EFFECT OF SOME FINELY DIVIDED MINERAL ADMIXTURES ON DRYING SHRINKAGE OF END RESTRAINED CONCRETE BEAMS

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Abstract

End restrained steel moulds having a channel section were used to study restrained shrinkage cracking. In these moulds concrete specimens from different mixes were cast to measure the free and restrained shrinkage strain. Three local admixtures of (FDMA) were used which are lime stone dust (LSD), Silica flour (SF) and bentonite (Bt). Three levels of addition were used for each type, (1.5%, 3% and 4% by weight of cement) for (LSD), *(2.5%, 5%* and 8% by weight of cement) for (SF) admixture and *(2.5%,* 4.5% and 6% by weight of cement) for bentonite admixture. The experimental results illustrate that For concrete specimens with different levels of (LSD), the free shrinkage strain decreased at early and later ages, while no noticeable effect was observed in free shrinkage strain with (SF) at all ages but it increased significantly with (Bt) addition .The increase of content of any admixture used leads to a decrease in cracking time, crack width and creep strain at (cracking time). Mathematical models 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

تأثير بعض المضافات المعدنية الدقيقة التجزئة على انكماش الجفاف للجسور الخرسانية المقيدة النهايات

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الخلاصة

في هذه الدراسة تم استخدام قوالب تقييد حديدية ذات مقطع على شكل (حديد ساقية) لدراسة تشققات الانكماش المقيد، هذه القوالب تم صب نماذج كونكرتية مختلفة فيها لغرض تحديد أو قياس انفعال انكماش الجفاف الحر والمقيد ولتعيين معامل المرونة والكثافة ورقم الارتداد. تم استخدام ثلاثة أنواع محلية من المضافات (FDMA) وهي (غبار الجير الحي LSD، مطحون السيليكا SF، البنتونايت Bt). لكل نوع من الأنواع استخدمت ثلاث نسب مئوية من وزن السمنت (1.5%,3%,4%) للمضاف غبار الجير الحي (LSD) وبنسب (2.5%,5%,8%) للمضاف مطحون السيليكا (SF) والنسب المئوية (2.5%,4.5%,6%) البنتونايت (Bt) .أوضحت النتائج العملية إن زيادة محتويات المضاف (LSD) يقلل انفعال انكماش الجفاف الحر للخرسانة في الأعمار المبكرة والمتأخرة، 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 اضافة(6%) في الأعمار المتأخرة وان زيادة محتوى أي مضاف يقلل من زمن حدوث التشقق ، عرض الشق وانفعال الزحف عند (زمن حدوث التشقق).تم استحداث موديلات تعتمد على معادلات غير خطية متعددة المتغيرات للحصول على قيم تخمينية استخدمت لإيجاد معامل ارتباط جيد (R) بين هذه الخواص بأقل (df) واقل متغيرات.

INTRODUCTION

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, [Al-Nassar,2002].

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 alternatively the tensile strain capacity of concrete is exceeded, cracking will take place.[Al-Nassar,2002]

Admixtures can be defined according to ACI committee 212 [ACI 212- 2R-81] 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 paste other features in their liquid, plastic state, setting, curing and hardened state.

Objective of the Work

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

The main variables used in this study are:

1- 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).

2-The levels of additions are as follows:

- Three levels of(LSD) admixture *(1.5%,* 3%, 4% by wt. of cement)

- Three levels of(SF) admixture *(2.5%, 5%,* 8% by weight of cement).
- Three levels of(Bt) admixture *(2.5%, 4.5%,* 6%) by weight of cement).

LITERATURES REVIEW

Shrinkage:

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 [Trisch and et – al ,2005].

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 adversly on the maintenance cost 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 [Tia and et- al ,2005].

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 [Bazant,2005] .

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 (> 5 micron) to smaller voids in the (CSH) gel that are filled with adsorbed water *(0.5-2.5 microns).* 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.

Haque [Haque, 1996] measured the drying shrinkage on (85 x 85 x 285 mm) prism specimen. The addition of both 5 and 10% silica fume of cement weight leads to a substantial reduction of drying shrinkage of their concrete.

Resistance of (FDMA) to Thermal Cracks:

The use of cement and pozzolan admixtures on concrete reduces oh the effects of high temperatures on concrete comparing with control concrete which contains only Portland cement. The reduction caused in temperature is proportional directly with admixture amount used as a compensated for the weight of cement in the mixture.[Concret Manual,8th Edition 1975]

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 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 exposure to high temperatures.

EXPERIMENTAL WORKS

Program of the Work and Mixes:

Three levels of each admixture were investigated , there are three admixtures which are limestone dust, Bentonite and Silica flour. These levels are *(1.5%,* 3 % and 4% by weight of cement limestone dust), *(2.5%, 5%,* 8% , by weight of cement silica flour), and *(2.5%, 4.5%, 6%* by weight of cement bentonite). Each set of the mixes was cast at the same time to ensure similar drying conditions. High slump mixes *(150* — 180) mm were chosen to ensure workable, compactable and higher tendency to drying shrinkage.

Finely Divided Mineral Admixtures

LimeStone Dust:

The limestone dust used in the experimental work is 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.

Silica Flour:

The silica flour used throughout the research is a granulated silica brought from General Company of Geological Mining and Survey in Baghdad which delivers delivered the local materials from A1-Sufra region in western desert. It is stored in a dry place and added to the concrete mixes as a dry powder.

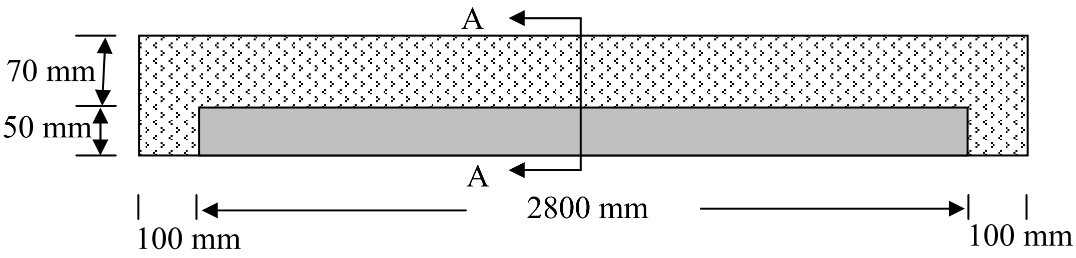
Bentonite:

Bentonite used throughout the research is brought also from General Company of Geological Mining and Survey in Baghdad. This Bentonite is yellowish — brown in colour. It is stored in a dry place and added to the concrete mixes as a dry powder.

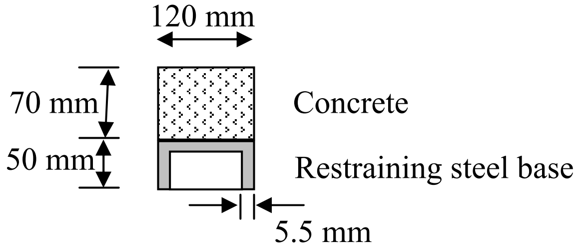
Moulds:

The moulds used in this study are as follows
1- Channel shape moulds having a channel section with the dimensions shown in

Figure (3. 1) is used to offer an end — restraining frame. This frame is used to study free shrinkage and shrinkage cracking of end — restrained concrete members.



Side view



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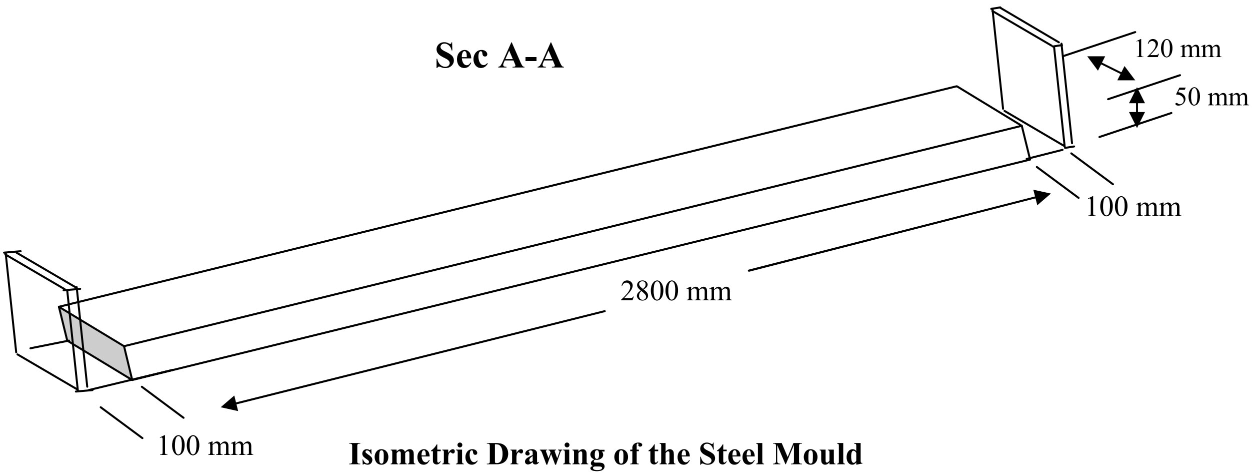

Isometric Drawing of the Steel Mould

Fig (3.1) Schematic Diagram of the Restraining Steel Mould

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

2- (150*150*1 50)mm cube moulds of concrete specimens for density and rebound number tests.

3- (l5O*300)nim cylinder moulds of concrete specimens for static modulus of elasticity test.

Mix Design and Proportions:

The concrete mix designed according to ACI mix design method (ACI 211.1. 77). This mix designed to obtain a target compressive strength of (30 MPa) at 28 days age and a slump range of (150 — 180) mm. The maximum size of coarse aggregate chosen to be *(12.5* 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^3)	Sand(kg/m^3)	Gravel(kg/m^3)	Water(kg/m^3)	W/Cratio
479	662	944	230	0.48

The mix proportions are (1:1.38:1.97)

Testing of the Concrete Specimens:

Restrained — Shrinkage Test:

Concrete beams were tested for restrained shrinkage. The shrinkage cracking model was based on the model devised by Al-Rawi [Al-Rawi,1985], 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 and the other for restrained shrinkage cracking test. The small depth of the beam (70 mm) would enable a fast rate of drying shrinkage without significant differential 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 (20 cm) gauge length and an accuracy of (0.002 mm/division) as in plate (3.1). the demec points were fixed (during the first stage of curing period) a long the center line of the web at (20 cm) apart using an adhesive epoxy resin. 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.

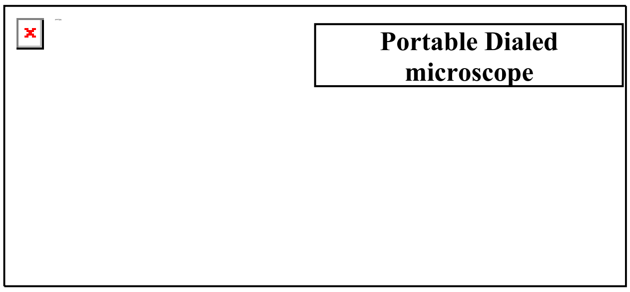

Plate (3.1) : Devices of Measurement of Concrete Shrinkage

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 at different periods measuring the widening of the artificial crack in the middle of the beam was conducted.

Readings were taken from the next day after curing period till (130 days) or when no movement could be recorded. The tensile strain capacity represent the free shrinkage strain revealed by the specimen due to drying from the moment of casting until the occurrence of cracking minus the loss in restraint during this period. The crack width was asured by a crack dial microscope.[plate (3.1)]

RESULTS AND DISCUSSION

Free Shrinkage Test:

By using the steel mould described in chapter three (concrete beam with a gap at the middle to ensure free movement) free shrinkage was measured for the concrete specimens and recorded in Table (4.1).

Curves showing free drying shrinkage strain development of concrete beams made with and without finely divided mineral admixtures are shown in Figures (4.1 to 4.3).

Table (4.1) : The Free Drying Shrinkage Strain Test Results for Concrete Specimens - Made with Admixtures of (FDMA)

Mix Symbol	Free drying shrinkage strain * 10^{-6}										
	Drying Period (days)										
	7	14	21	28	35	63	80	97	108	120	130
M_0	160	250	339	420	428	495	517	520	525	528	528
$LM_{1.5}$	71.4	160	250	321	339	380	395	400	405	410	412
LM_3	71.4	160	250	321	339	375	390	400	408	411	411
LM_4	71.4	160	250	321	339	385	415	430	436	440	441
$SM_{2.5}$	160	250	339	357	375	483	513	520	525	527	527
SM_5	160	250	339	357	428	508	520	526	530	533	533
SM_8	125	250	339	357	428	550	560	567	570	573	574
$BM_{2.5}$	160	250	339	357	482	570	610	625	635	640	641
$BM_{4.5}$	160	250	339	385	517	615	629	635	640	645	646
BM_6	160	250	428	480	482	573	640	655	662	666	668

From these Figures it can be seen that the free drying shrinkage increases with the age progress for all mixes, the rate of shrinkage development varies depending on to the evaporation intensity.

It can be noticed from Figure (4.1) and Table (4.1) that concrete mixes of ($LM_{1.5}$, LM_3, LM_4), had free drying shrinkage strains 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 Figure (4.2) that concrete mix (SM8) containing silica flour of (8%) the free drying shrinkage strain increased about (11% , for drying periods (63 & 130) days respectively compared with the control mix, while mixes (SM2.5 and SM5) did not differ in sigmficant effect on free drying shrinkage strain compared with the control mix for all drying periods.

It can be noticed from Figure (4.3) that 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 ccuitrol mix, except for the (28 days) age.

The percentage of increase in free drying shrinkage strain for concrete mix containing bentonite ($BM_{4.5}$) is about (24%,22%) for drying periods (63 & 130) days respectively compared with the control mix.

Another measurements of cracking time and free drying shrinkage strain at that time and other drying shrinkage data are listed in Table (4.2). it can be seen that the free drying shrinkage strain (at cracking time) depends on the type of the admixture and its content.

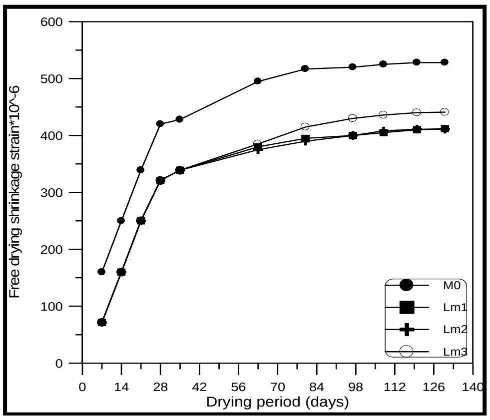

Figure (4.1) : Free Drying Shrinkage Versus Drying Periods for Concrete Mixes with

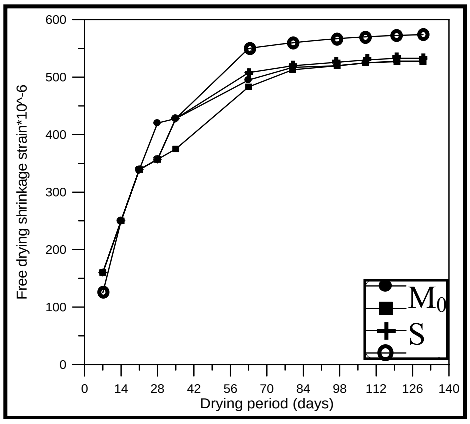

Figure (4.2) : Free Drying Shrinkage Versus Drying Periods for Concrete Mixes with Different Levels of (SF)

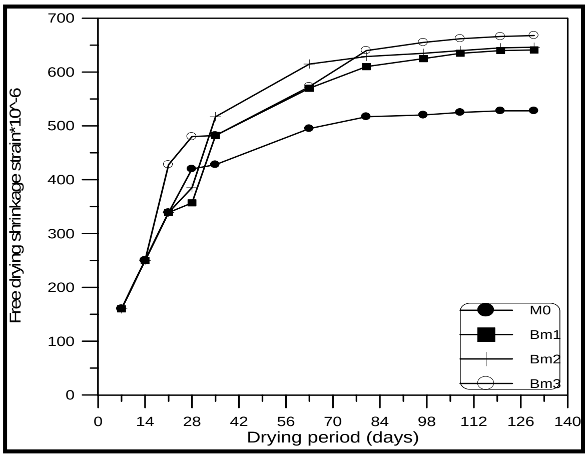

Figure (4.3) : Free Drying Shrinkage Versus Drying Periods for Concrete Mixes with Different Levels of (Bt)

Table (4.2) : Drying Shrinkage Data for Concrete Mix Made with Finely Divided Mineral Admixture (FDMA) at (130) Days Drying Period with (3) Days Curing Period

Mix symbol	Admixture content % by weight of cement	Cracking time (days)	Free shrinkage strain $*10^{-6}$ (at cracking time)	Loss of restraint $*10^{-6}$ 2	Tensile strain capacity $*10^{-6}$ (at cracking time) 3=1-2	Elastic tensile strain capacity $*10^{-6}$ (at cracking time) 4	Creep strain at cracking time $*10^{-6}$ (at cracking time) 5=3-4
M_0	0	36	428	94	334	125	209
$LM_{1.5}$	1.5	36	339	67	272	114	158
LM_3	3.0	34	339	66	273	104	169
LM_4	4.0	34	339	66	273	100	173
$SM_{2.5}$	2.5	34	364	78	286	114	172
SM_5	5.0	26	349	65	284	107	177
SM_8	8.0	26	351	67.4	283.6	114	170
$BM_{2.5}$	2.5	29	375	75	300	107	193
$BM_{4.5}$	4.5	29	395	73	322	125	197
BM_6	6.0	26	475	95	380	178.5	201.5

Restrained Shrinkage test:

When the concrete is stored in mould and exposed to dryness 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 [Al-Ali,1985]. 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 crack time was recorded.

Loss of restraint measurement and the first crack time are given in Table (4.2).

Crack Width:

The restrained shrinkage crack width test results of the concrete beams made with admixtures of (FDMA) are given in Table (4.3) and plotted in Figure (4.4) to Figure (4.6).

Table (4.3) Crack Development of the Concrete Made with And without Admixtures

Drying period (days)		34	40	46	52	58	64	70	82	94	106	120	130
Crack width (mm)	LM_3	0.29	0.42	0.53	0.61	0.65	0.68	0.705	0.728	0.749	0.764	0.771	0.773
	LM_4	0.28	0.43	0.54	0.6	0.66	0.68	0.70	0.723	0.745	0.755	0.762	0.762
	$SM_{2.5}$	0.32	0.46	0.56	0.62	0.65	0.674	0.695	0.716	0.726	0.735	0.739	0.74
Drying period (days)		26	32	38	44	50	56	62	74	86	103	120	130
Crack width (mm)	SM_5	0.3	0.46	0.6	0.71	0.78	0.84	0.862	0.87	0.883	0.89	0.897	0.897
	SM_8	0.32	0.47	0.59	0.67	0.7	0.725	0.745	0.756	0.765	0.77	0.773	0.775
	BM_6	0.5	0.645	0.765	0.85	0.89	0.91	0.933	0.95	0.951	0.952	0.953	0.956
Drying period (days)		36	42	48	54	60	66	72	84	96	108	120	130
Crack width (mm	M_0	0.35	0.49	0.6	0.68	0.74	0.76	0.783	0.804	0.819	0.829	0.835	0.835
	$LM_{1.5}$	0.32	0.47	0.563	0.66	0.72	0.74	0.76	0.783	0.8	0.817	0.823	0.823
Drying period (days)		29	35	42	48	54	60	66	72	86	103	120	130
Crack width (mm	$BM_{2.5}$	0.30	0.44	0.54	0.63	0.69	0.71	0.73	0.754	0.769	0.775	0.783	0.783
	$BM_{4.5}$	0.35	0.5	0.59	0.67	0.74	0.76	0.785	0.81	0.83	0.838	0.842	0.845

Figure (4.4) : Crack Development of Concrete Made With Different Levels of Limestone Dust Admixture And

Figure (4.5) : Crack Development of Concrete Made With Different Levels of Silica Flour Admixture and without

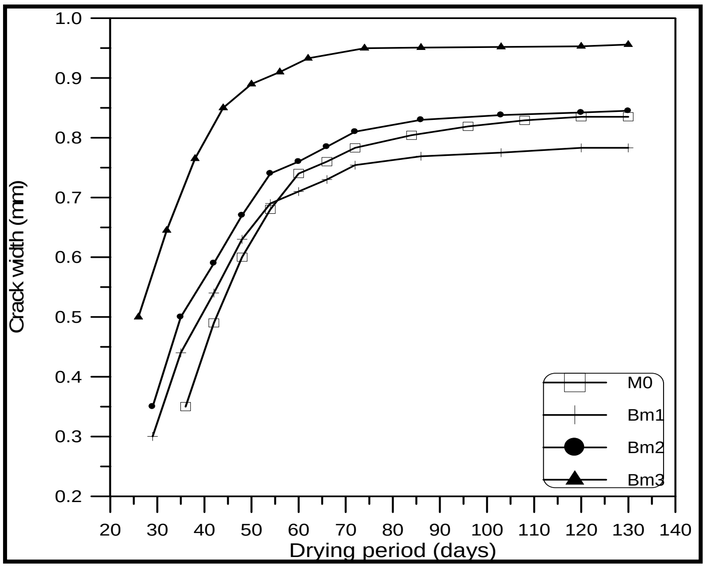

Figure (4.6) : Crack Development of Concrete Made with Different Levels of Bentonite Admixture and without It

From these tables and figures, it can be seen that the crack width of the concrete made with admixtures was either the same or lower than the crack width of control mix, except those (BM6) and (SM5) for the mix with (6%) Bentonite (BM3), the crack width was higher about (43%) compared with the control mix, on the contrary the (LM4) lime stone dust (4%) concrete mix has a crack width lower about (20%). Compared with the control mix.

The measurement of crack width for the specimens was achieved by a portable dialed microscope, every (6) days at early ages and every (12) days at later ages.

Position of The Crack:

Plates (4.1) and (4.2) 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 the member [Al-RAwi,1985].

Plate (4.1) : The Crack Location in Specimen (LM_3)

Plate (4.2) : The Crack Location in Specimen ($SM_{2.5}$)

Density:

Table (4.4) shows density test results for concrete specimens made with and with out (FDMA)

Modulus of Elasticity:

Table *(4.5)* shows Modulus of elasticity test results for concrete specimens made with and without(FDMA) .

Surface Hardness:

Table (4.6) shows surface hardness test results (rebound number) for concrete specimens made with and without (FDMA).

Table (4.4): Effect of The Admixture Type on Density of The Hardened Concrete

Mix symbol	Density (Kg/m^3)
M_0	2316
$LM_{1.5}$	2320
LM_3	2320
LM_4	2328
$SM_{2.5}$	2319
SM_5	2325
SM_8	2332
$BM_{2.5}$	2341
$BM_{4.5}$	2329
BM_6	2328

Table (4.5): Results of The Modulus of Elasticity for Concrete Specimens with Different Types of Admixtures

Mix symbol	Modulus of elasticity (GPa)
M_0	26.83
$LM_{1.5}$	27.05
LM_3	27.65
LM_4	28.69
$SM_{2.5}$	27.10
SM_5	27.52
SM_8	28.12
$BM_{2.5}$	28.96
$BM_{4.5}$	27.25
BM_6	25.65

Table (4.6) : Rebound Number for Concrete Made with Admixtures and without It

Mix symbol	Rebound number
M_0	29
$LM_{1.5}$	30
LM_3	30
LM_4	32
$SM_{2.5}$	29
SM_5	29
SM_8	32
$BM_{2.5}$	34
$BM_{4.5}$	30
BM_6	29

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 6.0". This program includes extensive statistical operations and regression analysis capabilities
The exponential equations used are of the following general forms.

$$Y = a_0 . X_1^{a1} . X_2^{a2} . X_3^{a3} .... X_n^{an} (4-1)$$ [1st……………..model]

$$Y = a_0 + a_1 X_1^{a2} + a_3 X_2^{a4} + a_5 X_3^{a6} + a_7 X_4^{a8} ...... a_{2n-1} X_n^{a2n} (4-2)$$ [2nd………..model]

[3rd…..model]

$$Y = a_0 X_1^{a1} + a_2 X_2^{a3} + a_4 X_3^{a5} + a_6 X_4^{a7} + a_8 X_5^{a9} .... a_{2(n-1)} X_n^{a2n-1} (4-3)$$

where:
Y = Dependent variable

X1, X2 , X3 ,Xn = Independent Variables.

a_0, a_1, a_2, a_3 constants.

Mathematical Models for Prediction of Free Shrinkage Strain (Sha)

To find the regression for prediction of (Sha), equations (4-lA), (4-2A) and (4-3A) 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/m^3) .

Dp = Drying period (days).

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

From Tables (4.7) and (4.8), the following equations could be used to estimate the properties after (FDMA)addition with high coefficient correlation , minimum value of the difference (df) and with fewer variables introduced in them .

$$Sha = 0.2724(Shb)^{1.17639} + 3608(Ra)^{0.01781} + -3673.8(Rn)^{-0.0085} + 1803.1(P)^{-6.041}$$
$$+213(Dp)^{0.107} + -6.72(E)^{1.212} ....(4-4) \quad [3^{rd} \text{ model}]$$

Table (4.7) : Regression Coefficients for Free Drying Shrinkage Prediction After Admixture Addition

Variable	Coefficient	Model 1	Model 2	Model 3
	a_0	0.105184	424.5904	0.272480
Shb	a_1	1.084105	1465.298	1.176395
	a_2		0.076292	
Ra	a_2	0.128403		3608.025
	a_3		2534.318	0.017812
	a_4		0.022879	
Rn	a_3	2.3080850		
	a_4			-3673.80
	a_5		0.00000	-0.008540
	a_6		7.309460	
ρ	a_4	0.870788		
	a_6			1803.199
	a_7		1505.970	-6.04169
	a_8		-10.3639	
DP	a_5	0.062887		
	a_8			213.3776
	a_9		941.0836	0.107874
	a_{10}		0.069470	
E	a_6	-4.55890		
	a_{10}			-6.72396
	a_{11}		-2221.47	1.212661
	a_{12}		00.315017	
R		0.91798	0.90468	0.93302

Table (4.8) : 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	±95.5789

Conclusions

1. The drying shrinkage strain development of concrete is affected by the type and amount of the finely divided mineral materials added the addition of limestone dust (LSD) contents to concrete mix decreases the free drying shrinkage at early and later ages of this concrete. At the addition level of (4%), the reduction in free drying shrinkage strain is about (36%) at (14) days drying period and about (17%) at (130) days drying period compared with that of the control mix and does not significantly affect free drying shrinkage strain of concrete when increasing its contents.
2. 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 was observed at early ages. The highest percentage of increase is about (11 %) at a percentage addition of (8%) (by weight of cement) at (63) days drying period.
3. 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 (27%) at a percentage addition of (6% by weight of cement) at (130) days drying period.
4. 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 (1.5%).
5. For the 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 (6%), which is higher about (43%), 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 (4.5%).

6. 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 is (R = 0.93 3).

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