

PRODUCTION OF A BANDER MATERIAL WITH AN EXPANSIVE NATURE USED FOR CRACKS REPAIRING IN BUILDINGS FROM A LOCALLY AVAILABLE MATERIALS ⁺

أنتاج مادة رابطة ذات طبيعة تمددية صالحة للاستخدام في إصلاح التشققات في الأبنية من مواد أولية متوفرة محليا

Jabbar Abbas Jabbar ^{*}

Abstract:

In this study a practical attempt is performed to produce a binder material of an expansion nature from the locally available materials in Iraq .The material is produced by mixing a limited portions of pure gypsum with cement to achieve the required expansion . Two types of locally produced cements are used , Ordinary Portland Cement (O.P.C.) and Sulphate Resisting Portland Cement (S.R.P.C.) of Al- Kufa and Karbala factories respectively. A technical gypsum is used throughout this work . Cement is added with three different levels (5,10 and 15)% from the dry weight of gypsum . Fresh mixture is tested for its spread ability , setting time , as well as small joists of (25 * 25* 250) mm size, are tested to investigate their soundness using autoclave method . Cubes of (50) mm size in addition to prisms of (40 * 40 * 160) mm are cast to measure their compressive strength and linear expansion respectively , in the hardened state of this mixture .Results indicated that , the material produced from the locally available materials was satisfactory for strength and durability required. The architectural presentation is fair to be used in cracks repair . The results showed that : 1.The produced material was workable in its fresh state and hard enough to resist loads as well as preventing moisture in its hardened state .2. The linear expansion of the produced material at (28) days age was about (100 and 75) % compared with the reference expansion at (2 hrs) age by using (O.P.C.) and (S.R.P.C.) addition respectively, which was less than that of pure plaster by about (250)% .3. The compressive strength is higher than that of pure gypsum which was about (150%) more for (10 % and 15%) addition of (O.P.C.) and (S.R.P.C.) respectively at the age of (7)days .4.The autoclave expansion was about (1%) as a maximum in the addition of (15%) of (O.P.C.) state.

المستخلص:

في هذه الدراسة تم أنجاز محاولة عملية لإنتاج مادة رابطة ذات طبيعة تمددية من المواد المتوفرة محليا. تم إنتاج المادة المذكورة وذلك بمزج كميات محددة من الجبس الفني والسمنت للحصول على التمدد المطلوب. تم استخدام نوعان من السمنت المحلي في هذا العمل وهما السمنت البورتلاندي العادي (O.P.C.) صنع معمل الكوفة الجديد والسمنت البورتلاندي المقاوم للأملح (S.R.P.C.) صنع معمل كربلاء ، في حين تم استخدام الجبس الفني . حيث أضيفت ثلاثة نسب من مادة السمنت إلى مادة الجبس الفني وهي (٥ ، ١٠ ، و ١٥) % وزنا من وزن مادة الجبس. أن المادة المنتجة تختلف في خواصها عن خواص المواد الأولية التي

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^{*} Ass. Prof. Babylon Technical Institute .

صنعت منها، حيث تم فحص الخليط في حالته الطرية لمعرفة قابلية أنتشاره ووقت تصلبه وفحص عوارض صغيرة قياس (٢٥ * ٢٥ * ٢٥٠) ملم لتحديد ثباتها بطريقة الأوتوكليف . في حين تم فحص مكعبات قياس (٥٠ * ٥٠) ملم لمعرفة مقاومة الانضغاط وعوارض صغيرة أخرى قياس (٤٠ * ٤٠ * ١٦٠) ملم لقياس التمددات الطولية لها في الحالة المتصلبة للخليط . أشارت النتائج إلى إمكانية إنتاج المادة الرابطة ذات الطبيعة التمددية حيث تتمتع المادة بالقوة والمتانة المطلوبة و المظهر المعماري الجيد للاستخدام في إصلاح الشقوق. إن النتائج قد بينت : ١. إن المادة المنتجة في الحالة الطرية تتمتع بقابلية تشغيلية وصلابة كافية لمقاومة الأحمال والرطوبة في الحالة الصلبة. ٢. إن التمددات الطولية للمادة المنتجة مقاسه بالعمر (٢٨) يوم مساوية إلى ما يقارب (١٠٠ و ٧٥) % مقارنة مع التمدد المرجعي بعمر (٢) ساعة وهي أقل بمقدار (٢٥٠ %) من مثيلاتها في الجبس الفني لوحده عند إضافة (السمنت البورتلاندي الاعتيادي والمقاوم) على التوالي. ٣. إن مقاومة الانضغاط أكبر بمقدار (١٥٠ %) من نظيرتها في حالة الجبس الفني لوحده بإضافة السمنت البورتلاندي المقاوم والاعتيادي عند نسبة إضافة (١٥ ، ١٠ ، %) على التوالي بالعمر (٧) أيام. ٤. أن التمدد مقاسا بطريقة الأوتوكليف كان بمقدار (١ %) كحد أقصى عند نسبة أضافه (١٥ %) من السمنت البورتلاندي العادي .

Introduction :

Withdrawal of water from concrete stored in unsaturated air , drying shrinkage is occurred . Apart of this movement is irreversible and should be distinguished from the reversible moisture movement caused by alternating storage under wet and dry conditions. The potential shrinkage of neat cement is restrained internally or externally.

Internal restraint is caused from aggregate and steel reinforcement , while external restraint is caused from edge or base element fixing. The result for restrained shrinkage is internal tensile stresses in magnitudes may overcome the tensile strength of concrete element. In general , shrinkage is occurred differentially and internal stresses are differential also , which lead to micro and macro cracks . [1]

Many attempts have been made to develop a type of cement which , on hydration , would counteract the deformation induced by shrinkage. In special cases , even a net expansion of concrete on hardening may be advantageous. The important limitations required in the produced material were , expansion must be occurred in the early ages without excessive expansion at later ages. Concrete containing an Expansive Cement expands in the first few days of its life, and a form of prestress is obtained by restraining this expansion with steel reinforcement . This steel is put in tension and concrete in compression . Restraint by external means is also possible. Such concrete is known as Shrinkage – Compensating Concrete . In this type of concrete a compressive stress of about (0.2 – 0.7) Mpa is induced , which is about equal to the tensile stresses resulting from shrinkage .

It is also possible to use Expansive Cement in order to produce a Self – Stressing Concrete , in which the restrained expansion , remaining after most of the shrinkage has occurred , is high enough to induce a significant compressive stress in concrete up to 7 Mpa . [2]

Expansive Cement is early developed in Russia and France [3] , where Lossier used a mixture of Portland Cement , an expanding agent , and a stabilizer. The expanding agent was obtained by burning a mixture of gypsum, bauxite, and chalk, which form calcium sulphate , and calcium aluminate. In the presence of water , these compounds react to form calcium sulphoaluminate hydrate (ettringite), with an accompanying expansion of cement paste .

The stabilizer, which is Blast Furnace Slag, slowly takes up the excess calcium sulphate and brings expansion to an end. Nowadays, three types of Expansive Cement are produced.

ASTM C845-96 [4] classified Expansive Cements collectively under designation of Type E-1, and according to the expansive agent used with Portland Cement and calcium sulphate is subdivided to K, M, and S. In each case, the agent is a source of reactive aluminate which combines with the sulphates in the Portland cement to form ettringite. The three types of expansive cement recognized by ASTM C845-96 and ACI 223R-93, are: [1]

(a) Type K which contains $C_4A_3SO_3$, and uncombined CaO. $C_4A_3SO_3$ is separately burned clinker and interground with Portland cement, ground separately and blended with Portland cement, or alternatively, formed simultaneously with Portland Cement clinker compounds during the burning process. Type K cement is produced by integral burning of the components or by intergrinding as previously mentioned. It is also possible, as is done in Japan, to add the expansive component at the concrete batching plant.

(b) Type M which contains CA and $C_{12}A_7$ interground or blended with Portland cement with suitable proportion of calcium sulphate.

(c) Type S which contains C_3A in excess of the amount normally present in Portland cement and more calcium sulphate than usually found in Portland cement.

In addition, in Japan, there was produced an expansive cement which uses specially processed CaO to produce free lime expansion. This cement is called Type O. [5]

ASTM C845-96 prescribes a maximum (7) day expansion of mortar of between $(400-1000) \times 10^{-6}$, the 28 day expansion must not exceed the (7) day expansion by more than 15%.

Because the formation of ettringite requires a large amount of water, wet curing of concrete is necessary for full benefits of the use of such cement to be reaped. ASTM C845-96 prescribes also when paste, mortar and concrete are made with this type of cement, that no sulphate presence internally or externally.

Very careful proportioning of the cement ingredients is necessary in order to obtain the desired expansion. In general, about (8 to 20) parts of the sulphoaluminate clinker are mixed with 100 parts of Portland cement and 15 parts of the stabilizer is recommended.

Research Significance :

In this study, the expansive binder material is formulated on the basis of Type S, but in opposite nature. We used an excessive amount of sulphates with a limited amount of C_3A due to the simplicity of controlling the sulphate amount and its nature as well as to the economic purpose. Technical gypsum is used as a main material which is a rather pure hemihydrate calcium sulphate. Cement was used as a minor source material of tricalcium aluminates to avoid the disadvantage of the excess amount of C_3A presence. This mixture characterized by both properties required, which are, earlier expansion when the solid body of the mixture is not mature yet, as well as the resistance to load and moisture. The resulting mixture is a waterproof binder material with cracks refinement ability.

3. Experimental Work :

The details of materials used with some important properties are explained as follows :

1. plaster :

A locally available technical gypsum of trowel brand manufactured by the Iraqi United factory is used through out this work. The material is tested according to the Iraqi Organization of Standards (I . O . S . 28 _ 88) [6] to investigate some important chemical, physical, and mechanical properties. Table (3.1) explains these investigated properties

Table (3. 1) : Chemical, Physical and Mechanical Properties of plaster

Property	Test Results	Requirements (I.O.S. 28-88)
Chemical Composition (%):		
SO ₃	55.5	> 45
CaO	36.5	>30
SiO ₂	0.50	-
MgO	0.64	-
Fe ₂ O ₃	0.30	-
L.O.I	4.00	-
Physical Properties:		
Fineness (retained on sieve NO.16)	5%	5 % (max.)
Setting Time (Vicat test, min.)	15	8-25
Bulk Density (gm/cm ³)	1.15	-
Mechanical Properties:		
Compressive Strength at 7days (Mpa)	5.5	≥ 5

2. Cement

Two types of Iraqi cements are used in this work . First one is (Ordinary Portland Cement, O.P.C.) cement produced by the AL- Kufa Plant , and the second is (Sulphate Resistance Portland Cement , S.R.P.C.) produced by Kerbela Plant. The reason for using the two types of cement is to investigate the effect of tricalcium aluminates content on the behavior of the resulting mixture with respect to the soundness property. Three percentages (5,10, and15) % of both types of cement are added to the plaster . The physical , chemical , and mechanical properties of cements used are mentioned in Table 3.2(A,B,C) , which are performed according to the Iraqi Organization of Standards (I . O . S . 5 _ 84) .[7]

Table (3. 2 A):Chemical Properties of the Two Types of Cement

Oxides	Percentages%		Requirements of I.O.S. 5_84 %
	O.P.C.*	S.R.P.C.**	
CaO	66.5	62.6	-
SiO ₂	20.5	21.6	-
Al ₂ O ₃	6.6	4.2	-
MgO	1.7	1.7	≤5
Fe ₂ O ₃	3.7	5.1	-
SO ₃	2.5	2.1	≤2.8, ≤2.5
L.O.I	3.1	1.5	≤4
I.R	1.1	0.9	≤1.5
L.S.F	0.98	0.88	0.66-1.02
Major Compounds	O.P.C.*	S.R.P.C.**	Requirements of I.O.S. 5_44 %
C3S	58.3	49.1	-
C2S	14.8	25.0	-
C3A	11.3	2.5	-, ≤3.5
C4AF	11.2	15.5	-

Table (3.2 B) : Physical Properties of the Two Types of Cement

Property	O .P.C.*	S.R.P.C.**	Requirements of I.O.S. 5-84
Fineness(Blaine cm ₂ lgm)	2850	3100	>2300
Soundness (autoclave)%	0.50	0.30	<0.8
Setting Time			
I.S.T(min.)	90	120	> 45
F.S.T(min .)	130	170	<600

Table (3.2 C) : Mechanical Properties of the Two Types of Cement

Compressive Strength of Mortar Mpa	O.P.C.*	S.R.P.C.**	Requirements of I.O.S.5-84
3days	19	16	>15
7days	25	24	>23

* O.P.C. : Ordinary Portland Cement.

**S.R.P.C. Sulphate Resistance Portland Cement.

3 . Mixtures:

After the addition of the selected percentages of cement , the mixtures are dry mixed thoroughly to obtain the homogeneity in color . Each dry mixture is added to three different water contents to specify its standard consistency for the resulting mixture in each addition ratio , which is differed from that of the plaster alone . Twenty four different mixtures were cast in the work. The color of dry and wet mixture was differed according to the added cement portion . The color was light gray , dark gray and dark at (5, 10, and 15) % added percentages respectively. The following results for the achieved standard consistency are tabulated in Table (3. 3) . Standard consistency is performed according to the Iraqi Organization of Standards (I.O.S. 28_88) [6] on the average diameter of spreading of (100 ± 3) mm for the wet mixture .

Table (3.3) Standard Consistency for Different Cement Contents Additions

Addition Ratio% of Cement	Standard Consistency%	
	O.P.C.	S.R.P.C.
0	0.70	0.70
5	0.90	0.70
10	0.85	0.80
15	0.80	0.90

4. Casting and Testing:

Two series of mixes were casted , each one is contained twelve different mixtures. The first mix is formulated from O.P.C addition to the plaster and the second is formulated from S.R.P.C addition . Each of previous mixes are casted with the three different addition percentages (5 ,10, and 15) % . For each mix ,the standard consistency is tested according to the Iraqi Organization of Standards (I.O.S.28_88) [6] and the results are tabulated in Table (3.3) above . The setting time is measured also according to the previous specification in the standard water content previously measured . Soundness using autoclave method is tested ,therefore , joists of (25 * 25 * 250) mm size are casted and tested according to the Iraqi Organization of Standards (I.O.S.5_84) [7]. The following results of the setting time and soundness are tabulated in Table (3.4) below.

Table (3.4) Setting Time and Soundness Results for Different Cement Percentages Addition

Addition Ratio Of Cements%	Setting Time (min.)		Soundness %	
	O.P.C	S.R.P.C.	O.P.C	S.R.P.C
0	16	16	-----	-----
5	7	13	-----	-----
10	10	10	0.7	0.6
15	10	10	1.0	0.9

Cubes of (50* 50 * 50)mm in the standard consistency of all mixtures with cement are casted to measure their compressive strength according to the Iraqi Organization of Standards (I.O.S. 28_88) [6] .The results are illustrated in the Fig.(4.1) .

Prisms of (40*40*160) mm are casted also to investigate their linear expansion . these prisms are casted in the standard consistency of all mixes . The test is performed according British Standard Institution (B.S.1191_76) [8] . The results are shown in the Fig.(4.2A and 4.2b) .

Results and Discussion:

1. Standard Consistency :

Indicating to the Table (3.3) ,It is clear that , for O.P.C. case standard consistency is decreased with the percentages addition of cement. The maximum value at the (5%) addition and the minimum value at the (15%) addition of cement . It was 90% and 80% for the previous addition ratios. It is noticed also , that , the reduction value in the standard consistency was about 0.05% for each 5% addition ratio increment. As compared with the reference mix , standard consistency is about 70% which is increased significantly of about 25% on the first stage of addition ratio. Also, standard consistency is started to reduce gradually for the second and third stages addition ratios to be near that of reference mix. To explain these previous behaviors , we can say that , when 5% of the first stage of addition ratio , cement take some portion of mixing water for its hydration which is led to reduce the water content in the mixture. This process is reflected to increase the water demand to maintain its standard spread of the total mixture. At the second and the third stages of (10 ,and 15) % addition , cement is played as a render factor of gypsum particles collection which is led to reduce water demand ,which is required to achieve the standard consistency .

For S.R.P.C . case , the behavior trend is contradicted to the previous trend of O.P.C. When the cement is added in three stages , standard consistency is increased about 0.15% for each of the second and the third stage of addition. On the 5% stage of addition, standard consistency was about the same of that reference mix , while it was about 90% on the 15% addition ratio. As compared with the reference mix , there is no noticeable increment occurred in the standard consistency on the 5% addition , which is related to the less activity of this type of cement to affect water content of mixture. The activity of this cement is noticed on the second and the third stages of addition ratios , which is reflected on the water content required for standard spreading.

2. Setting Time and Soundness :

Indicating to the Table (3.4) , setting time of O.P.C. mixtures decreased to (7) min. on the 5% addition ratio and is increased to about (10) min. on the (10, 15)% addition ratios . As compared with the setting time of reference mix which is about (16) min. , the behavior is agreed with the of behaviors of previous consistency. Cement in the first stage of addition is played as accelerator , while it was a retarder for the setting time in the other two stages comparing with the first stage of addition .

Setting time of S.R.P.C mixture is decreased slightly on the 5% addition ratio to be about (13) min. and is decreased to about (10) min. on the other addition ratios . It is also noticed that , setting time is to be constant at (10) min. on the second and the third stages of addition ratios for both types of cement.

In general , setting time was less for each mixture as compared with that of pure plaster mix . The cement addition for all portions is regarded to be as accelerator compared with the pure

plaster mix . This is related to the higher surface area of cement and its higher demand for water .

Results of soundness indicated that , the maximum expansion is occurred on the (15 %) cement added for the O .P. C. Specimens of pure plaster and mixtures of (5%) cement addition are cracked and their expansion is not measured.

3. Compressive Strength Results:

Cubes of (50* 50 * 50) mm of the standard mixtures with cement are tested to investigate their compressive strength. The test is carried after (7days) of air curing at (20 to 23) C° in about (65 %) relative humidity as indicating in the specification used . Compressive strength is illustrated in Figure (4.1) which showed the strength for the different cement addition of both types of cement .

Results for O.P.C are about (150 %) higher than those corresponding of pure plaster paste on the (10 %) cement ratio addition . There was some reduction is occurred on the ratio of (15 %) cement addition , but the cement plaster mix result was still higher than that of pure one. In spite of this reduction , there was also an increase of about (100 %) in the compressive strength compared with the corresponding of pure plaster paste at this cement ratio. This reduction, may be related to the higher content of C₃A on this ratio of cement addition [9 , 10]. This figure showed that the optimum results are obtained on (10 %) cement addition .

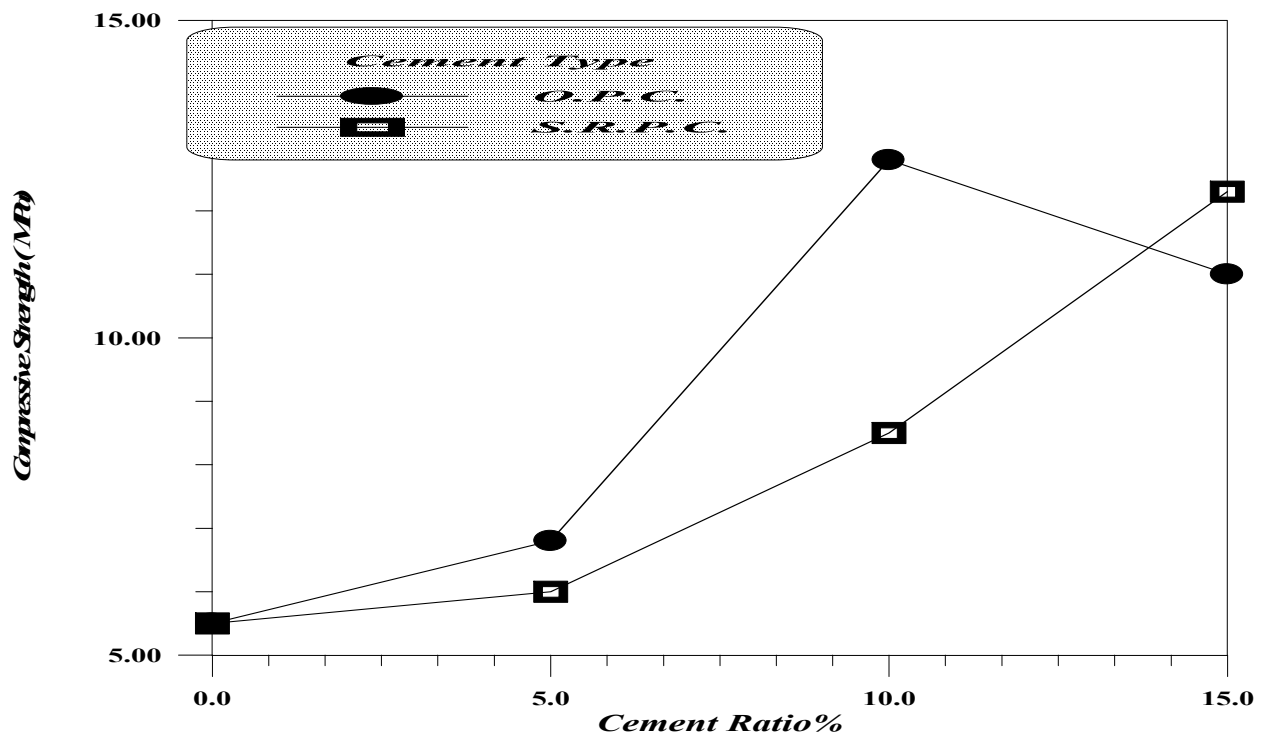


Fig.(4.1) Relation between Compressive Strength and Cement Ratio for the Two types of Cement

In the case of S.R.P.C addition , the increments in the results compared with those for O.P.C. plaster mix were less. Compressive strength was higher compared with the reference mix, and there was no reduction is occurred . The higher increase in the compressive strength is occurred on (15 %) cement addition which was about

(150 %) compared with that of reference mix. These increments may be attributed to the accumulated gel of plaster and cement formations compared with the less destructive effect of ettringite formation in this case. [9]

4. Linear expansion Results:

Prisms of (40 * 40 * 160) mm were casted for the three mixes which were pure plaster , O.P.C. plaster , and S.R.P.C. plaster mixes . All of the mixes are casted on their standard consistencies in three different cement content additions . The expansion is measured at (2 hrs) according to the B . S. 1191 in 1976 [8] and is regarded as the reference expansion . Fig. (4.2A and 4.2B) show the results of this test at (7 ,28 days) of age for the different cement ratio addition of the two types of cement used . In these Figures. , the age is in log scale . The

comparison here is established with that of the reference expansion which is measured at (2hrs) age.

Pure plaster gave continuous expansion at the all tested ages of (2hrs , 7 days and 28 days) .

Expansion was about (250 %) higher for all mixes than that reference expansion at (28 days) age . Using O.P.C. plaster mix restrained this expansion to (50 , and 100) % higher at the ages of (7 and 28) days only for all cement ratio addition . S.R.P.C was the best , The expansion was decreased to about (75 %) higher than that of the control one as a maximum at (28 days) age for all percentages of cement addition .

These behaviors can be demonstrated to the cement gel formation , which catch the excessive expansion of hemi hydrate sulphate inversion to hydrate sulphate . This inversion process is accompanied with swelling and porous structure . The physical structure of cement plaster mixes were less porosity and more density due to the refinement ability of cement plaster mixture [11]

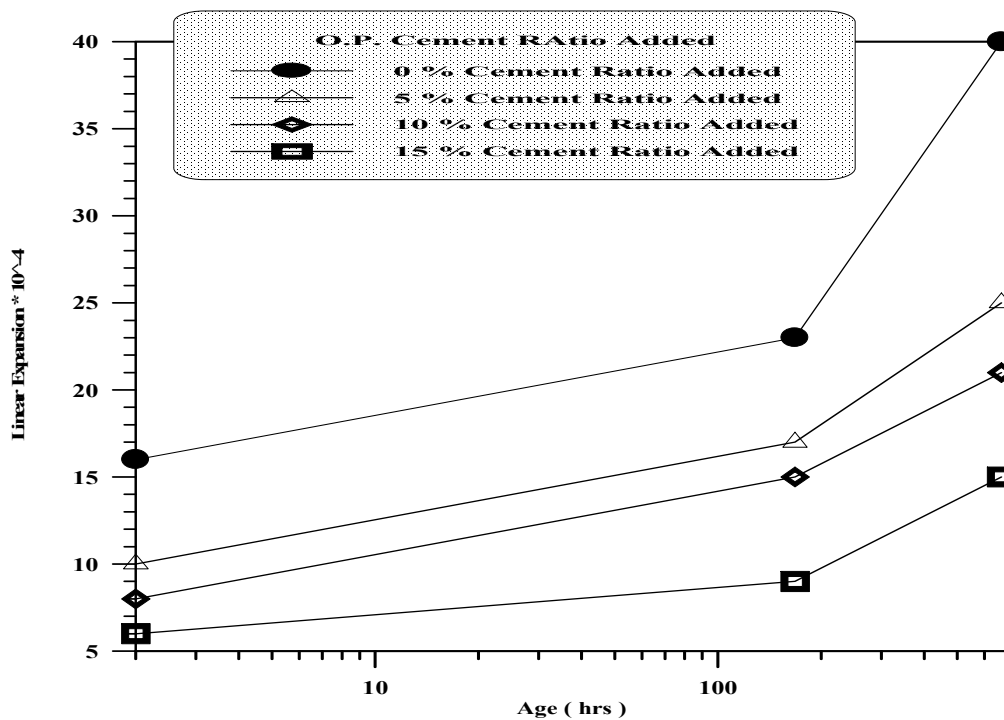


Fig. (4.2 A) Relation between the Linear Expansion and the Tested Ages for Different Addition Percentages of (O.P.C.) Cement

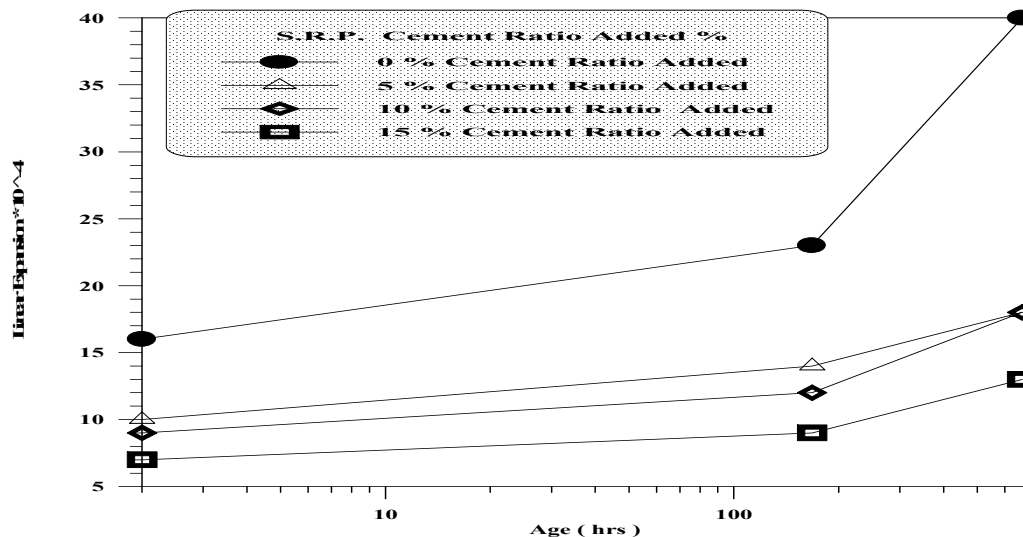


Fig. (4.2 B) Relation between the Linear Expansion and the Tested Ages for Different Addition Percentages of (S.R.P.C.) Cement

Conclusions:

From the previous data and materials used in this study , the following conclusions can be drawn :

1. Expansive material can be made using locally available technical plaster and O.P.C. or S.R.P.C.
2. The standard consistency of expansive mixture is different from that of pure plaster .It was about (0.8) % and (0.9)% for O.P.C and S.R.P.C addition respectively.
3. The optimum mixture is obtained by mixing (10% O.P.C. : 90% plaster or 15% S.R.P.C. : 85% plaster).
4. Using O.P.C is regarded to be satisfactory for compressive strength requirement but not for that of soundness requirement .The higher compressive strength is devouted from both O.P.C. and S.R.P.C addition , which is about (150)% higher than that corresponding of pure plaster
5. The linear expansion which is increased progressively for pure technical gypsum is restrained in the produced expansive mixture . It was about (100 and 75)% higher than reference mix compared with the (250) % at the age of (28 days) for O.P.C and S.R.P.C addition respectively.

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