Enhancing the compressive strength property of gypsum used in walls plastering by adding lime

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Abstract:

This study aims to improve the compressive strength and the adhesive for the Iraqi gypsum by using the lime as a local material to improve the properties of the Iraqi gypsum in binding and plastering works. The lime was used to replace 10%, 20%, and 30% of the total gypsum quantity to study the development of the paste material and its effect on the compressive strength, its structure and the water quantity. The initial and final setting time was conducted with the compressive strength test. The results showed a full improvement in the compressive strength for the cubes at the age of 7 days comparing to the gypsum paste. There was a change in the setting time with the replacement of gypsum with lime in addition to the increase in the density of the final product. The results showed the possibility of developing the Iraqi product and the recommendation to use in a wide range in the finishing works which can be more economic in the work.

Key words: Gypsum, Lime, Compressive Strength, DSC, Walls plastering, $CaCO_3$

الخلاصة

يهدف هذا البحث الى تحسين خواص مقاومة الانضغاط والتماسك لمونة الجص العراقي باستخدام مادة النورة كمادة محلية لتحسين المنتج العراقي كمادة رابطة في اعمال اللبخ والبناء. استخدمت النورة لاستبدال 10%، 20%، 30% من كمية الجص الكلية لغرض دراسة تطور المادة الرابطة وتاثيرها على مقاومة الانضغاط والبناء الهيكلي وكمية الماء .تم اجراء الفحوصات الفيزيائية والكيميائية للمادة بعد خلط النسب المطلوبة .كذلك تم اجراء فحص التماسك الابتدائي والنهائي ومقاومة الانضغاط .اظهرت النتائج حصول تحسن كامل في مقاومة الانضغاط للمكعبات بعمر 7 ايام مقارنة مع مادة الجص وكذلك تغيير في زمن التماسك الابتدائي والنهائي.اضافة الى زيادة كثافة المادة النهائية. اظهرت النتائج امكانية تطوير المنتج العراقي والتوصية باستخدامه في اعمال الانهائات بشكل واسع مما يوفر اقتصادية أكثر في العمل.

الكلمات المفتاحية :- الجبس، الجير، قوة ضاغطة، دسك، الجدران التجصيص، CaCO3

Introduction:

Gypsum which is chemically known as ($CaSO_4.2H_2O$) is widely distributed mineral found worldwide in sedimentary evaporate deposits. It is one of the first minerals to precipitate and is typically found beneath rock salt deposits in marine salt domes (Shainberg *et.al.*,1992).

In the construction field gypsum paste and mortar is one of the most ancient building materials in the world. It was used in a wide range in old Iraq, which is known as Mesopotamia. It has been used as a bonding material to build houses, temples and finishing the walls. Different sites in Iraq showed that gypsum were used in its construction such as Al Ekhaider fort which is located in Karbala, Babylon Temple located in Babylon Province (Al Hillah City) and Al Mustansiria School in Baghdad (2012 ،رؤوف واخرون). Gypsum as a binder is one of the main plastering materials in Iraq; however, the production process is still undeveloped and without quality control Figure (1).

Figure 1 Old gypsum factory.

In Iraq, the Gypsum as a powder is still one of the main building material which is used for different construction applications. This can be related to different reasons such as its low cost, availability of its raw materials, and can be used also in the production of isolating materials. As aforementioned, it is still the main building material to cover the cement on the walls before the use of Plaster of Paris. Moreover, gypsum is used in the middle and the south of Iraq to cover the roofs as a binding material beneath the mud tiles. In addition to that, there is still a desire for low cost housing to use gypsum mortar as a binding material for the bricks in wall building and ceilings.

Nevertheless, paucity in the published studies and researches regarding the way of developing gypsum paste and mortar has been noticed. In the previous Iraqi studies, reed and a coconuts skin fibers have been added to the gypsum mortar to increase the compressive strength, tensile strength and flexural strength. The results showed an increase in the strength property; however, strength increment didn't pass 26% (البغدادي، 2010). In another study silica fume, Polyvinyl Acetate, FurFural, Carbon Fibers and Poly propylene Fibers were used to increase the flexural strength; however, compressive strength was out of the scope of the study which left a wide range of questions related to the effect of such materials on gypsum strength (رؤوف واخرون، 2012).

So far there is no study introduced the possibility of using Iraqi lime as the main material to improve the compressive strength of the local gypsum. The aim of this investigation is to develop the Iraqi local Gypsum that is used in wall plastering, the production of gypsum board and building to be better in its properties. Moreover, this study will introduce the Iraqi Gypsum as one of the best materials in the Arab region, which needs a little development to be exported outside Iraq as a good building material.

The main objective is to facilitate the possibility of developing the manufacturing process and support the knowledge regarding the use of such materials which is available widely in Iraq. The results of this study will participate in bring up the mixture of gypsum and lime to produce better binding material. Moreover, this study will support the Iraqi building materials to be used as a competitive for the materials that are being imported from outside Iraq.

Experimental Program

Materials

Gypsum:

Gypsum powder was brought from the local market. The origin of the raw gypsum is located in Najaf City desert which is one of the main sources for gypsum manufacturing in the middle area of Iraq. Figure 2 shows the raw materials as the main source to produce gypsum, which is taken from the local factory. As can be seen, the raw materials are a mixture of quartzite sand. Figure 3 shows the gypsum after burning and before grinding. In this study, the gypsum powder was sieved by 200 mm sieve (1.18 mm) to remove the debris and extraneous materials such as agglomerated particles.

Figure (2) Raw materials for gypsum before burning in oven.

Figure (3) The gypsum after burning and before grinding.

Lime

Lime as a powder was brought from (Karbala factory for cement and lime) which is the main source for lime production in Iraq. Figure 4 shows the Limestone stone (calcium carbonate) $CaCO_3$ as the main materials for lime manufacturing. Figure 5 shows the Lime after burning in the kiln and after grinding for direct use.

In this investigation, hard lime was used as the main additive to enhance the gypsum properties. Figure 6 shows that particle size of the lime and it can be seen that more than 75 percent of the particle size are in the range of 10 μm which is classified as a very fine material. Table 1 shows the chemical composition of the lime which is supplied by the factory. As can be seen the main component is the calcium oxide (CaO).

Figure (4) Calcium Carbonate $CaCO_3$ rocks (Limestone).

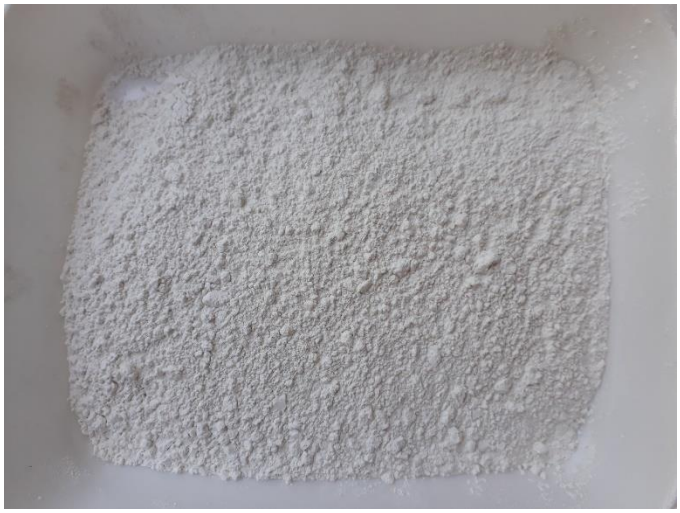
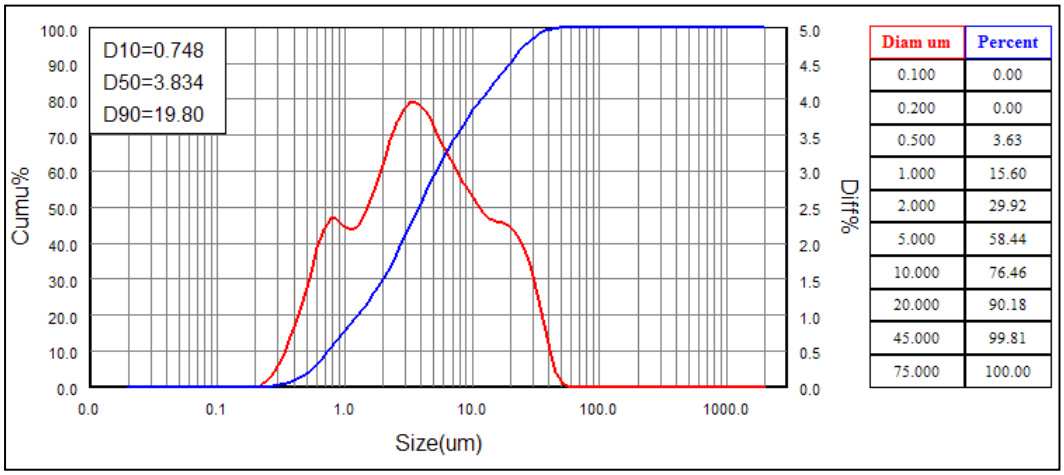


Figure (5) Lime after burning and grinding



Diam um	Percent
0.100	0.00
0.200	0.00
0.500	3.63
1.000	15.60
2.000	29.92
5.000	58.44
10.000	76.46
20.000	90.18
45.000	99.81
75.000	100.00

Figure (6) Particle size analysis of the lime

Table 1 Lime powder oxides provided as a percentages

Properties	Specification No. 708-2004	Percentages
CaO%+MgO	Not Less than 85% for live Lime	96.03
MgO%	Not more than 5%	0.16
Fe_2O_3%		0.11
Al_2O_3%		0.75
SiO_2%		1.03
Oxides	Less than 5%	1.89
SO_3%		0.50
L.O.I		1.47
Total		99.89
Activity (CaO)		94.21
CO_2	Less than 5%	2016
Slacking Time	10-15	12
Slacking temperature	Not Less than 70 °C	83

Characterization:

DSC test

Differential Scanning Calorimetry (DSC) is a thermoanalytical technique that measure temperature and heat flows associated with thermal transition in the material. The specimens for this test are powder prepared from samples from the raw gypsum and lime. Approximately (5) mg of the sample was weighed, and placed in an aluminum pan before being sealed with a small-hole pan cap. The sample pan was placed in the sample holder, while the reference pan was in its holder. The DSC was operated using a setting of nitrogen at 10mL/min and heating rate at 10 °C/min.

As can be seen from Figure 7, one major endothermic peak was detected for the Gypsum. This major peak centered around 60 °C 165 °C which may correspond to release of free water by evaporation (Mansour *et.al.*, 2013). Lime did not show such behavior of releasing water and that is compatible with the manufacturing process; however, a slightly exothermic chemical reaction has been detected at 393 °C.

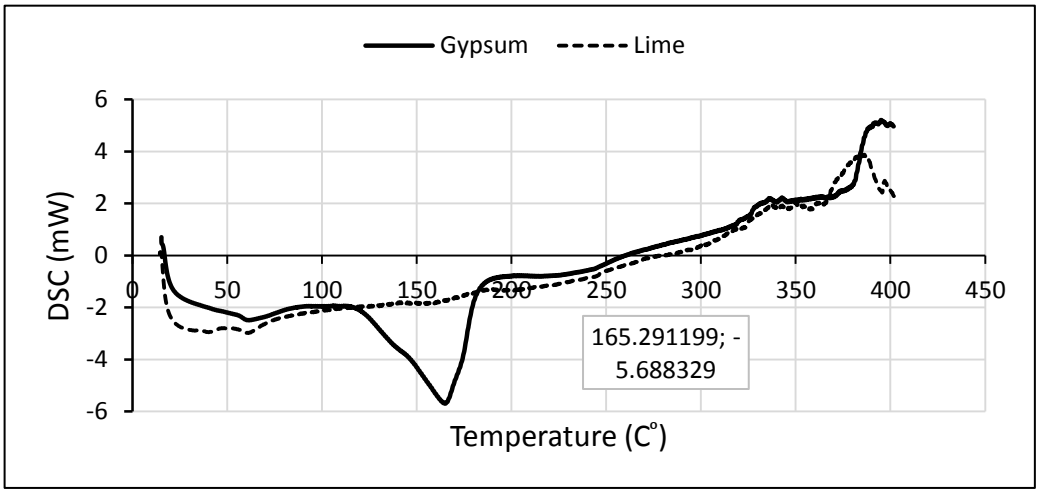


Figure (7) DSC test for raw Gypsum and raw Lime

Methodology (Experimental Work)

In this study, Iraqi Gypsum and lime were used in all the stages of the research. Gypsum was sieved by sieve number 200 (1.18) mm in order to remove agglomerate and unwanted materials. Initial setting time test and final setting time with the water content was calculated for the gypsum paste to be sure that it complies with the Iraqi specifications (المواصفة القياسية العراقية، 1988). Compressive strength at the ages of 7 days was used to evaluate the effect of lime on the density and strength of the gypsum mortar. The selected gypsum was bought from the market, which is widely used in the construction sector to cover the walls of the buildings.

Physical Tests

Fineness test:

Gypsum fineness test was conducted according to the Iraqi Specifications and it was less than 8% which is compatible to the Iraqi specifications. The gypsum finance is calculated according to equation (1):

Gypsum finance = (the left weight on sieve/Weight of the sample) * 100 ----------(1)

Gypsum paste consistency

Different experiments have been conducted to find out the suitable quantity of water for the consistency. According to the try and error method, the required quantity of water to mix 100 g of gypsum was 35 g which showed the best quantity of water for workability.

Initial and final setting time

The initial and final setting time for the paste of the gypsum paste and gypsum mixed with lime paste was conducted according to the standard test method for time setting of hydraulic cement by Vicat Needle (ASTM C191, 2008). The setting time test was conducted in order to measure the changes in the matrix texture and the time required for paste transformation from slurry state (liquid state) to solid state after mixing with water. The initial setting time was 8 min while the final setting time was 25 min which is compatible with the Iraqi Specifications (1988 ،المواصفة القياسية العراقية). The mixing method was conducted by spreading the gypsum on the suitable quantity of water for the right consistency that have been found previously.

Results and Discussions

Setting time:

Table (2) shows the initial and final setting time for the reference mix and the gypsum-lime mixes. As can be seen the partial replacement of lime has affected the initial and final setting time. In general, the initial setting time and final setting time for gypsum-lime mixes was lower than the initial and final setting times comparing to the reference mix which contained 100% gypsum. The reduction in the setting time is attributed to the effect of the chemical reaction between the lime and the gypsum. According to (Yu, et al, 2012, Lanzon and Garcia-Ruiz, 2012) the reaction process starts in gypsum after the contact between water and $CaSO_4$ particles. The hemihydrate will be dissolved in water and needle like crystals precipitate in a kind of exothermic reaction as explained in Equation 2.

$$CaSO4.0.5H_2O + 1.5\ H_2O \longrightarrow CaSO4.2H_2O + heat \text{ ----------(2)}$$

Partial replacement of gypsum with lime influence on the kinetics of hydration reaction and consequently affecting the gypsum plaster setting time. The chemical analysis of lime shows around 96% of Calcium Oxide which speed up the hydration process and reduce the setting time producing higher heat of reaction. As can been seen from Table 02, the reduction in the initial setting time was 43%, 33%, and 9% for mixes contained 10%, 20%, and 30% of lime, respectively, while the reduction in the final setting time was 78%, 74%, and 61% for mixes contained 10%, 20%, and 30% of lime, respectively. The detected effect of lime on the setting time of gypsum is incompatible with the results obtained by previous research which showed an increase in setting time with 15% of addition of lime (فريح واخرون، 2005).

Table (2) Initial and final setting time

Mix	Gypsum	Lime	Initial Setting Time	Final Setting Time
Reference	100%	0	8 Min	25 Min
Mix 1	90%	10%	4.53 Min	5.41 Min
Mix 2	80%	20%	5.33 Min	6.56 Min
Mix 3	70%	30%	7.30 Min	9.7 Min

Density:

The bulk density of gypsum paste and gypsum-lime paste are illustrated in Figure (8). The results show that a higher bulk density was obtained with the addition of lime as a partial replacement by weight. As can be seen, there was an increase of 6.2%, 9.51%, and 9.7% for mixes with 10% lime, 20% lime, and 30% lime, respectively comparing to the reference mix with 100% gypsum. This may be related to the condensation of the lime particles with gypsum particles due it its smaller particle size. This effect of lime can be considered as a positive effect on the gypsum paste microstructure by increasing the heat of hydration and increasing the hydration products consequential with denser paste. Using lime has changed significantly the microstructure of the crystal structure of the gypsum.

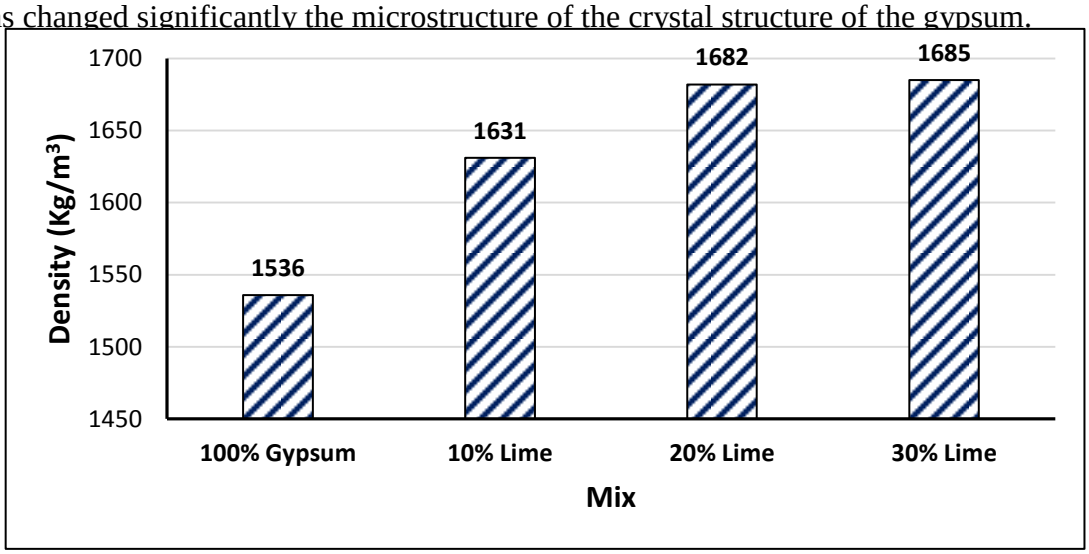


Figure (8) Bulk density for Gypsum pastes with and without lime.

Compressive strength:

Figure (9) shows the compressive strength of 100% gypsum paste and gypsum-lime paste with three different percentages 10%, 20%, and 30% as a partial replacement by weight. As can be seen, the maximum strength for 100% gypsum paste was 3 MPa which is obtained at the age of 7 days. The results showed that the selected gypsum is compatible with the Iraqi specifications. Using lime as a partial replacement by weight showed a development in the compressive strength. As can be seen from Figure (9) there was no improvement in the compressive strength with 10% lime mix which may be attributed to the low content of lime, thus it showed undetected effect on the strength. Previously it was reported that using lime in other mortars with small percentages does not modify the microstructure of the binder (Pacheco-Torga *et.al.*, 2012). An increase in compressive strength was detected for pastes containing 20% and 30% of lime as a partial replacement by weight of the gypsum. The results showed an increase in the compressive strength with 47% and 100% for 20% lime and 30% lime, respectively. This can be attributed to the chemical reaction of the gypsum and lime in the presence of water. The replacement of lime affected the hydration process and caused rapid hydration due to the increase of the surface area of the mixture. The increment in the compressive strength may confirm that the lime is an active additive to the gypsum to increase the hydration rate and hydration products. This behavior resulted due to the formation of carboaluminate (Acharya and Patro, 2015) and that was clear from the setting time test which resulted in lowering the

required time. Previously, the effect of adding 15% of lime to the gypsum showed an increase in compressive strength around 34.1% (2005 ،فريح واخرون).

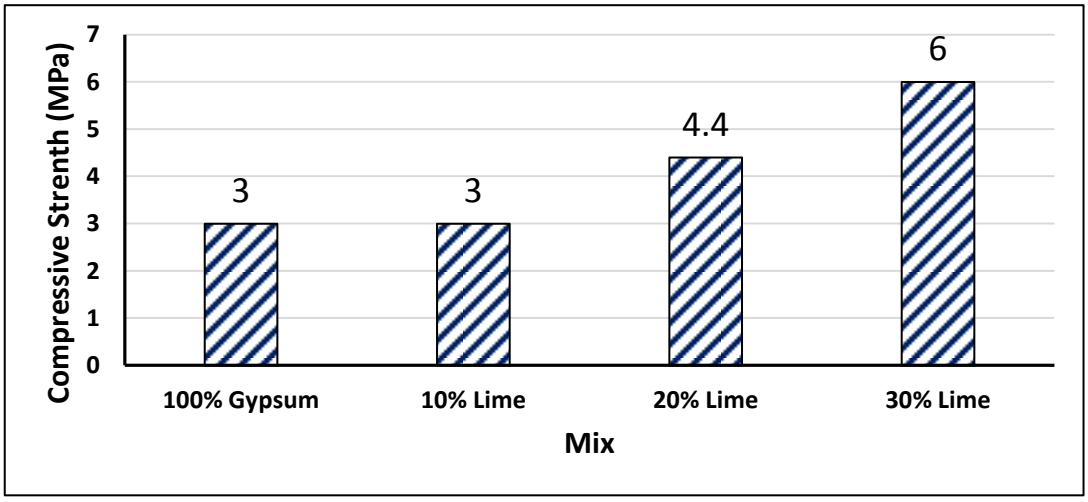


Figure (9) Compressive strength results for gypsum – lime mixes.

Conclusions

The results of this study can draw the following conclusions

1. One of the main manufacturing process defects of the Iraqi gypsum is the use of raw materials without sieving to remove the debris and the extraneous materials which may effects the final product.
2. The investigated gypsum has low compressive strength and low workability.
3. Using Lime as a partial replacement by weight of gypsum has reduced the setting time.
4. Using lime was effective in increasing the bulk density of the gypsum paste.
5. The results showed an increase in the compressive strength with the use of lime as a partial replacement of gypsum. Using 30% of lime showed the best results.
6. The results showed the possibility of using lime as an additive to develop the production process of the gypsum, which can improve the mechanical property of the final product. The chemical effect of adding lime has accelerated the hydration process and reduced the setting time.
7. Using lime as a partial replacement of the gypsum can be used in developing the Iraqi gypsum to be used in variety products. It is a promising mixture to produce a very good quality new binder for house building, false ceiling with better quality and finally better new gypsum for covering walls.

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References:

Acharya, Prasanna K., Patro, Sanjaya K., 2015 , Effect of lime and ferrochrome ash (FA) as partial replacement of cement on strength, ultrasonic pulse velocity and permeability of concrete. Construction and building materials, Volume 94, p.p. 448-457.

ASTM C. 191–08 , 2008 , ASTM International, West Conshohocken, PA, USA, Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle.

Lanzon, M., Garcia-Ruiz, P.A. , 2012 , Effect of citric acid on setting inhibition and mechanical properties of gypsum building plasters, Construction and Building Materials. Volume 28, p.p. 506-511

Mansour, Ben Mohammed., Soukaina, Cherif. Amel, Benhamou Brahim. and Sadok Ben Jabrallah, 2013 , Thermal characterization of a Tunisian gypsum plaster as construction material, Energy Procedia, Volume 42, p.p. 680-688.

Pacheco-Torgal, F., Faria, J., Jalali, S. , 2012 , Some considerations about the use of lime-cement mortars for building conservation purposes in Portugal: A reprehensible option or a lesser evil? Construction and Building Materials, Volume 30, p.p. 488-494.

Shainberg, I., Sumner, M.E., Miller, W.P., Farina, M.P.W., Pavan, M.A., and Fey, M.V. , 1992 , Use of Gypsum on Soils: A Review, p.p 1-111.

Yu, Q.L., Brouwers, H.J. H. , 2012 , Thermal properties and microstructure of gypsum board and its dehydration products: a theoretical and experimental investigation, Fire Mater. Volume 36 575-589. DOI: 10.1002/fam.1117.

البغدادي، عالية عبد الرزاق موسى 2010 ، تحسين الخواص الميكانيكية لمونة الجص باستخدام المضافات النباتية، مجلة التقني – المجلد الثالث والعشرون / العدد 1، ص.ص. (1-24)

الجهاز المركزي للتقييس والسيطرة النوعية 1988 ، المواصفات القياسية العراقية للجص الاعتيادي رقم 27 و 28.

رؤوف، زين العابدين محمد، العبيدي، ندى مهدي فوزي، العبيدي، هديل خالد عواد 2012 ، تحسين خواص الجص بإستخدام المضافات، مجلة الهندسة العدد 1 مجلد 18 كانون الثاني، ص.ص. (1-18).

فريح، قيس جواد، القيسي، وليد عبد الرزاق، عبد الخالق، لمى سعيد، 2005 ، تحسين زمن التجمد للجص الفني العراقي باستخدام المضافات الطبيعية، مجلة الهندسة والتكنولوجيا، المجلد 24، العدد 9.