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Modification of gypsum products (Part I): physical and mechanical properties of adding some additives on different types of gypsum products

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ABSTRACT

Aims: A pilot study was done to evaluate the physical and mechanical properties of the Iraqi plaster (Al-Ahliya gypsum) and Plaster of Paris (British Gypsum), and to improve the quality by the incorporation of some additives. **Materials and Methods:** Two types of gypsum products were used in this study (Iraqi plaster, Plaster of Paris). Three types of additives {gum arabic at a concentration of (0.1%, 0.25%, 0.35%, 0.50%), calcium oxide at a concentration of (0.1%, 0.25%, 0.35%, 0.50%, 0.75%), and ferric oxide acts as a pigment (blue or red) at a concentration of (0.1%, 0.2%)} were incorporated after preparation into the weighted dried gypsum powder. The effects of these additives on the physical and mechanical properties of the experimental gypsum products (Iraqi plaster and Plaster of Paris) have been evaluated by measuring the water/powder ratio, setting time, linear setting expansion, and compressive strength. Four hundred sixty gypsum samples were prepared for this study. Mean, standard deviation, variance (ANOVA), and Duncan's multiple range tests were used to analyze the measurements. **Results:** ANOVA showed that there was a significant difference in the water/ powder ratio, setting time, linear setting expansion, and compressive strength between Iraqi plaster and Plaster of Paris depending upon the type and the concentration of each additive used. **Conclusions:** The last concentration of each additive (gum arabic 0.5%, calcium oxide 0.75%, or ferric oxide 0.2%) in all the experimental measurements that are incorporated within the two gypsum products showed results within the acceptable range of American Dental Association (ADA) specification No. 25.

Key Words: Gypsum products, gum Arabic, calcium oxide**,** ferric oxide.

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INTRODUCTION

Gypsum materials are used extensively to make models casts and dies in dentistry.[1] Gypsum products probably serve the dental profession more adequately after slight modification.[2]

Several studies have been attempted to come up with an improved system for models and die construction.[3] Other study attempted to improve the mechanical properties of the gypsum products where oriented mainly towards the decrease of gauging water requirement.[4] In order to improve gypsum materials many attempts have been made by the use of various additives to gain several modifications related to the chemical, mechanical, physical and other properties of the gypsum materials.[5,6] A pilot study was to improve the physical, and mechanical properties of the Iraqi plaster (Al–Ahliya gypsum) and Plaster of Paris (British gypsum) by incorporation of some additives.

MATERIALS AND METHODS

The Materials used in this study are Iraqi Plaster (Al-–Ahliya Co. for gypsum industries Ltd/ Baghdad), Plaster Of Paris (British gypsum Newark U.K 41593/106), Calcium oxide from Calcium carbonate (B.D.H. chemicals, U.K), Ferric oxide (Aldrich Chem. Inc. Ltd. / U.K), and Gum Arabic (B.D.H Acacia).

● ***Preparation of the Gypsum Samples:***

Prior to weight the gypsum sample, the dry material was thoroughly remixed by complete stirring or by rolling the container end over with a sufficient air space to permit the material to move freely. Sieving procedure had been done using sieve size of 100 µm. 100 gm of dried gypsum materials were weighted using an accurate electronic digital balance, and then the dried material was sieved for 20 minutes. The weights of the sieved materials were for the Iraqi plaster 91.047gm, and Plaster of Paris 97.345gm.

● ***Preparation of the Additives, includes:***

Gum Arabic: The natural form of this material is obtained (B.D.H Acacia) as crystals with different shape, size and color. Before adding the material to the powdered gypsum, gum arabic was grounded to a fine powder and sieved by using a sieve of 100 µm.

Calcium Oxide (CaO): This material was prepared by converting the calcium carbonate ($CaCO_3$) to calcium oxide (CaO) by heating the sample in a digital muffle furnace at a temperature of 900°C for three hours according to the following equation:

$$\underset{\text{Calcium carbonate}}{CaCO_3} \xrightarrow[\text{Temp. 900°C}]{} \underset{\text{Calcium oxide}}{CaO + CO_2}$$

The resultant product was sieved using a sieve size of 100 µm, and then placed in a closed container to prevent the contamination of the product from humidity.

Ferric Oxide (Fe_2O_3): Also known as Iron III oxide usually comes in two colors (blue and red) as a ready material (pigments) obtained from Aldrich Chem. Inc. Ltd. U.K.

● ***Tests of the current study:*** The samples were prepared by mixing of the gypsum products with different concentration of the addictives as shown in Figure (1) and the following tests were done

● *Water/Powder Ratio Measurement (Consistency Test):* The water/ powder ratio was measured by using modified Vicat apparatus that gives a penetration of 30±2 mm. according to ADA specifications No. 25 for gypsum products (1975). 300 gm of test sample was added to a known volume of distilled water with 4 % sodium citrate (act as a retardor) and then mixed mechanically with vacuum mixer.

● *Setting Time Measurement:* The setting time was measured according to ADA specification No. 25 (1975) by a standard Vicat apparatus which consists of a frame bearing a 300 gm movable rod, one end of the rod has a needle of 1mm in diameter and 5cm in length. Two hundred gm of the powder were mixed mechanically with distilled water according to the previously determined water/ powder ratio. The total time elapsed from the starting point of mixing to that where the needle first fail to penetrate the sample completely was taken as the Vicat setting time for that sample

● *Linear Setting Expansion Measurement:* The setting expansions of the specimens were measured by modification of the method described by ADA specification No.25 (1975).

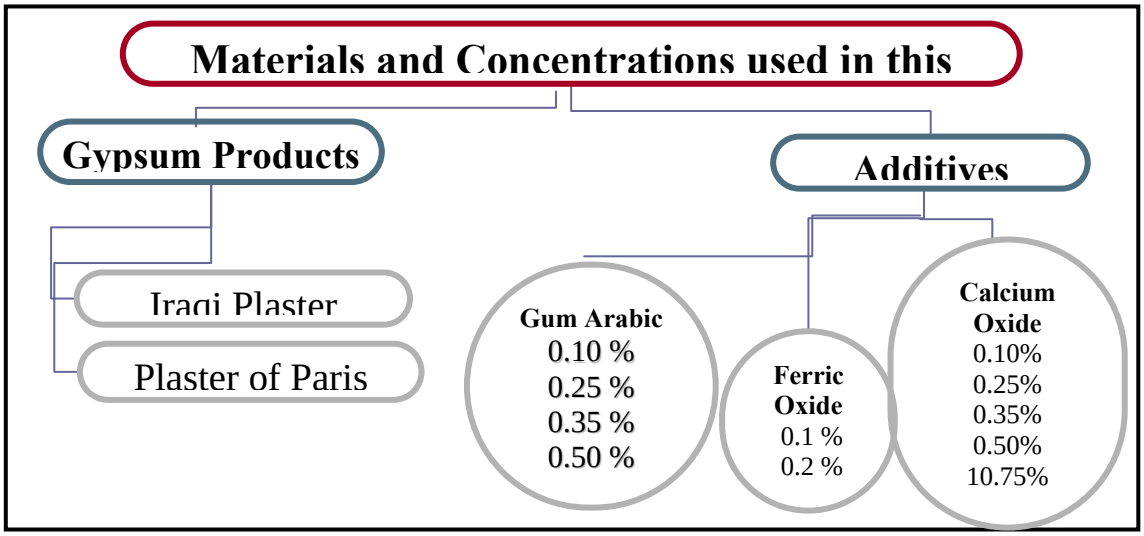

Figure (1): Materials and concentrations Of additives.

The apparatus consisted of rectangular metal box having the dimension of 104 mm in length and 58 mm in width with one fixed end stop and one movable brass slide. The motion of the free brass end was monitored by a dial gauge against the brass slide movement of the free brass end, which was monitored, by a dial gauge. The initial reading (IR) was taken one minute prior to measuring of the Setting time and final reading (FR) was taken two hours after mixing. The setting expansion was calculated according to the following formula:

ΔL % = FR-IR /L ×100 (Al–Ameer)[7],

ΔL %=Percentage of setting expansion.

L = Actual length of the specimen (as measured by the digital vernier in millimeter).

● *Compressive Strength Measurement of gypsum products:* This test was determined according to ADA specifications No. 25 (1975) with special split moulds used to prepare specimens Figure (2). The sample was crushed after
two hours from the start point of mixing by using unconfined compression machine and calculated according to the following formula: (surface area =3.14 Cm^2) Compressive Strength =Load (Kg) (Salem *et al*.)[8]; Area (Cm^2)

RESULTS AND DISCUSSION

The examined water/ powder ratio varies according to the type of gypsum materials being used (Tables 1 & 2), and the type and concentration of the additives being incorporated within the gypsum products. The actual amount of water necessary to mix the calcium sulfate hemi hydrate is greater than the theoretical amount required for the chemical reaction (18.6 ml /100gm); the water requirement in excess to that necessary for the chemical reaction is called *excess water*. Adhesion between the particles of the hemi hydrate is an important factor in determining the amount of water required to produce a product that can be poured.

These additives collectively when mixed with gypsum powders act as " *surface active agents"* by changing the condition of the surface of grains and the forces between them to be more easily wetted by water and these results are supported by Ridge and Boell.[9] Also, this may be due to the specification effect of the formed calcium hydroxide Ca(OH)2 /gum arabic mixture, which increases the pH of the mixture (increase alkalinity of the mixture).The emulsifying effect and the change in grain arrangements both result from gum arabic addition. [10]

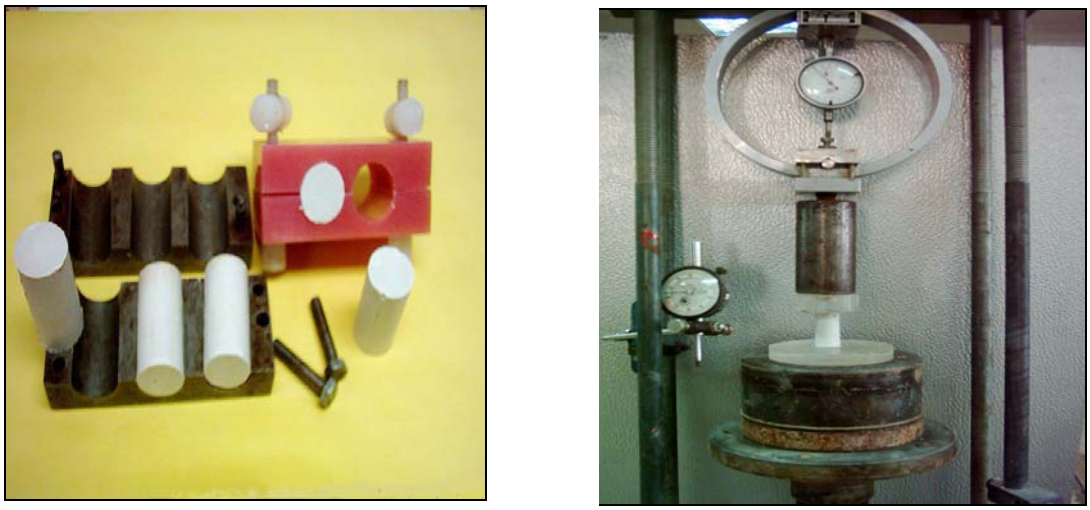

Figure (2): Split moulds with cylindrical sample

The most effective and practical method for the control of setting time is by the addition of certain *chemical modifiers* to the mixture of dental plaster or stone.[11,12] Retardors generally act by forming an adsorbed layer on the hemi hydrate to reduce its solubility and on the gypsum crystals present to inhibit growth[2]. In formulating dental products, manufacturers adjust the rate of setting reaction of raw hemi hydrate by adding accelerators or retardors and often as a balance mixture to meet the ADA requirements (Tables 3 & 4). This can be explained that the rate of setting reaction is affected by the type and the concentration of the chemical modifiers, which were added within the gypsum materials. [13]

Gypsum products with additives exhibit a retardation effect, this can be explained by the increase in alkalinity resulted from the effect of slaked calcium oxide $Ca(OH)_2$ in the mixture which acts as a retardor. This is supported by Brukl *et al.* [14], and due to the coating effect of gum arabic making gypsum particles (nuclei of crystallization) to be coated with a thin layer of soluble gum Arabic.[15] From the results of the linear setting expansion (Tables 5 & 6) for the gypsum materials, there was a significant difference in the linear setting expansion for the Iraqi plaster and plaster of Paris (model plaster). The results obtained from these gypsum products remained within the acceptable range of American Dental Association (ADA) specification for linear setting expansion measured after two hours from the start point of mixing. This explains that the chemical composition of the gypsum product has a balance blended mixture between the chemical modifiers (retardors and accelerators) and the raw hemi hydrate. The factors that affected the strength of the gypsum materials are mainly include the amount of water required (water/powder ratio) to gain a workable mass (which is inversely related to the compressive strength); method of drying plus time intervals which aid the dental gypsum cast with sufficient time for the evaporation of the excess water from the set mass. After incorporation of additives, there was an increase in the compressive strength for both of Iraqi plaster and Plaster of Paris (Tables 7 & 8). This can be explained by the reduction in the water/ powder ratio for the Iraqi plaster due to the emulsifying effect of combined additives, act of calcium oxide as a hardener modifier, and improved the adhesive forces between particles. [4, 10, 16, and 17]

Table (1): Effect of additives on the water/powder ratio of gypsum products

Additive	**Iraqi plaster alone**	**Iraqi plaster + Gum**		**POP alone**	**Plaster of Paris + Gum**	
Gum Arabic %		**Mean ± SD**	**N**		**Mean ± SD**	**N**
0.10	47.90	49.40 ± 0.5477 ef	5	41.90	42.10 ± 0.223 c	5
0.25		49.70 ± 0.447 de	5		42.15 ± 0.223 c	5
0.35		49.20 ± 0.273 f	5		41.70 ± 0.447 d	5
0.50		49.00 ± 0.000 f	5		40.95 ± 0.111 e	5
Calcium Oxide %		**Iraqi plaster + CaO**			**Plaster of Paris + CaO**	
0.10	47.90	49.90 ± 0.223 d	5	41.90	44.10 ± 0.223 b	5
0.25		50.05 ± 0.111 cd	5		47.10 ± 0.223 a	5
0.35		50.40 ± 0.223 c	5		47.20 ± 0.273 a	5
0.50		51.95 ± 0.111 a	5		47.45 ± 0.111 a	5
0.75		51.10 ± 0.223 b	5		47.10 ± 0.223 a	5
Ferric Oxide %		**Iraqi plaster + Fe2O3**			**Plaster of Paris + Fe2O3**	
0.10	47.90	47,60 ± 0.547 g	5	41.90	41.60 ± 0.418 d	5
0.20		47.80 ± 0.447 g	5		41.70 ± 0.447 d	5

.Mean: Measured in (ml/100gm); N: number of samples. POP: Plaster Of Paris; Means of water/ powder ratio with letters vertically were statistically significant.

Table (2): Analysis of variance (ANOVA) of the water/powder ratio for the two gypsum products

W/P ratio	SS	Df	Mean Square	F- value	*P*-value
Iraqi Plaster	82.461	10	8.246	72.566	0.001*
Plaster of Paris	369.909	10	36.991	439.89	0.001*

Df: Degree of freedom; SS: Sum of Squares.
*Significant difference

Table (3): Effect of additives on the Setting time of gypsum products.

Additive	Iraqi plaster alone	Iraqi plaster + Gum		POP alone	Plaster of Paris + Gum	
Gum Arabic %		**Mean ± SD**	**N**		**Mean ± SD**	**N**
0.10	10.50	5.90 ± 0.223 g	5	3.30	4.10 ± 0.223 g	5
0.25		11.10 ± 0.223 e	5		5.60 ± 0.380 e	5
0.35		12.20 ± 0.273 d	5		5.10 ± 0.223 f	5
0.50		13.20 ± 0.273 c	5		7.00 ± 0.353 d	5
Calcium Oxide %		**Iraqi plaster + CaO**			**Plaster of Paris + CaO**	
0.10	10.50	13.10 ± 0.223 c	5	3.30	9.50 ± 0.500 c	5
0.25		14.20 ± 0.273 a	5		12.30 ± 0.447 b	5
0.35		14.10 ± 0.651 b	5		12.30 ± 0.273 b	5
0.50		16.10 ± 0.223 a	5		13.40 ± 0.223 a	5
0.75		16.30 ± 0.212 a	5		13.60 ± 0.418 a	5
Ferric Oxide %		**Iraqi plaster + Fe2O3**			**Plaster of Paris + Fe2O3**	
0.10	10.50	10.36 ± 0.415 f	5	3.30	3.30 ± 0.447 h	5
0.20		10.30 ± 0.447 f	5		3.60 ± 0.418 h	5

Mean: Measured in (minute); N: number of samples; POP: Plaster Of Paris; Means of setting time with letters vertically are statistically significant.

Table (4): Analysis of variance (ANOVA) of the setting time for the two gypsum products.

Setting time	SS	Df	Mean Square	F- value	*P*-value
Iraqi plaster	443.462	10	44.346	384.707	0.001*
Plaster of Paris	856.427	10	85.643	630.147	0.001*

Df: Degree of freedom; SS: Sum of Squares
* Significant difference

Table (5): Linear setting expansion of gypsum products with additives.

Additive	Iraqi plaster alone	Iraqi plaster + Gum		POP alone	Plaster of Paris + Gum	
Gum Arabic %		**Mean ± SD**	**N**		**Mean ± SD**	**N**
0.10	0.238	0.218 ± 0.00836 a	5	0.102	0.0980 ± 0.013 b	5
0.25		0.1660 ± 0.00547 b	5		0.1340 ± 0.013 a	5
0.35		0.218 ± 0.0216 a	5		0.1080 ± 0.013 b	5
0.50		0.1360 ± 0.0450 cd	5		0.100 ± 0.010 b	5
Calcium Oxide %		**Iraqi plaster + CaO**			**Plaster of Paris + CaO**	
0.10	0.238	0.160 ± 0.01871 bc	5	0.102	0.100 ±0.01225 b	5
0.25		0.1220 ± 0.00836 de	5		0.1240 ±0.0114 a	5
0.35		0.0980 ± 0.00836 ef	5		0.0980 ± 0.0083 b	5
0.50		0.0780 ± 0.01643 f	5		0.0720 ± 0.010 c	5
0.75		0.0780 ± 0.02168 f	5		0.0680 ± 0.0083 c	5
Ferric Oxide %		**Iraqi plaster + Fe2O3**			**Plaster of Paris + Fe2O3**	
0.10	0.238	0.2380 ± 0.01924 a	5	0.102	0.1020 ± 0.008367 b	5
0.20		0.1040 ± 0.01140 ef	5		0.1080 ± 0.004472 b	5

Mean: Measured in %; N: number of samples; POP: Plaster Of Paris; Means of the linear setting expansion with letters vertically are statistically significant.

Table (6): Analysis of variance (ANOVA) of linear setting expansion for the two gypsum products.

Setting expansion (%)	SS	Df	Mean Square	F- value	P-value
Iraqi plaster	0.167	10	0.01671	42.439	0.001*
Plaster of Paris	0.01833	10	0.001833	16.134	0.001*

Df: Degree of freedom; SS: Sum of Squares.
* Significant difference

Table (7):Effect of additives on the Compressive strength of gypsum products

Additive	Iraqi plaster	Iraqi plaster + Gum		POP	Plaster of Paris + Gum	
Gum Arabic %	Alone	Mean ± SD	N	alone	Mean ± SD	N
0.10	74.47	68.30 ± 1.2981 fg	5	85.92	77.760 ± 4.894 cd	5
0.25		65.58 ± 0.8585 g	5		73.420 ± 2.411 e	5
0.35		68.56 ± 1.5453 f	5		74.560 ± 1.128 de	5
0.50		70.68 ± 0.5848 ef	5		83.852 ± 4.669 ab	5
Calcium Oxide %		**Iraqi plaster + CaO**			**Plaster of Paris + CaO**	
0.10	74.47	70.680 ± 0.5848 ef	5	85.92	80.940 ± 0.606 bc	5
0.25		74.440 ± 3.6384 cd	5		80.940 ± 1.094 bc	5
0.35		72.900 ±1.7790 de	5		81.920 ± 1.703 bc	5
0.50		73.420 ± 2.4118 d	5		80.720 ± 1.500 bc	5
0.75		78.204 ± 1.0854 ab	5		82.620 ± 2.072 ab	5
Ferric Oxide %		**Iraqi plaster + Fe2O3**			**Plaster of Paris + Fe2O3**	
0.10	74.47	74.150 ± 1.7263 cd	5	85.92	84.2800 ± 5.6901ab	5
0.20		73.600 ± 2.3022 d	5		86.5200 ± 1.5205 a	5

Mean: Measured in(kg/cm²); N: number of samples; POP: Plaster Of Paris; Means of the compressive strength with letters vertically are statistically significant

Table (8): Analysis of variance (ANOVA) of the compressive strength for the two gypsum products

Compressive strength (Kg/ cm²)	SS	Df	Mean Square	F- value	P-value
Iraqi plaster	984.179	10	98.418	20.949	0.001*
Plaster of Paris	806.267	10	80.627	8.999	0.001*

Df: Degree of freedom SS: Sum of Squares.
* Significant difference

CONCLUSIONS

The concentration of each additive (gum arabic 0.5%, calcium oxide 0.75%, or ferric oxide 0.2%) in all experimental measurements that incorporated within the two gypsum products showed a results within the acceptable range of American Dental Association (ADA) specification No. 25. The name of the new Modified Gypsum resulted from this research was (MGII. MIN).

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