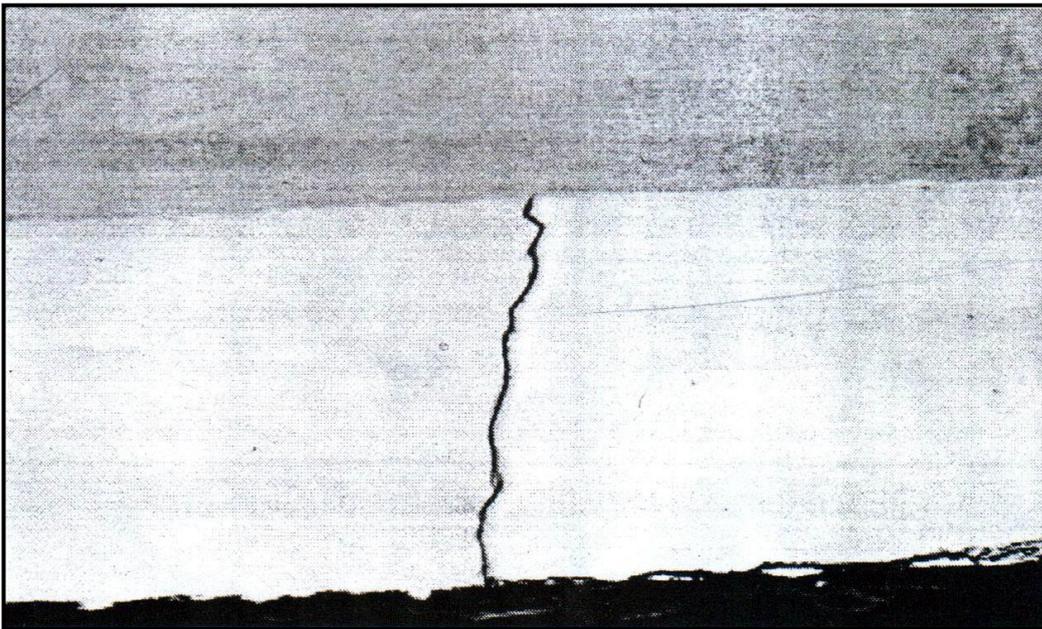
Plate (٤.٤) : The Crack Location in Specimen (BM₂.₅)
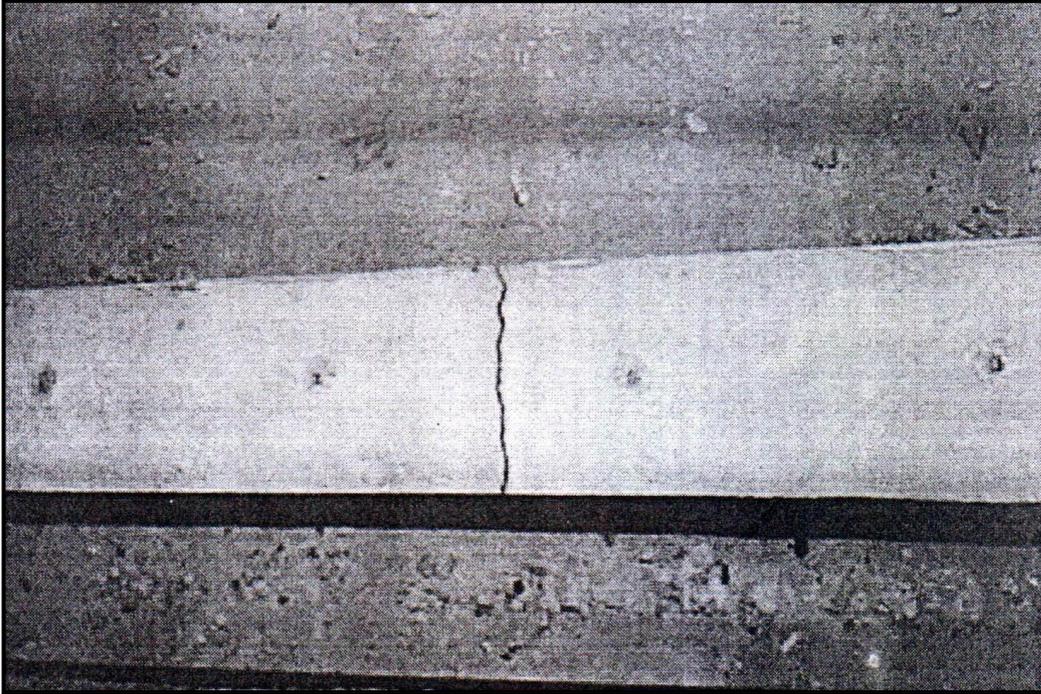
Plate (٤.٥) : The Crack Location in Specimen (BM٤.٥)

٤.٧ Compressive Strength :

The compressive strength test results of the concrete specimens made with and without admixtures at age (٧ and ٢٨ days) are given in Table (٤.٧a) and plotted in Figure (٤.١٣) to Figure (٤.١٥).

From these results the following observations can be noticed :

١. The different rates of strength development can be attributed to the influence of type of the admixture and the occurred decrease in the (w/p) due to admixture addition. The variation in the compressive strengths are given in Table (٤.٧b) .

٢. It is found from Figure (٤.١٣) that the early compressive strength of admixture mixes, were greater than the control mix except the mix which has Bentonite (٦٪) (BM٦) it was lower than the control mix about (٤%). It was increased about (١٦%) for concrete made with the Bentonite admixture at level (٢.٥٪).

٣. It can be seen from Tables (٤.٧a – ٤.٧b) and Figures (٤.١٣) – (٤.١٥) that the compressive strength increased with the increasing levels of the admixtures, but for Bentonite addition the compressive strength increased with level (٢.٥٪) , then started to decrease till lower than control mix at level (٦٪) as shown in Table (٤.٧b), this behavior is the same for the concrete specimens at ages (٧,٢٨) days.

The increase of compressive strength of the admixture concrete can be attributed to the reduction in (w/p) due to the absorption of these fine particles of the admixture to water content, this leads to increment in concrete strength, also these fine materials reveal a high gain of concrete strength due to their fineness and large surface area , especially at early age , and that can be attributed to the accelerated hydration of cement paste and to the filler effect of these materials [٥٨].

Table (٤.٧a) : Compressive Strength Test Results for the Concrete Mixes Made with Admixtures and without it

Mix symbol	W/C ratio	Slump (mm)	Compressive strength (Mpa)	
			Age (days)	
			٧	٢٨
M٠	٠.٤٨	١٧٥	١٨.٩٢	٢٨.٣
LM١.٥	٠.٤٨	١٦٩	١٨.٩١	٢٨.٥
LM٣	٠.٤٨	١٦٨	٢٠.٠	٢٩.٤
LM٤	٠.٤٨	١٦٦	٢١.٠	٣٠.٠
SM٢.٥	٠.٤٨	١٧٠	١٨.٩٧	٢٨.٨
SM٥	٠.٤٨	١٦٤	١٩.٢	٢٩.٥
SM٨	٠.٤٨	١٥٧	٢٢.٣٠	٣١.٠
BM٢.٥	٠.٤٨	١٦٦	٢٣.٤	٣٢.٨
BM٤.٥	٠.٤٨	١٦١	٢٠.٥	٢٩.٢
BM٦	٠.٤٨	١٥٧	١٨.٣	٢٧.١

Table (٤.٧b) : Percentage Change in The Compressive Strength Test Results Due To Adding Admixtures

+

Mix symbol	Change in compressive strength for concrete mixes compared with control mix (%) at age	Change in compressive strength for concrete compared with control mix mixes (%) at age

	(٧) days	(٢٨) days
M.	-	-
LM١.٥	- ٠.٠٥٢	+ ٠.٧٠
LM٢	+ ٥.٧	+ ٣.٨٨
LM٤	+ ١١.٠	+ ٦.٠
SM٢.٥	+ ٠.٢٦	+ ١.٧٦
SM٥	+ ١.٤٧	+ ٤.٢
SM٨	+١٧.٨٦	+٩.٥٤
BM٢.٥	+ ٢٣.٦٧	+ ١٥.٩
BM٤.٥	+ ٨.٣٥	+ ٣.١٨
BM٦	- ٣.٢٧	- ٤.٢٤

The reduction in compressive strength of concrete containing Bentonite admixture (BM٦) can be attributed to the high reduction in (w/c) due to the high fineness , high absorption of water and the large amount of this admixture, which leads to lack in hydration action and presence of air voids in concrete structure .
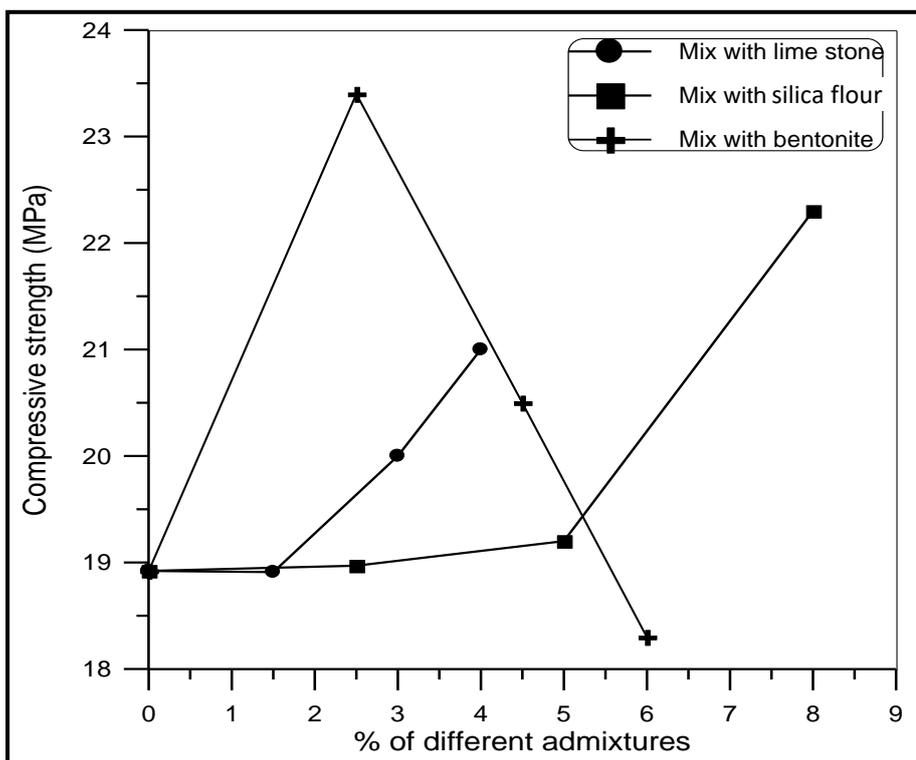
Control Mix Line

% Admixture Content

Figure (٤.١٣) : Effect of The Admixtures Type on Compressive Strength of Concrete At (٧ Days) Age
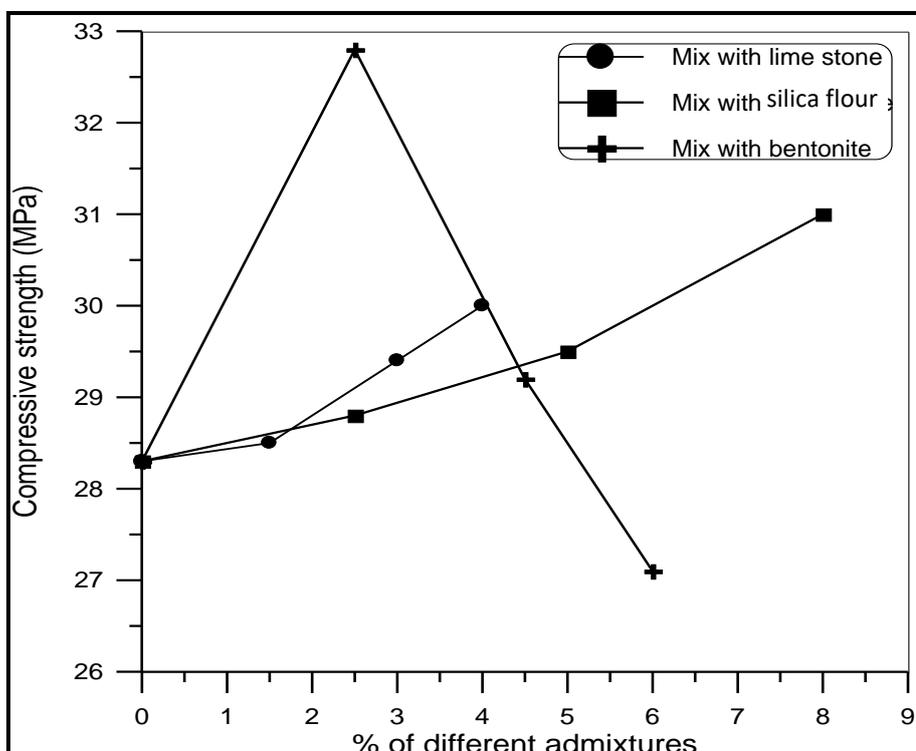
Figure (٤.١٤) : Effect of The Admixtures Type on Compressive Strength of Concrete At (٢٨ Days) Age
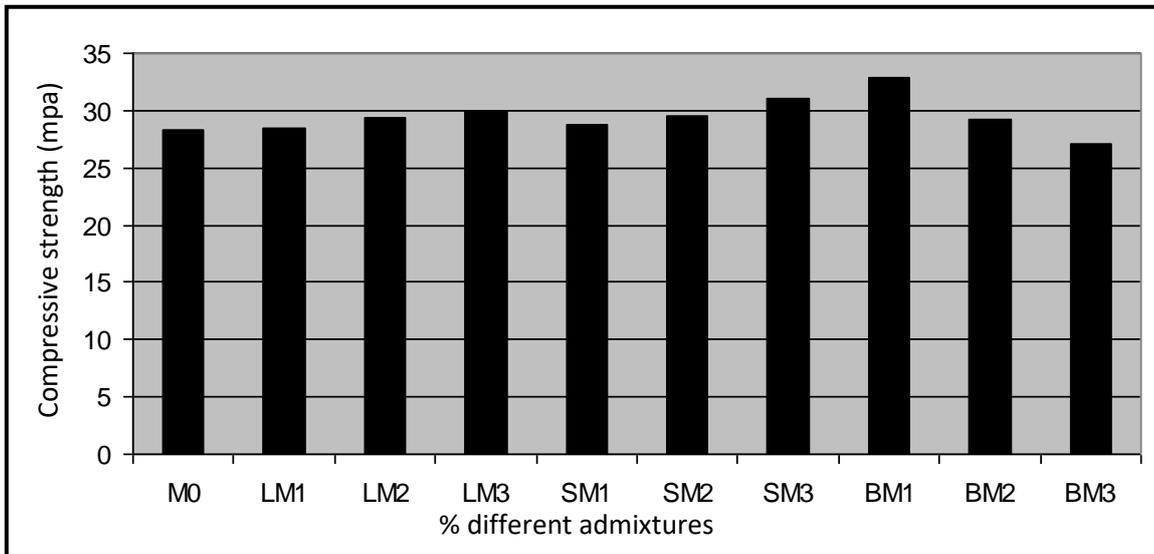
Figure (٤.١٥) : Effect of The Admixtures Type on Compressive Strength of Concrete At (٢٨ Days) Age.

٤.٨ Splitting Tensile Strength

The splitting tensile strength of concrete specimens made with admixtures and without it at age (٢٨ days) are shown in Table (٤.٨) and plotted in Figure (٤.١٦). The influence of these admixtures on the splitting tensile strength is found to be somewhat similar to that of compressive strength .

The best value of splitting tensile strength has been achieved for (٢.٥ %) Bentonite , at this level the percentage of increase was about (٢٠ %) more than that of the control mix , while there was a slight decrease for (٣ %) lime stone dust addition about (٢ %) .

Table (٤.٨) : Splitting Tensile Strength Test Results for The Concrete Mixes Made with Admixtures and without it

Mix Symbol	Slump (mm)	Splitting tensile strength (MPa)
		Age (٢٨ days)
M٠	١٧٥	٢.٨٥
LM١.٥	١٦٩	٢.٩٥
LM٢	١٦٨	٢.٨
LM٤	١٦٦	٣.٠
SM٢.٥	١٧٠	٢.٨٥
SM٥	١٦٤	٢.٨٥
SM٨	١٥٧	٣.٣
BM٢.٥	١٦٦	٣.٤١

BM$_{٤٥}$	١٦١	٣.٢١
BM$_٦$	١٥٧	٢.٩٤

dust

% Admixture Content

Figure (٤.١٦) : Effect of The Admixtures Type on Splitting Tensile Strength of Concrete

٤.٩ Flexural Strength :

The flexural strength of concrete specimens containing various content of limestone dust, and silica flour and Bentonite as an admixture to concrete mixes was determined after (٢٨ days) of moist curing and shown in Table (٤.٩) and Figure (٤.١٧). The influence of the various contents of the admixtures used in this study is found to be somewhat similar to that of compressive strength . Results indicate that the flexural strength increases with the admixture addition except those mixes (LM١.٥) and (BM٦). The best value of flexural strength has been achieved for (٢.٥٪) Bentonite, at this level the percentage of increase was about (١٥ %) more than that of the control mix .

Table (٤.٩) : Flexural Strength Test Results for the Concrete Mixes Made with Admixtures and without it.

Mix symbol	Flexural strength (MPa)
	Age (٢٨ days)
M.	٤.٣٦
LM١.٥	٤.٣٠
LM٣	٤.٥٠
LM٤	٤.٥
SM٢.٥	٤.٤
SM٥	٤.٦
SM٨	٤.٧١
BM٢.٥	٥.٠
BM٤.٥	٤.٤٥
BM٦	٤.٠
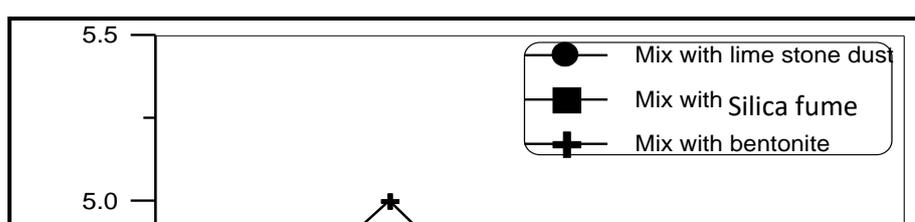
Control Line Mix

‒ ‒

% Admixture Content

Figure (٤.١٧) : Effect of The Admixture Type on Flexural Strength of Concrete

٤.١٠ Modulus of Elasticity :

The results of the modulus of elasticity for concrete specimens made with and without admixtures are given in Table (٤.١٠) and plotted in Figure (٤.١٨). Results illustrate that the increase of any admixture addition increases the modulus of elasticity except Bentonite at level (٦٪). There was a reduction of about (٤%).

Table (٤.١٠) : Results of The Modulus of Elasticity for Concrete Specimens with Different Types of Admixtures

Mix symbol	Modulus of elasticity (GPa)
M.	٢٦.٨٣
LM₁.₅	٢٧.٠٥
LM₃	٢٧.٦٥
LM₄	٢٨.٦٩
SM₂.₅	٢٧.١٠
SM₅	٢٧.٥٢
SM₈	٢٨.١٢
BM₂.₅	٢٨.٩٦
BM₄.₅	٢٧.٢٥
BM₆	٢٥.٦٥

% Admixture Content

Figure (٤.١٨) : Effect of The Admixture Type on Modulus of Elasticity of Concrete

٤.١١ Density :

Table (٤.١١) and Figure (٤.١٩) to Figure (٤.٢١) shows density test results for concrete specimens made with and without admixtures . From this table it can be seen that the addition of finely divided mineral admixture to concrete mixes increases their densities. especially with Bentonite at level (٢.٥ %) , The increment of the density is due to filling the pores present in concrete structure by the fine particles of the admixture. From this Figure, it can be seen that beyond (٢.٥ %) of Bentonite, the rate of increase in the density of concrete started to

decrease because of the decrease in workability which tends to impair the compaction for the mix , thus this property will increase voids.

Table (٤.١١) : Effect of The Admixture Type on Density of The Hardened Concrete

Mix symbol	Density (Kg/m³)
M.	٢٣١٦
LM١.٥	٢٣٢٠
LM٣	٢٣٢٠
LM٤	٢٣٢٨
SM٢.٥	٢٣١٩
SM٥	٢٣٢٥
SM٨	٢٣٣٢
BM٢.٥	٢٣٤١
BM٤.٥	٢٣٢٩
BM٦	٢٣٢٨
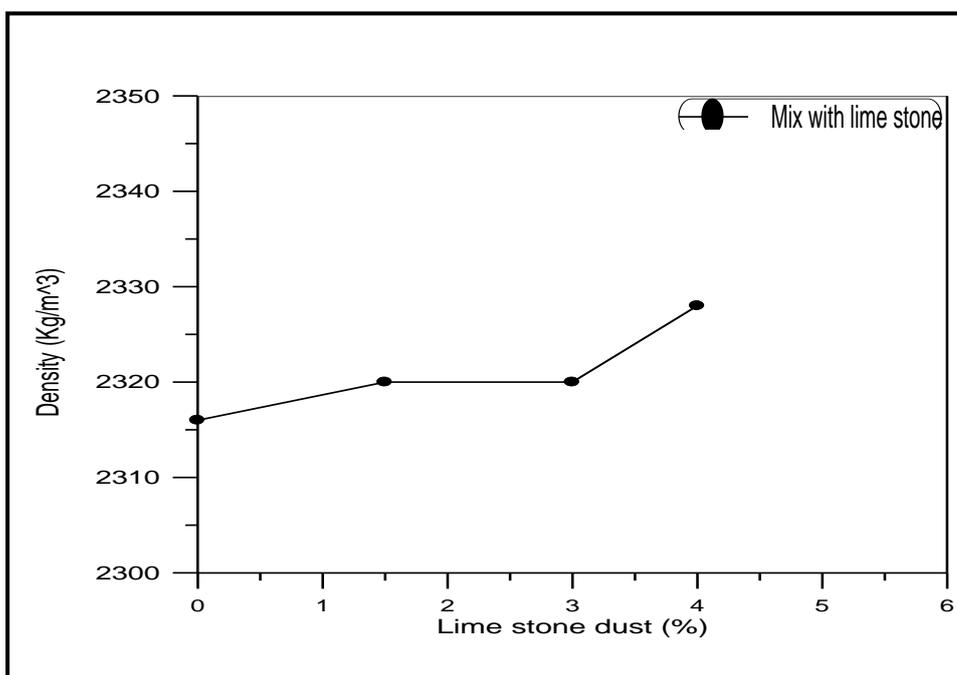
Figure (٤.١٩) : Effect of Adding Lime Stone Dust on The Density of Concrete
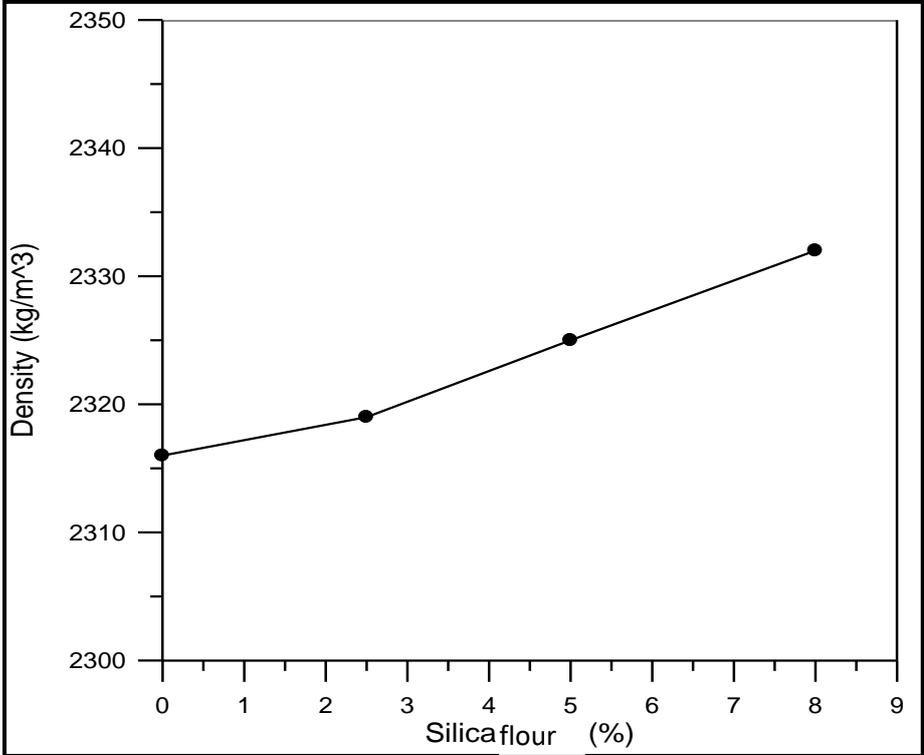
Figure (٤.٢٠) : Effect of Adding Silica Flour on The Density of Concrete
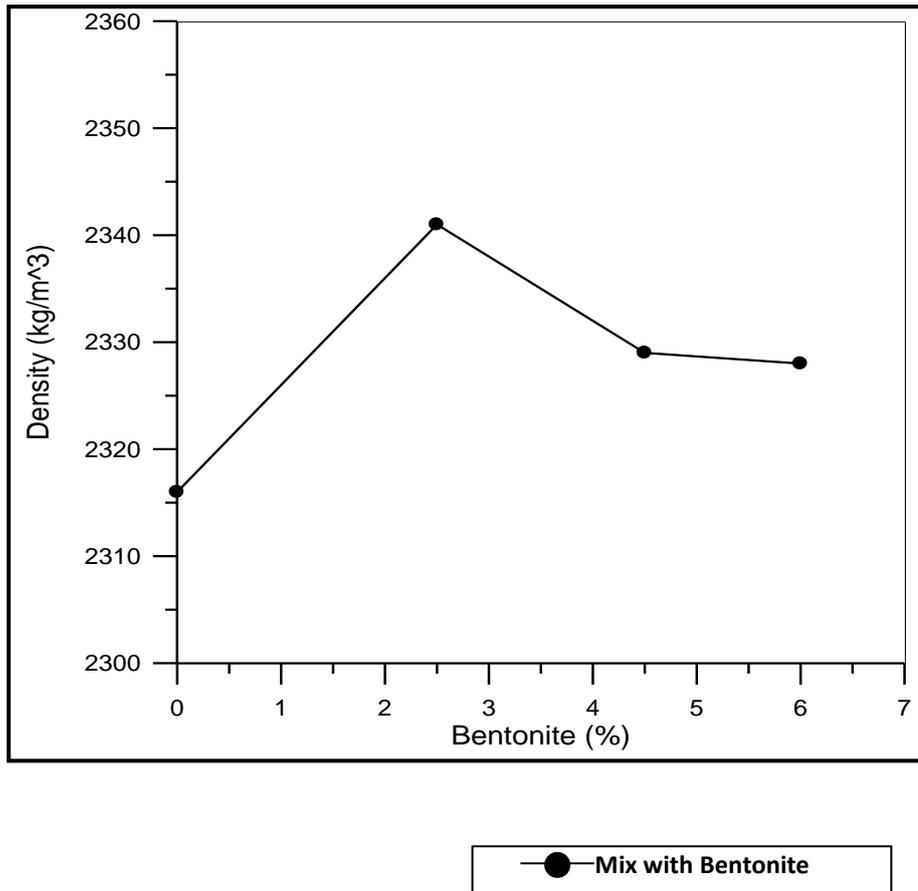
Figure (٤.٢١) : Effect of Adding Bentonite on The Density of Concrete

٤.١٢ Surface Hardness Test Results

Surface Hardness of the concrete specimens was assessed by the " Schmidt rebound hammer". Table (٤.١٢) shows the test results of the these concrete specimens made with and without admixtures. It can be seen from this Table that, the concrete specimens with admixtures have a slight increment in rebound number due to the increasing of its density.

The increment of rebound number for concrete with Bentonite at level (٢.٥ %) is about (١٧%) compared with the control mix .

Table (٤.١٢) : Rebound Number for Concrete Made with Admixtures and without It

Mix symbol	Rebound number
M.	٢٩
LM١.٥	٣٠
LM٣	٣٠
LM٤	٣٢
SM٢.٥	٢٩
SM٥	٢٩
SM٨	٣٢
BM٢.٥	٣٤
BM٤.٥	٣٠
BM٦	٢٩

٤.١٣ Comparison of Observed Shrinkage Strain Values with Predicted Shrinkage Strain Values by Estimated Models :

١- Committee European du Beton (CEB – FIP), ١٩٧٠ [٨٣]

The shrinkage deformation $\in$ sh (t , tsh.$\cdot$) measured from the start of drying tsh.$\cdot$ is expressed as:

$\in$ sh (t , tsh.٥) = $K_1 K_2 K_3 K_4$

where K_1 = coefficient for ambient humidity (Fig. ٤.٢٢)

K_2 = coefficient for concrete composition , (Fig. ٤.٢٣)

K_3 = coefficient for theoretical thickness (Fig. ٤.٢٤)

K_4 = coefficient for the time (Fig. ٤.٢٥)

٢- American concrete Institute model ACI ٢٠٩R-٩٢ [٨٤].

$$\in sh(t) = \frac{t}{t+35} \in sha$$

Where $\in sh(t)$ = shrinkage at any time (t)

$\in$ sha = ٧٨٠ X ١٠$^{-٦}$. K_1 K_2 K_3 K_4 K_5 K_6 K_7

Where :

$\in$ sha : ultimate drying shrinkage strain.

K_1 = factor for curing period from Table (٤.١٣)

K_2 = (١.٤ − ٠.٠١ H) if ٤٠ % ≤ H ≤ ٨٠ %

= (٣.٠ − ٠.٠١ H) if ٨٠ % ≤ H ≤ ١٠٠ %

K_3 = factor for volume/surface ratio from Table (٤.١٤) if v/s ≤ ٣٧.٥ mm

$K_{٤} = ٠.٨٩ + ٠.٠٠٢٦٤\ S$

$$K_{٥} = ٠.٣ + ٠.٠١٤\ \dfrac{\text{fine aggregate content}}{١٠٠}\quad \text{if} \quad \dfrac{\text{fine agg.}}{} \leq ٥٠\%$$

$$= ٠.٩ + ٠.٠٠٢\ \dfrac{\text{fine aggregate content}}{١٠٠}\quad \text{if} \quad \dfrac{\text{fine agg.}}{} \geq ٥٠\%$$

$K_{٦} = ٠.٧٥ + ٠.٠٠٠٠٦١\ Cc$

$K_{٧} = ٠.٩٧ + ٠.٠٠٠٨\ Ac$

Where

H = Ambient relative humidity .

v/s = Volume to surface area ratio .

S = Slump of fresh concrete

Cc = Cement content

Ac = Air content
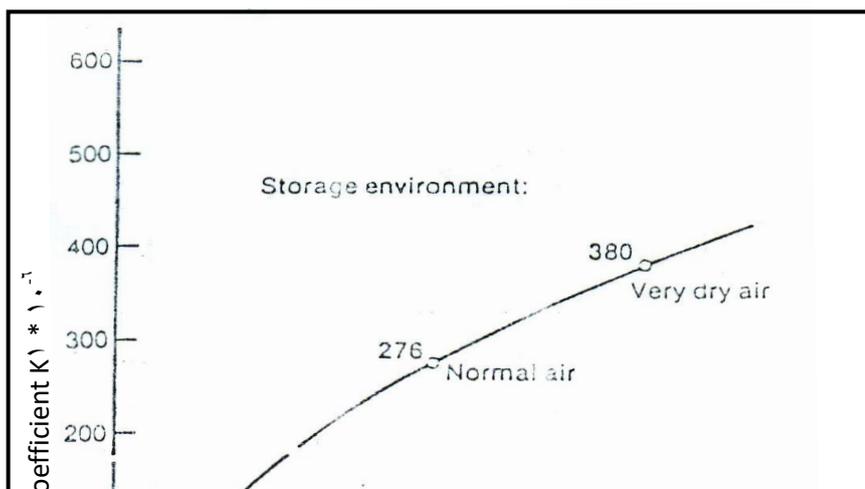
Figure (٤.٢٢) : (CEB-FIP). ١٩٧٨ Shrinkage Prediction Curve,   (K₁ :

Coefficient for Ambient Humidity)
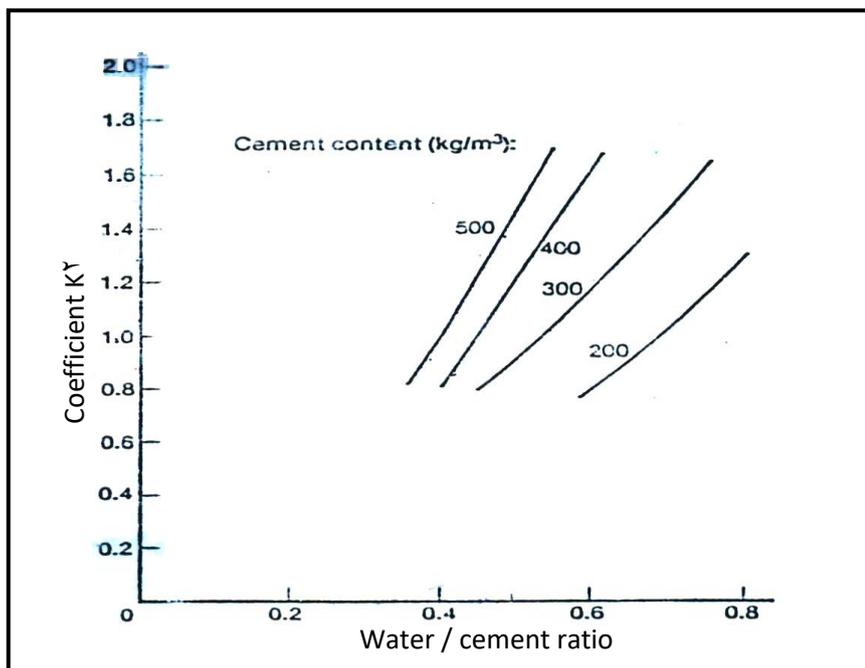
Figure (٤.٢٣) : (CEB-FIP). ١٩٧٨ Shrinkage Prediction Curve,   (K٢ :

Coefficient for Concrete Composition)
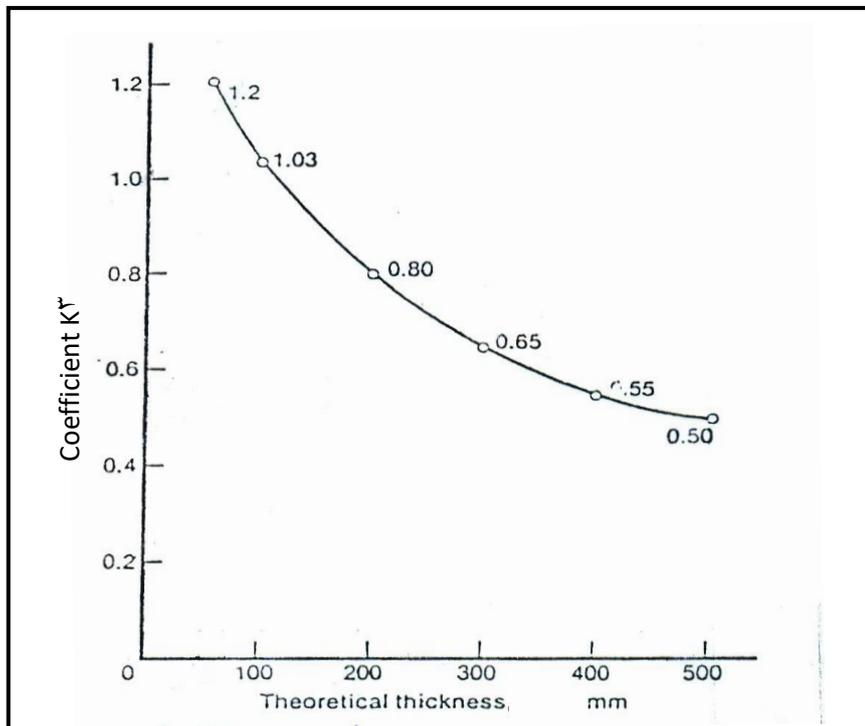
Figure (٤.٢٤) : (CEB-FIP). ١٩٧٨ Shrinkage Prediction Curve,   (K٣ :

Coefficient for Theoretical Thickness)
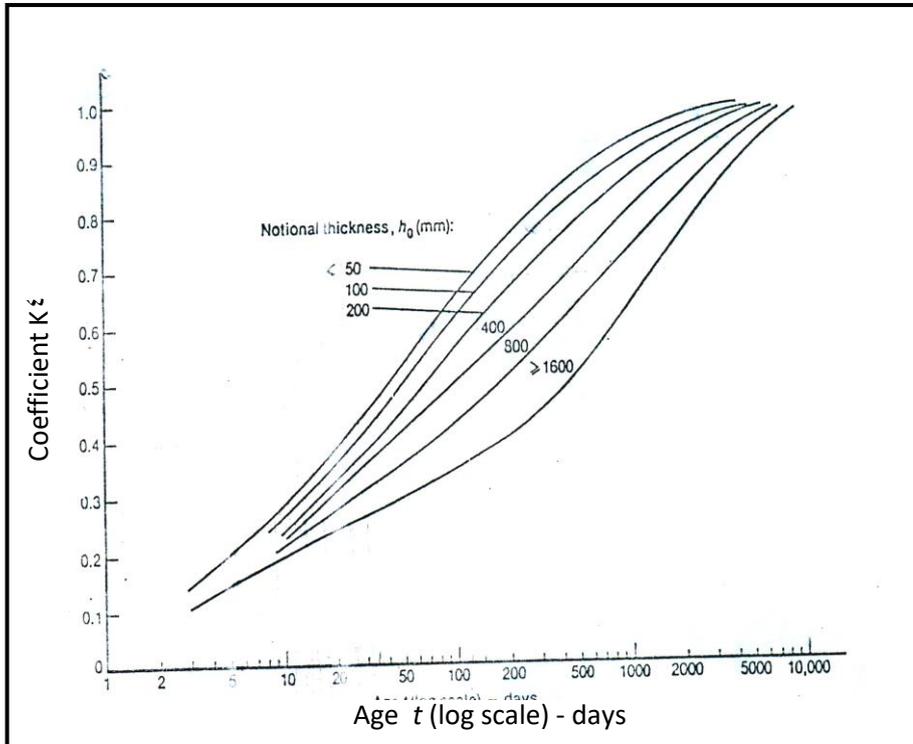
Figure (٣.٢٥) : (CEB-FIP). ١٩٧٨ Shrinkage Prediction Curve, (K₄ :

Coefficient for the Time)

Table (٤.١٣) : K₁ (Factor for Curing Period) [٨٦]

Curing time (days)	K_1
١	١.٢
٣	١.١
٧	١
١٤	٠.٩٣
٢٨	٠.٨٦
٩٠	٠.٧٥

Table (٤.١٤) : K_2 (Factor for v/s Ratio) [٨٤]

v/s (mm)	K_2
١٢.٥	١.٣٥
١٩	١.٢٥
٢٥	١.١٧
٣١	١.٠٨
٣٧.٥	١.٠٠

٤.١٤ Mathematical Models for Prediction of Some Properties of Concrete after Adding Different Levels of Some Finely Divided Mineral Admixtures :

In order to obtain useful mathematical relationships , that yield good prediction accuracy , nonlinear regression is used for this purpose ,

due to its efficiency in derivation of exponential equations, which are extremely useful for fitting experimental data.

The analysis has been carried out by the aid of a computer program package called "STATISTICA ٦.٠". This program includes extensive statistical operations and regression analysis capabilities .

Several combinations of variables were used in order to obtain the best regression to predict free drying shrinkage strain, compressive strength, splitting tensile strength , flexural strength and modulus of elasticity with high accuracy .

The exponential equations used are of the following general forms .

$$Y = a_0 . X_1^{a1} . X_2^{a2} . X_3^{a3} .... X_n^{an} \qquad [\text{٢١}^{st} \text{ model}] .... (٤-١)$$

$$Y = a_0 + a_1 X_1^{a2} + a_3 X_2^{a4} + a_5 X_3^{a6} + a_7 X_4^{a8} .... a_{2n-1} X_n^{a2n} \qquad [\text{٢}^{nd} \text{ model}] ..... (٤-٢)$$

$$Y = a_0 X_1^{a1} + a_2 X_2^{a3} + a_4 X_3^{a5} + a_6 X_4^{a7} + a_8 X_5^{a9} .... a_{2(n-1)} X_n^{a2n-1}$$

$$[\text{٣}^{rd} \text{ model}] ... (٤-٣)$$

where :

Y = Dependent variable

$X_١$, $X_٢$, $X_٣$, ... X_n = Independent Variables .

$a_٠$, $a_١$, $a_٢$, $a_٣$, ... = constants .

The properties of concrete are assumed to be known before addition of the different Levels of finely divided mineral admixtures, such

as , rebound number , density , initial compressive strength , drying period , percentage of admixture and modulus of elasticity .

٤.١٤.١ Mathematical Models for Prediction of Free Drying Shrinkage Strain (Sha)

To find the regression for prediction of (Sha), equations (٤-١A) , (٤-٢A) and (٤-٣A) can be written as follows :

$$Sha = a_0 (Shb)^{a1} . (Ra)^{a2} . (Rn)^{a3} . (p)^{a4} . (Dp)^{a5} . (E)^{a6} ....(4-1A)$$

$$Sha = a_0 + a_1 (Shb)^{a2} + a_3 (Ra)^{a4} + a_5 (Rn)^{a6} + a_7 (p)^{a8} + a_9 (D_p)^{a10} + a_{11} (E)^{a12} ....(4-2A)$$

$$Sha = a_0 (Shb)^{a1} + a_2 (Ra)^{a3} + a_4 (Rn)^{a5} + a_6 (p)^{a7} + a_8 (Dp)^{a9} + a_{10} (E)^{a11} ....(4-3A)$$

Where :

Sha = Free drying shrinkage strain after addition of admixture $(*10^{-6})$.

Shb = Free drying shrinkage strain before addition of admixture $(*10^{-6})$.

Ra = Percentage of admixture by wt. of cement (%).

Rn = Rebound number after addition of admixture (by wt. of cement).

ρ = Density of concrete after addition of admixture (Kg/m³) .

Dp = Drying period (days).

E = Modulus of elasticity of concrete (GPa) after addition of admixture.

Table (٤.١٦) : Regression Coefficients for Free Drying Shrinkage Prediction After Admixture Addition

Variable	Coefficient	Model ١	Model ٢	Model ٣
	$a_٠$	٠.١٠٥١٨٤	٤٢٤.٥٩٠٤	٠.٢٧٢٤٨٠
Shb	$a_١$	١.٠٨٤١٠٥	١٤٦٥.٢٩٨	١.١٧٦٣٩٥
	$a_٢$		٠.٠٧٦٢٩٢	
Ra	$a_٢$	٠.١٢٨٤٠٣		٣٦٠٨.٠٢٥
	$a_٣$		٢٥٣٤.٣١٨	٠.٠١٧٨١٢
	$a_٤$		٠.٠٢٢٨٧٩	
Rn	$a_٣$	٢.٣٠٨٠٨٥٠		
	$a_٤$			-٣٦٧٣.٨٠
	$a_٥$		٠.٠٠٠٠٠٠	-٠.٠٠٨٥٤٠
	$a_٦$		٧.٣٠٩٤٦٠	
ρ	$a_٤$	٠.٨٧٠٧٨٨		
	$a_٦$			١٨٠٣.١٩٩
	$a_٧$		١٥٠٥.٩٧٠	-٦.٠٤١٦٩
	$a_٨$		-١٠.٣٦٣٩	
DP	$a_٥$	٠.٠٦٢٨٨٧		
	$a_٨$			٢١٣.٣٧٧٦
	$a_٩$		٩٤١.٠٨٣٦	٠.١٠٧٨٧٤
	$a_١٠$		٠.٠٦٩٤٧٠	
E	$a_٦$	-٤.٠٠٨٩٠		

		Model 1	Model 2	Model 3
	a_{10}			-6.72396
	a_{11}		-2221.47	1.212661
	a_{12}		00.315017	
R		0.91798	0.90468	0.93302

Table (4.17) : Confidence Intervals and Difference Ranges (Df) for Proposed Models of (Sha)

Confidence Interval %	Difference Interval * 10^{-6}		
	Model 1	**Model 2**	**Model 3**
50	±40.851	±37.982	±32.67
75	±71.819	±66.089	±56.078
90	±103.431	±94.78	±79.973
95	±124.0768	±113.520	±95.57889

From Tables (4.16) and Table (4.17) , the following equations could be used to estimate the properties after adding addition with high

coefficient correlation , minimum value of the difference (df) and with fewer variables introduced in them .

$$Sha = 0.2724(Shb)^{1.17639} + 3608(Ra)^{0.01781} + -3673.8(Rn)^{-0.0085} + 1803.1(P)^{-6.041}$$
$$+ 213(Dp)^{0.107} + -6.72(E)^{1.212} ....(4-4)$$

[٣rd model]

Final, residual analysis must be done to show the best model of prediction when it was assumed that the residuals should be normal distributed , have independence with mean equal to zero, and variance equal to be $\delta_e^{٢}$ {NID (٠, $\delta_e^{٢}$)}.

A histogram of residuals shows a roughly normal curve with zero value of mean . An alternative for the same purpose is the normal probability plot, with the observed cumulative probabilities of occurrence of the residuals on the y axis , and of expected normal probabilities of occurrence on the x axis , such that a ٤٥-degree line will appear when observed values conform to normally expected .

Ideally , the points should lie along the diagonal [٨٥]. Then the zero value of mean can be shown by Figure (٤.٢٦) to explain the normality of residuals a long with Figure (٤.٢٧).

The final plot Figure (٤.٢٨) is the scatter plot of predicted value against residuals . It shows no pattern , thereby confirming that the assumptions of linearity and homogeneity of variance have been met.
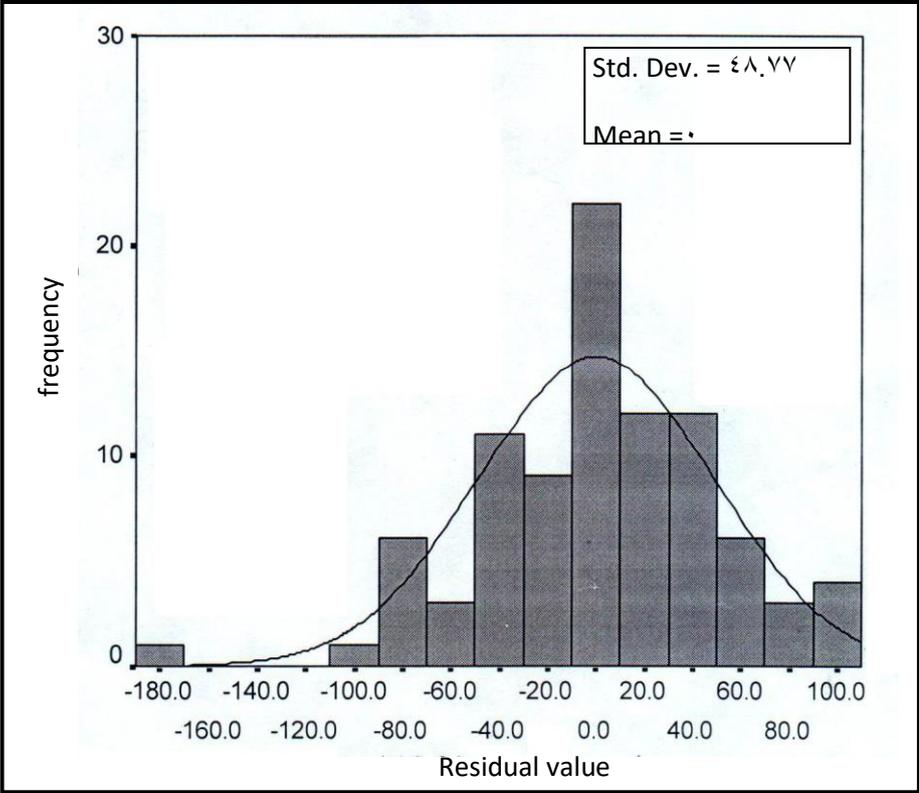
Figure (٤.٢٦) : The Histogram of Residuals[*]
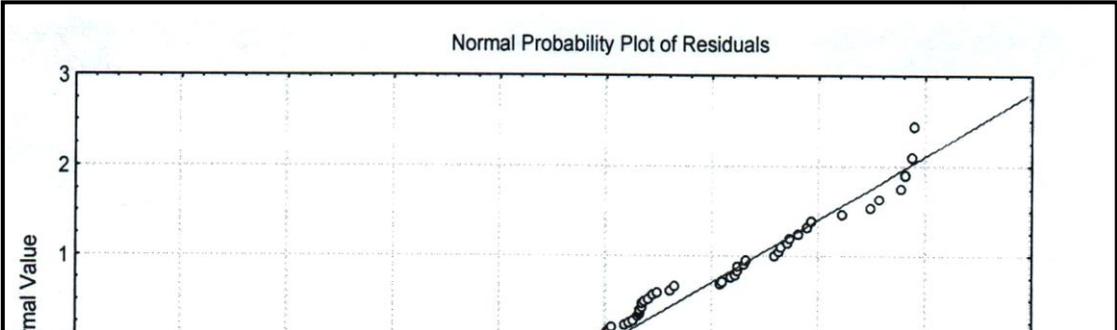
Figure (٤.٢٧) : Cumulative Probability Plot of Residuals*

* with property (Free drying shrinkage strain) for equation (٤-٣) [model ٣].

Table (٤.١) : The Free Drying Shrinkage Strain Test Results for Concrete Mix Specimens

Made with Admixtures of (FDMA) and without it

Mix symbol	Free drying shrinkage strain * ١٠⁻⁶										
	Drying Period (days)										
	٧	١٤	٢١	٢٨	٣٥	٦٣	٨٠	٩٧	١٠٨	١٢٠	
M.	١٦٠	٢٥٠	٣٣٩	٤٢٠	٤٢٨	٤٩٥	٥١٧	٥٢٠	٥٢٥	٥٢٨	٥
M١.٥	٧١.٤	١٦٠	٢٥٠	٣٢١	٣٣٩	٣٨٠	٣٩٥	٤٠٠	٤٠٥	٤١٠	٤
M٢	٧١.٤	١٦٠	٢٥٠	٣٢١	٣٣٩	٣٧٥	٣٩٠	٤٠٠	٤٠٨	٤١١	٤
M٤	٧١.٤	١٦٠	٢٥٠	٣٢١	٣٣٩	٣٨٥	٤١٥	٤٣٠	٤٣٦	٤٤٠	٤
M٢.٥	١٦٠	٢٥٠	٣٣٩	٣٥٧	٣٧٥	٤٨٣	٥١٣	٥٢٠	٥٢٥	٥٢٧	٥
M٥	١٦٠	٢٥٠	٣٣٩	٣٥٧	٤٢٨	٥٠٨	٥٢٠	٥٢٦	٥٣٠	٥٣٣	٥
M٨	١٢٥	٢٥٠	٣٣٩	٣٥٧	٤٢٨	٥٥٠	٥٦٠	٥٦٧	٥٧٠	٥٧٣	٥
M٣.٥	١٦٠	٢٥٠	٣٣٩	٣٥٧	٤٨٢	٥٧٠	٦١٠	٦٢٥	٦٣٥	٦٤٠	٦
M٤.٥	١٦٠	٢٥٠	٣٣٩	٣٨٥	٥١٧	٦١٥	٦٢٩	٦٣٥	٦٤٠	٦٤٥	٦
M٦	١٦٠	٢٥٠	٤٢٨	٤٨٠	٤٨٢	٥٧٣	٦٤٠	٦٥٥	٦٦٢	٦٦٦	٦

**with property (Free drying shrinkage strain) for equation (٤-٣) [model ٣].

Table (٤.٢) : Drying Shrinkage Data for Concrete Mix Made with Finely Divided Mineral Admixture (FDMA) and without it at (١٣٠) Days Drying Period with (٣) Days Curing Period

Admixture content % by weight of cement	Cracking time (days)	Free shrinkage strain *10^{-6} (at cracking time) ١	Loss of restraint *10^{-6} ٢	Tensile strain capacity *10^{-6} (at cracking time) ٣=١-٢	Elastic tensile strain capacity *10^{-6} (at cracking time) ٤	Cree cracki (at cr
٠	٣٦	٤٢٨	٩٤	٣٣٤	١٢٥	
١.٥	٣٦	٣٣٩	٦٧	٢٧٢	١١٤	
٣.٠	٣٤	٣٣٩	٦٦	٢٧٣	١٠٤	
٤.٠	٣٤	٣٣٩	٦٦	٢٧٣	١٠٠	
٢.٥	٣٤	٣٦٤	٧٨	٢٨٦	١١٤	
٥.٠	٢٦	٣٤٩	٦٥	٢٨٤	١٠٧	
٨.٠	٢٦	٣٥١	٦٧.٤	٢٨٣.٦	١١٤	
٢.٥	٢٩	٣٧٥	٧٥	٣٠٠	١٠٧	
٤.٥	٢٩	٣٩٥	٧٣	٣٢٢	١٢٥	
٦.٠	٢٦	٤٧٥	٩٥	٣٨٠	١٧٨.٥	

Table (٤.٦) Crack Development of the Concrete Made with And without Admixtures

Drying period (days)		٣٤	٤٠	٤٦	٥٢	٥٨	٦٤	٧٠	٨٢	٩٤	١٠٦	١٢٠	١٣٠
Crack width	LM٣	٠.٠٢٩	٠.٠٤٢	٠.٠٥٣	٠.٠٦١	٠.٠٦٥	٠.٦٨	٠.٧٠٥	٠.٧٢٨	٠.٧٤٩	٠.٧٦٤	٠.٧٧١	٠.٧٧٣
	LM٤	٠.٠٢٨	٠.٠٤٣	٠.٠٥٤	٠.٠٦	٠.٠٦٦	٠.٦٨	٠.٧٠	٠.٧٢٣	٠.٧٤٥	٠.٧٥٥	٠.٧٦٢	٠.٧٦٢

(mm)	SM ٢.٥	٠.٠٣٢	٠.٠٤٦	٠.٠٥٦	٠.٠٦٢	٠.٠٦٥	٠.٦٧٤	٠.٦٩٥	٠.٧١٦	٠.٧٢٦	٠.٧٣٥	٠.٧٣٩	٠.٧٤
Drying period (days)		٢٦	٣٢	٣٨	٤٤	٥٠	٥٦	٦٢	٧٤	٨٦	١٠٣	١٢٠	١٣٠
Crack	SM ٥	٠.٠٣	٠.٤٦	٠.٦	٠.٧١	٠.٧٨	٠.٨٤	٠.٨٦٢	٠.٨٧	٠.٨٨٣	٠.٨٩	٠.٨٩٧	٠.٨٩٧
width	SM ٨	٠.٠٣٢	٠.٤٧	٠.٥٩	٠.٦٧	٠.٧	٠.٧٢٥	٠.٧٤٥	٠.٧٥٦	٠.٧٦٥	٠.٧٧	٠.٧٧٣	٠.٧٧٥
(mm)	BM ٦	٠.٠٥	٠.٦٤٥	٠.٧٦٥	٠.٨٥	٠.٨٩	٠.٩١	٠.٩٣٣	٠.٩٥	٠.٩٥١	٠.٩٥٢	٠.٩٥٣	٠.٩٥٦
Drying period (days)		٣٦	٤٢	٤٨	٥٤	٦٠	٦٦	٧٢	٨٤	٩٦	١٠٨	١٢٠	١٣٠
Crack	M.	٠.٠٣٥	٠.٤٩	٠.٦	٠.٦٨	٠.٧٤	٠.٧٦	٠.٧٨٣	٠.٨٠٤	٠.٨١٩	٠.٨٢٩	٠.٨٣٥	٠.٨٣٥
width (mm	LM ١٠.٥	٠.٠٣٢	٠.٤٧	٠.٥٦٣	٠.٦٦	٠.٧٢	٠.٧٤	٠.٧٦	٠.٧٨٣	٠.٨	٠.٨١٧	٠.٨٢٣	٠.٨٢٣
Drying period (days)		٢٩	٣٥	٤٢	٤٨	٥٤	٦٠	٦٦	٧٢	٨٦	١٠٣	١٢٠	١٣٠
Crack	BM ٢.٥	٠.٠٣٠	٠.٤٤	٠.٥٤	٠.٦٣	٠.٦٩	٠.٧١	٠.٧٣	٠.٧٥٤	٠.٧٦٩	٠.٧٧٥	٠.٧٨٣	٠.٧٨٣
width (mm	BM ٤.٥	٠.٠٣٥	٠.٥	٠.٥٩	٠.٦٧	٠.٧٤	٠.٧٦	٠.٧٨٥	٠.٨١	٠.٨٣	٠.٨٣٨	٠.٨٤٢	٠.٨٤٥

Table (٤.١٥) : Comparison Between the Predicted Shrinkage Strain Using the Models of (ACI) and (CEB-FIP) with the Observed Shrinkage Strain at Ages Of [٣٥ , ٩٧ , ١٣٠] Days

Observed shrinkage strain 10^{-6}			Predicted shrinkage strain 10^{-6} by (CEP-FEP) model			Predicted shrinkage stra... By using ACl mod...	
٣٥ days	٩٧ days	١٣٠ day	٣٥ days	٩٧ days	١٣٠ days	٣٥ days	٩٧ days

٤٢٨	٥٢٠	٥٢٨	٤٠٩	٥١٧	٥٣٧	٤٧٨	٦٨٥
٣٣٩	٤٠٠	٤١٢	**The Admixture factor is not**			٤٧٢	٦٧٥
٣٣٩	٤٠٠	٤١١	**obtainable in this model**			٤٧١	٦٧٣
٣٣٩	٤٣٠	٤٤١				٤٧٠	٦٧٢
٣٧٥	٥٢٠	٥٢٧				٤٧٣	٦٧٦
٤٢٨	٥٢٦	٥٣٣				٤٦٧	٦٦٨
٤٢٨	٥٦٧	٥٧٤				٤٦٦	٦٦٦
٤٨٢	٦٢٥	٦٤١				٤٧٠	٦٧٢
٥١٧	٦٣٥	٦٤٦				٤٦٥	٦٦٥
٤٨٢	٦٥٥	٦٦٨				٤٦٧	٦٦٨

CHAPTER FIVE

CONCLUSIONS & RECOMMENDATIONS

٥.١ Conclusions :

Based on the experimental results presented in chapter four and on the basis of the observations made in the present work, the following conclusions can be drawn :

١- The drying shrinkage strain development of concrete is affected by the type and amount of the finely divided mineral materials added, addition of (LSD) contents to concrete mix decrease the free drying shrinkage at early and later ages of this concrete. At the level addition of (٤٪), the reduction in free drying shrinkage strain is about (٣٦٪) at (١٤) days drying period and about (١٧%) at (١٣٠)

days drying period compared with that of the control mix and not significantly affect free drying shrinkage strain of concrete when increase its contents.

٢- The addition of different contents of silica flour admixture to concrete mixes slightly increases the free drying shrinkage strain at later ages, but no significant effect were observed at early ages. The highest percentage of increase is about (١١٪) at a percentage addition of (٨٪) (by weight of cement) at (٦٣) days drying period.

٣- The addition of different contents of Bentonite admixture to concrete mixes evidently increases the free drying shrinkage strain at later ages, but no evident influence was observed at early ages. The highest percentage of the increase is about (٢٧%) at a percentage addition of (٦٪ by weight of cement) at (١٣٠) days drying period.

٤- Cracking time is decreased with the addition of different contents of admixtures (LSD, SF, Bt) to concrete mixes, while it is the same of that of the control mix with (LSD) addition at level (١.٥٪).

٥- The tensile strain capacity at cracking time is decreased with the addition of different contents of admixtures (Silica flour and lime stone dust) to concrete mixes.

٦- The tensile strain capacity at cracking time is decreased with the addition of Bentonite admixture at level (٢.٥٪ and ٤.٥% by weight of cement)to concrete mixes, while it increases about (١٣.٧٪) at level (٦%) Bentonite addition.

٧- The presence of the lime stone dust, Silica flour and Bentonite as admixtures in concrete mix shows a significant decrease in creep strain at cracking time. The maximum reduction in creep strain is about (٢٤%) with limestone dust at level (١.٥٪ by weight of cement), and the minimum reduction is about (٤%) with the Bentonite admixture at level (٦٪ by weight of cement),

٨- The free drying shrinkage strain at cracking time decreases with increasing the percentage of admixture content of lime stone dust, Silica flour and Bentonite, excluding the Bentonite content of (٦٪ by weight of cement) which increases the free drying shrinkage strain at cracking about (١١%).

٩- For all concrete mixes containing different contents of the admixtures, crack width is lower than that of the control specimens, excluding the concrete mix made with Bentonite addition of (٦٪), which is higher about (٤٣%), than that of the control mix, while the crack width is the same of the control specimen for the mix with Bentonite admixture addition of (٤.٥%).

١٠- The density of concrete containing finely divided mineral admixtures is very little increased with increasing the percentage content of these admixtures. The maximum density has been achieved with (٢.٥٪) of Bentonite.

١١- The development of the compressive strength at (٧, ٢٨) days age was dependent on the type and amount of the admixture. It increases with increasing the percentage content of any admixture (lime stone dust, Silica flour and Bentonite) except with Bentonite

at level (٦٪) , it is lower than that of the control mix by about (٤٪) for (٢٨) days age. The highest increase in compressive strength at (٢٨) days age is about (١٦%) with Bentonite admixture at level (٢.٥٪), while it does not affect significantly with lime stone dust at level (١.٥٪ by weight of cement).

١٢- The flexural strength increases with increasing the content of any admixture (lime stone dust, Silica flour, and Bentonite) except with Bentonite at level (٦٪) and with lime stone dust at level (١.٥٪). The highest increase in flexural strength is about (١٥%) with Bentonite at level (٢.٥٪) while the highest decrease is about (٨.٢٪) obtained with Bentonite at level (٦٪).

١٣- Increasing of the percentage of any admixture increases the splitting tensile strength except with lime stone dust at level (٣٪). The highest increase is about (٢٠٪) with Bentonite at level (٢.٥٪).

١٤- The static modulus of elasticity increases with increasing the content of any admixture except with Bentonite at level (٦٪). The highest increase is about (٨%) obtained with Bentonite at level (٢.٥٪), and the lowest increase is about (٠.٨٢٪) with lime stone dust at level (١.٥٪).

١٥- An accurate mathematical models can be proposed by using the drying period, density , rebound number, modulus of elasticity and percentage of admixture (by weight of cement) for prediction of free drying shrinkage of concrete after adding some of (FDMA). The highest correlation coefficient (R = ٠.٩٣٣) and minimum value of

the difference (df = ± ٩٥.٥٧) was obtained when the models include all these variables.

٥.٢ Recommendations for Further Work :

١. A comparison of the influence of active and inert finely divided mineral admixtures on free and restrained shrinkage cracking of concrete.

٢. The effect of some of finely divided mineral admixtures on durability of plain and reinforced concrete.

٣. Studying the influence of other types of admixtures such as (Pozzolanic materials, water-repellant, magnesium and calcium silicates, colloidal

silica and barium sulfate) on drying shrinkage cracking of end-restrained concrete members.

٤. Studying the effect of finely divided mineral materials on drying shrinkage cracking of concrete with constant slump and variable ratios of w/c.

٥. Studying the effect of adding finely divided mineral admixtures on concrete exposed to cycles of (wetting and drying).

٦. Studying the effect of these materials (silica flour, Bentonite, lime stone dust) on durability of concrete exposed to hydrostatic pressure.

٧. The effect of cementation materials on shrinkage cracking of base restrained concrete.

٨. An advanced study to create a prediction model for creep and shrinkage of concrete containing finely divided mineral materials.

٩. A study to investigate the drying shrinkage cracking problem using superplasticizers when the finely divided mineral admixtures are used as cement or sand replacement.

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