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Evaluation of Thermal Effect, Setting Temperature of Plaster and Its Effect on the Softening of Wax on Various Gypsum Products after Adding Additives

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Abstract Two types of plaster (Al-Ahliyah Plaster and Plaster of Paris) were used as an experimental group and two types of stones (Elite and Silky Rock) represented the control group. In addition, five chemical materials as additives were chosen in this study (gum Arabian, rosin, potassium sulfate, borax and ferric oxide) at 0.25% concentration. One or two of each above additives were added to dental plasters to prepare 1394 samples. This study included the evaluation of the following characteristics: W/P ratio, setting temperatures, setting time. The results of the above measurements were subjected to descriptive analysis (mean and standard deviation). One-way analysis of variance (ANOVA) showed that there is a significant difference among the experimental groups, Duncan's Multiple Range Test was also used to show the level of significance presented in each group. It is concluded that both types of dental plasters produced setting temperatures are however lower than that of the dental stones (control group) and their setting temperatures are more suitable for wax pattern than that of stone, but with additives, the setting temperature will be increased. This belongs mainly to the changes in the chemical structure of the gypsum. Also the results showed that, the mechanical properties of Al-Ahliyah plaster (local plaster) could be improved by the addition of some additives such as resin and gum Arabian.

Keywords: *gypsum temperature, water powder ratio, setting time, setting temperature*

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1. Introduction

Numerous studies have disclosed that many substances, when added to the calcium sulfate hemihydrate powder or to the gauging water, alter its setting time, setting expansion and other properties [1,2,3,4]. Some other studies concluded that the addition of chemicals to gypsum products does not only change their setting characteristics, but the morphological changes would occur to the crystals. The reaction of hemihydrate and water is exothermic; Anderson and Craig *et al*. [5,6], stated that as much as the mixture of gypsum is thick, a higher setting temperature would be produced. In addition, Sebbahi *et al.* [7] showed that, during the setting reaction, plaster generates heat that may exceed 40°C. This temperature may affect the accuracy of wax pattern of the dentures during flask procedure. The heat from setting plaster may cause expansion and distortion of the waxed model which could be minimized by reducing - as much as possible - both the temperature to which the model is elevated and the time during which it is at elevated temperatures [8].

Set plaster is made of entangled needles of gypsum crystals ($CaSO_4.2H_2O$). It is also obtained by the solution mediated phase transition of calcium sulfate hemihydrate ($CaSO_4.½H_2O$). The cohesion and mechanical strength of the solid are due to both entanglement and inter-crystalline interaction [9]. The additives will affect greatly on these bonds [10], by their adsorption on the surfaces of crystals, which may result in changes in gypsum properties [11].

$$CaSO_4.2H_2O \xrightarrow{110\text{-}130°C} CaSO_4.½H_2O \xrightarrow{1200\text{-}1300°C} CaSO_4 \xrightarrow{200\text{-}1000°C} CaSO_4$$

Gypsum Calcium Sulfate Dihydrate — Plaster or Stone Hemihydrate — Hexagonal Anhydrate — orthorhombic Calcium Sulfate Anhydrate

This study aimed to evaluate the effect of some additives on setting temperatures of gypsum products before and after their incorporation, Chemical structure of gypsum products before and after their incorporation, setting temperature of plaster and its effect on the softening of wax.

2. Materials and Methods

Two types of dental plaster were used in this study (commercial plaster and plaster of Paris) with one or two of the following chemical materials as additives (gum

Arabian, rosin, potassium sulfate, ferric oxide and borax), the manufactures of the materials as shown in Table 1:

Table 1. The materials with manufactures that used

MATERIALS	MANUFACTURE	BATCH NO.
Al-Ahliyah plaster (type II)	Al-Ahliyah CO. for gypsum industries LTD	
Plaster of Paris (type II)	British gypsum, New Yawk, U.K.	41593
Gum Arabic	**Natural product Lebanon**	
Rosin	Natural product Lebanon	
Potassium sulfate	Aldrich CO.	
Ferric oxide	Aldrich CO.	
Borax	Aldrich CO.	
Elite (type III) (control sample)	Zhermack SPA-45021 Italy	ISO 6873
Silky Rock (type IV) (control sample)	Whip-mix Group USA	70398

The additives were added to the powder of dental plaster in a percentage of (0.25 gm/ 100gm powder, the mixture was mixed by divided the additive in a small parts then mix a small parts gradually with the plaster). Firstly, each additive was added separately to the two types of plaster, and after that a combination was made between each additive with others, and then added to the two types of plaster. The effects of these additives on the physical and mechanical properties of dental plaster were evaluated, which include Water/Powder ratio, setting time, setting temperatures, of the prepared samples before and after addition of these chemical materials, the total study samples were 1394.(all the tests were done under the same conditions of the temperature and humidity).

The preparations of all test samples was performed according to ADA specification No.25 (1975) for gypsum product. The testing procedures were conducted at room temperature of (23± 2°C) and a relative humidity of (50 ± 10%). The additives were mixed with plaster (0.25gm/100gm plaster) by manual mixing firstly then completed by electric mixture.

2.1. Preparation of Samples

The pure crystals of Arabian gum without apparent impurities were used. At first, they were ground in blender and then sieved using 150µm mesh sieve. The other additives (potassium sulfate, borax and ferric oxide), which were synthetic chemical materials, present ready in a form of fine particles and supplied in a tight closed containers produced by Aldrich Company. The additives used in this study were in a form of powder, so they were added to the hemihydrate (plaster) powder directly. The pre-weighed plaster or stone mixed with distilled water for all the tests (except in the consistency test in which 4% sodium citrate solution was used instead of distilled water).

2.2. Measuring Water/Powder Ratio (Consistency Test)

According to ADA Specification No. 25, Vicat. Apparatus was used for measuring the Water/Powder ratio.

2.3. Measuring of Setting Time

The setting time was measured according to ADA Specification No.25 (1975) using a standard *Vicat* apparatus.

2.4. Measuring of Setting Temperatures

Measuring of Gypsum temperature: This test was employed to measure the heat accompanied the exothermic reaction of plaster or stone with water [13,14]. A digital thermometer (Model MY-64, China) was used for this purpose with a thermocouple probe, which is a highly heat sensitive wire, that helps in transmitting the heat from the sample to the thermometer, Figure 1. Before measuring the setting temperature of any gypsum sample, the digital thermometer was calibrated. This process was done by using two mercuric thermometers, one placed in cold water and the other placed in hot water. The tip of the thermocouple probe placed in each container of water alternatively and then the temperature of the digital thermometer was compared to that of the mercuric thermometer. The procedure was repeated several times with and without covering, the end of the thermocouple probe was covered with an aluminum foil.

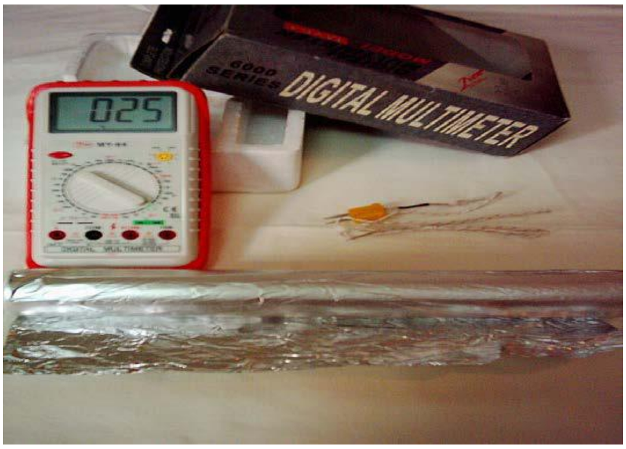

Figure 1. Digital Thermometer, Thermocouple probe and Aluminum foil

2.5. Measuring of Wax-Gypsum Temperature

One hundred gram of powder was mixed with distilled water according to the above determined Water/Powder ratio, and then poured in a mould made from a non-corroding and non-absorbent material.

Figure 2. Measuring of the Surface temperatures

The tip of the thermocouple Probe was inserted inside the specimen after covering the end of the probe with a piece of aluminum foil to facilitate its removal after setting of the gypsum specimen. For measuring the surface temperature, the same procedure was followed;

except that the tip of the probe was placed just in contact with the surface of the specimen. Powder (100gm) is prepared and mixed with distilled water and poured in the mould. A piece of base plate wax in a form of circle is cut and adapted on the top surface of the specimen. Then the tip of the thermocouple probe is inserted in the wax, at the interface between wax and gypsum, Figure 2. For both gypsum and wax, the time was recorded from the start of mixing until the maximum temperature at which no further increase beyond them is obtained.

3. Results

Table 2 Means and Standards Deviation of the water /powder ratio, setting time and thermal degree of the gypsum.

Table 2. Means and Standards time, of the control samples.

Gypsum Products	W/P (ml/100gm)	S.T (minute)
	Mean ±SD	*Mean ±SD*
Al-Ahliyah Plaster	47.8±0.27	9.2 ±0.75
Plaster Of Pairs	41.2±0.27	3.3 ±0.67
Elite	29.6±0.54	17.6 ±0.41
Silky Rock	22.3±0.44	10 ±0.35

W/P: Water/powder ratio, S.T.: Setting Time.

Table 3 shows the mean and standard deviation (control values) of the setting temperatures (Inner temperatures, Surface temperatures and Wax-Gypsum temperatures) with their related times, for dental plasters (Al-Ahliyah and Plaster of Paris) and dental stones (Elite and silky Rock) used in this study.

Table 3. Mean and Standard Deviation for the Maximum Setting temperatures and Time of the Control Samples.

Gypsum Products	I.Temp. (°C)	Time (minute)	S.Temp. (°C)	Time (minute)	W.Temp. (°C)	Time (minute)
	Mean ±SD	*Mean ±SD*	*Mean ±SD*	*Mean ±SD*	*Mean ±SD*	*Mean ±SD*
Al-Alhliyah	43.6 ±0.57	19.1 ±1.15	41.3 ±0.57	23.3 ±2.08	40.3 ±0.57	24.3 ±1.52
PlasterOf Pairs	51.6 ±0.57	8.1 ±0.57	45.6 ±0.57	8.1 ±0.57	44.6 ±0.57	8.6 ±0.57
Elite	56.6 ±1.52	27.4 ±0.57	49.6 ±0.57	24.8 ±2.00	49.3 ±1.15	27.0 ±1.52
Silky Rock	56.6 ±1.52	24.8 ±0.28	50.3 ±0.57	26.5 ±0.57	49.3 ±0.57	28.1 ±0.57

I.Temp.: Inner Temperature (maximum).
S.Temp.: Surface Temperature (maximum).
W.Temp.: Wax-Gypsum Temperature (maximum).

3.1. The Effect of Additive on Water/Powder Ratio of Gypsum Products Samples

One-Way analysis of variance (ANOVA) showed that there is a high significant difference in water/powder ratio between dental plasters (with and without additives) and dental stones at (f=1678.5 and $p<0.001$).

It was shown that there is a slight increase in the water/powder ratio of Al-Ahliyah plaster (calcium sulphate hemihydrate) after the addition of each of these chemical materials; however, this increase in water requirements was statistically not significant in comparison with the control sample as revealed by Duncan's multiple range test, Table 4. Only the addition of gum Arabian showed a significant increase in the water/powder ratio of Al-Ahliyah plaster. The results also revealed an increase in the water/powder ratios occurred only after the addition of combination of additives. Duncan is multiple range test; Table 4 showed statistical differences in all values when compared with the control sample. The (gum Arabian + rosin) combination showed the highest mean value of water/powder ratio (50.7ml), whereas addition of (rosin + borax) showed the lowest mean value (49.7ml). The other combinations were arranged between the highest and lowest mean values. In addition, Table 4 showed the effect of adding chemical additives on the water requirement of Plaster of Paris. It was noticed that all these additives were statistically significant when compared with the control sample (41.2ml). The highest mean value accompanied the addition of rosin (42.2ml), while the addition of ferric oxide showed the lowest value (41.6ml).

The results of adding combination of additives to Plaster of Paris were listed in Table 5. They showed that all these combinations were statistically significant, (gum Arabian+ ferric oxide) and (potassium sulfate+ ferric oxide) combinations have the highest mean values (44.5ml). On the other hand, (potassium sulfate+ borax) showed the lowest mean value (43.8ml) when compared with the control.

Table 4. Duncan's Multiple Range Test for the water/powder ratio of the Experimental Groups (one additive).

Chemical Additives	N	Al-Ahliyah Plaster		N	Plaster of Paris	
		Mean(ml) ± SD	**DMRT**		**Mean(ml) ± SD**	**DMRT**
Gum Arabian	5	48.7 ± 0.27	B	5	41.9 ± 0.27	BC
Rosin	5	48.2 ± 0.27	A	5	42.2 ± 0.27	C
Potassium Sulfate	5	48.1 ± 0.41	A	5	41.9 ± 0.22	BC
Borax	5	48.0 ± 0.35	A	5	41.7 ± 0.22	B
Ferric Oxide	5	47.8 ± 0.27	A	5	41.6 ± 0.22	B
Control	5	47.8 ± 0.27	A	5	41.2 ± 0.27	A

N: number of sample.
DMRT: Duncan is multiple range test. (Different letters mean that the groups were significantly statistically different).

Table 5. Duncan's Multiple Range Test for the water/powder ratio of the Experimental Groups (two additives).

Chemical Additives	N	Al-Ahliyah Plaster		N	Plaster of Paris	
		Mean(ml) ± SD	DMRT		Mean(ml) ± SD	DMRT
Gum Arabic + Rosin	5	50.7 ± 0.22	D	5	44.3 ± 0.22	DE
Gum Arabic + Potassium Sulfate	5	50.3 ± 0.22	CD	5	44.2 ± 0.27	CDE
Gum Arabic + Borax	5	49.9 ± 0.67	BC	5	44.1 ± 0.27	BCD
Gum Arabic + Ferric Oxide	5	49.9 ± 0.27	BC	5	44.5 ± 0.35	E
Rosin + Potassium Sulfate	5	50.2 ± 0.27	BC	5	44.3 ± 0.27	DE
Rosin + Borax	5	49.7 ± 0.44	B	5	44.1 ± 0.22	BCD
Rosin + Ferric Oxide	5	50.1 ± 0.22	BC	5	43.9 ± 0.22	BC
Potassium Sulfate + Borax	5	49.8 ± 0.27	BC	5	43.8 ± 0.27	B
Potassium Sulfate + Ferric Oxide	5	49.9 ± 0.22	BC	5	44.5 ±0.41	E
Borax + Ferric Oxide	5	50.3 ± 0.44	CD	5	44.0 ± 0.00	BCD
Control	5	47.8 ± 0.27	A	5	41.2 ± 0.27	A

N: number of sample.
DMRT: Duncan is multiple range test. (Different letters mean that the groups were significantly statistically different).

3.2. The Effect of Additives on Setting Temperatures of the Gypsum Products

The results of the setting temperatures for gypsum products in this study can be subdivided into three groups:

The Inner temperatures. The Surface temperature and the Wax-Gypsum temperatures.

3.2.1. The Inner Temperature of Gypsum Products

One-Way analysis of variance (ANOVA) showed that there is a high significant difference in the values of the inner temperatures between dental plasters (with and without additives) and dental stones at (f=34.278 and $p<0.001$). In Table 6, it was noticed that the setting temperatures were 49.6, 50.3, 54.0, 49.0 and 48.5 °C after the addition of gum Arabian, rosin, potassium sulfate, borax and ferric oxide additives to Al-Ahliyah plaster respectively. Therefore, the maximum increase in temperature occurred after the addition of potassium sulfate (accelerator). While the minimum increase in temperature occurred after the addition of ferric oxide, although Duncan's multiple range test showed that there are significant differences in the setting temperatures of all additives when compared with that of the control group. It was noticed that all the additives had increase the internal temperatures of the studied samples.

Table 6. Duncan's Multiple Range Test for the setting temperatures (Inner) of the Experimental Group (one additive).

Chemical Additive	N	Al-Ahliyah Plaster		N	Plaster of Paris	
		Mean(°C) ±SD	DMRT		Mean(°C) ±SD	DMRT
Gum Arabic	5	49.6 ±0.57	BC	5	54 ±1.00	B
Rosin	5	50.3 ±0.57	C	5	53.6 ±0.57	B
Potassium Sulfate	5	54.0 ±1.00	D	5	54.3 ±1.15	B
Borax	5	49.0 ±1.00	BC	5	51.0 ±1.00	A
Ferric Oxide	5	48.5 ±0.50	B	5	50.6 ±0.57	A
Control	5	43.6 ±0.57	A	5	51.6 ±0.57	A

DMRT: Duncan is multiple range test. (Different letters mean that the groups were significantly statistically different).

The setting temperature of Al-Ahliyah plaster (control) is 43.6°C and the combination of additives raised the temperatures of the setting reaction from 5 to 7°C more than the control in all cases except with the addition of potassium sulfate which raises the temperature about 9 to 10°C more than the control sample. The time taken by the samples to reach their maximum temperatures was also measured. The control sample of Al-Ahliyah plaster needs about 19 minutes to reach its setting temperature. All the additives took nearly the same time except in case of addition of borax or potassium sulfate, where the time is differed greatly.

The setting temperatures in case of Plaster of Paris with and without additives also were measured. The control sample (Plaster alone) reaches to 51.6°C, which is more than the control sample of Al-Ahliyah plaster (43.6°C). Borax and ferric oxide showed reduction in the setting temperatures of Plaster of Paris (51.0, 50.6°C); however, this reduction is not significant when compared with the temperature, occurs after the addition of control. While the significant increase in gum Arabian (54°C), rosin (53.6°C) and potassium sulfate (54.3°C).

The addition of two combined additives to the powder of Plaster of Paris leads to an increase in its setting temperature significantly, Table 7. The increase in temperature was noticed to reach its maximum by the addition of potassium sulfate and any other additive, although the time, needed to reach this temperature, has been reduced. While addition of borax, plus any other additive, showed the least increase in temperature to be occurred and the time to reach this temperature has been prolonged. The inner temperatures of the two dental stones, Elite and Silky Rock, were measured in this study and compared with that of the dental plasters.

It was noticed, as presented in Table 3 that the two stones have setting temperatures about (56°C) which is higher than the two dental plasters with or without additives. In addition, the time needed by Elite stone is (27.3) minutes, while Silky Rock needs (24.8) minutes to reach the maximum temperature which is also higher than that of dental plasters.

Table 7. Duncan's Multiple Range Test of the setting temperatures (Inner) of the Experimental Group (two additives)

Chemical Additives	N	Al-Ahliyah Plaster		N	Plaster of Paris	
		Mean(°C) ± SD	DMRT		Mean(°C) ± SD	DMRT
Gum Arabic + Rosin	5	50.0 ±0.00	BC	5	54.6 ±0.57	CD
Gum Arabic + Potassium Sulfate	5	53.0 ±1.00	EF	5	56.0 ±0.00	E
Gum Arabic + Borax	5	49.6 ±0.57	BC	5	53.0 ±1.00	B
Gum Arabic + Ferric Oxide	5	49.6 ±0.57	BC	5	53.3 ±1.15	BC
Rosin + Potassium Sulfate	5	53.3 ±1.15	F	5	56.3 ±0.57	E
Rosin + Borax	5	49.6 ±1.15	BC	5	53.3 ±0.57	BC
Rosin+ Ferric Oxide	5	48.6 ±1.15	B	5	54.6 ±0.57	CD
Potassium Sulfate + Borax	5	52.3 ±0.57	EF	5	53.6 ±0.57	BC
Potassium Sulfate+ Ferric Oxide	5	51.6 ±0.57	DE	5	55.5 ±0.50	DE
Borax + Ferric Oxide	5	50.6 ±0.57	CD	5	54.0 ±1.00	BC
Control	5	43.6 ±0.57	A	5	51.6 ±0.57	A

DMRT: Duncan's multiple range test. (Different letters mean that the groups were significantly statistically different).

3.2.2. Surface Temperatures of Gypsum Products

Surface temperatures of the samples, during setting, and the time that has been spent during reaction were studied.

One-Way analysis of variance (ANOVA) showed that there is a high significant difference in the values of surface temperatures between dental plasters (with and without additives) and dental stones at ($f=51.109$ and $p<0.001$).

It was noticed that the surface temperature of gypsum is less than that of the inner temperature in all samples. The surface temperature of Al-Ahliyah plaster is 41.3°C, the additives lead to a significant increase in the surface temperatures of the samples as shown by Duncan's Multiple Range Test. It reached its maximum by the addition of potassium sulfate either alone as in Table 8 or in combination with other additives as in Table 8. While gum Arabian, rosin, borax and ferric oxide although they are significantly different when compared with the controls, but they showed only (2-3°C) higher temperature than those controls.

The times taken during the setting reaction to reach the highest temperatures were not greatly different from that of the control. Only with the addition of potassium sulfate or borax in which changes in times were observed.

Table 8. Duncan's Multiple Range Test for the setting temperatures (Surface) of the Experimental Group (one additive)

Chemical Additives	N	Al-Ahliyah Plaster		N	Plaster of Paris	
		Mean(°C) ± SD	DMRT		Mean(°C) ±SD	DMRT
Gum Arabic +Rosin	5	50.0 ±0.00	BC	5	54.6 ±0.57	CD
Gum Arabic +Potassium Sulfate	5	53.0 ±1.00	EF	5	56.0 ±0.00	E
Gum Arabic +Borax	5	49.6 ±0.57	BC	5	53.0 ±1.00	B
Gum Arabic +Ferric Oxide	5	49.6 ±0.57	BC	5	53.3 ±1.15	BC
Rosin + Potassium sulfate	5	53.3 ±1.15	F	5	56.3 ±0.57	E
Rosin + borax	5	49.6 ±1.15	BC	5	53.3 ±0.57	BC
Rosin + Ferric Oxide	5	48.6 ±1.15	B	5	54.6 ±0.57	CD
Potassium Sulfate +Borax	5	52.3 ±0.57	EF	5	53.6 ±0.57	BC
Potassium Sulfate+ Ferric Oxide	5	51.6 ±0.57	DE	5	55.5 ±0.50	DE
Borax +Ferric Oxide	5	50.6 ±0.57	CD	5	54.0 ±1.00	BC
Control	5	43.6 ±0.57	A	5	51.6 ±0.57	A

Table 9. Duncan's Multiple Range Test for the setting temperatures (Surface) of the Experimental Group (two additives)

Chemical Additives	N	Al-Ahliyah Plaster		N	Plaster of Paris	
		Mean(°C) ± SD	DMRT		Mean(°C) ± SD	DMRT
Gum Arabic + Rosin	5	43.6 ±0.57	BC	5	50.6 ±0.57	E
Gum Arabic + Potassium Sulfate	5	48.1 ±1.04	E	5	51.5 ±0.50	E
Gum Arabic + Borax	5	44.1 ±0.28	C	5	48.6 ±1.04	D
Gum Arabic+Ferric Oxide	5	42.3 ±0.76	AB	5	47.8 ±0.28	CD
Rosin + Potassium Sulfate	5	47.8 ±1.04	E	5	53.1 ±0.76	F
Rosin + Borax	5	43.0 ±0.00	BC	5	49.0 ±1.00	D
Rosin+ Ferric Oxide	5	43.0 ±1.00	BC	5	46.0 ±1.00	AB
Potassium Sulfate + Borax	5	46.1 ±0.28	D	5	46.8 ±0.76	BC
Potassium Sulfate+ Ferric Oxide	5	45.6 ±0.57	D	5	47.8 ±0.28	CD
Borax + Ferric Oxide	5	44.0 ±1.00	C	5	45.3 ±0.57	A
Control	5	41.3 ±0.57	A	5	45.6 ±0.57	AB

DMRT: Duncan's multiple range test. (Different letters mean that the groups were significantly statistically different).

3.2.3. The Wax - Gypsum temperatures

The temperature of a piece of modeling wax placed in contact with the top surface of the experimental plasters was measured with its corresponding times.

One-Way analysis of variance (ANOVA) showed that there is a high significant difference in the values of the wax temperatures between dental plasters (with and without additives) and dental stones at (f=35.933 and p<0.001). Results showed that wax placed against Al-Ahliyah plaster (control) reaches 40.3°C, while Plaster of Paris (control) reaches 44.6°C.

Duncan's Multiple Range Test also showed that as the surface temperatures of plaster samples were increased after additives incorporation, directly the temperatures of wax also increased significantly, as shown in the following Table 10 & Table 11.

Table 10. Duncan's Multiple Range Test for the setting temperatures (Wax-Gypsum) of the Experimental Group (one additive)

Chemical Additive	N	Al-Ahliyah Plaster		N	Plaster of Paris	
		Mean(°C) ± SD	DMRT		Mean(°C) ± SD	DMRT
Gum Arabic	5	43.0 ±0.50	B	5	46.0 ±1.00	BC
Rosin	5	42.8 ±0.76	B	5	47.3 ±1.15	C
Potassium Sulfate	5	43.3 ±0.57	B	5	47.0 ±1.00	C
Borax	5	42.5 ±0.50	B	5	43.8 ±0.76	A
Ferric Oxide	5	42.5 ±0.50	B	5	45.3 ±0.57	AB
Control	5	40.3 ±0.57	A	5	44.6 ±0.57	AB

N: number of sample. DMRT: Duncan's multiple range test. (Different letters show that the groups were significantly statistically different).

Table 11. Duncan's Multiple Range Test for the setting temperatures (Wax-Gypsum) of the Experimental Group (two additives)

Chemical Additives	N	Al-Ahliyah Plaster		N	Plaster of Paris	
		Mean(°C) ± SD	DMRT		Mean(°C) ± SD	DMRT
Gum Arabic + Rosin	5	42.6 ±0.57	CDE	5	49.1 ±0.28	H
Gum Arabic + Potassium Sulfate	5	43.6 ±0.57	FG	5	48.6 ±0.57	GH
Gum Arabic + Borax	5	42.6 ±0.57	CDE	5	45.8 ±0.28	CDE
Gum Arabic + Ferric Oxide	5	41.8 ±0.28	BC	5	46.8 ±1.04	EF
Rosin + Potassium Sulfate	5	44.5 ±0.50	G	5	45.8 ±1.04	CDE
Rosin + Borax	5	41.5 ±0.50	B	5	47.5 ±0.50	FG
Rosin+ Ferric Oxide	5	42.3 ±0.57	BC	5	43.0 ±1.00	A
Potassium Sulfate + Borax	5	43.5 ±0.50	BC	5	44.3 ±0.57	B
Potassium Sulfate+ Ferric Oxide	5	43.3 ±0.57	EF	5	46.0 ±1.00	DE
Borax + Ferric Oxide	5	42.5 ±0.50	DEF	5	44.5 ±0.50	BC
Control	5	40.3 ±0.57	A	5	44.6 ±0.57	BCD

N: number of sample; DMRT: Duncan's multiple range test. (Different letters mean that the groups were significantly statistically different).

3.2.4. The Effect of Additives on the Setting Time of Gypsum Products Samples

One-way ANOVA revealed that there is a high significant difference in the setting time between dental plasters and dental stones at (f=325.26 at p<0.001). Duncan's Multiple Range Test, Table 12 & Table 13 showed that additives have an effect on the setting time of Al-Ahliyah plaster. The addition of rosin or gum Arabian lead to reduction in the setting times (7.5, 8.1min) respectively. A more pronounced reduction in the setting time is occurred after the addition of potassium sulfate to Al-Ahliyah plaster (4.2min). On the other hand, increase in the setting time of Al-Ahliyah plaster is recorded after the addition of borax, which reaches (12.6min). These four additives showed statistically significant differences in their setting time when compared with the control samples (9.2min). Whereas the addition of ferric oxide showed no significant effect on the setting time of Al-Ahliyah plaster. On the other hand, it was showed that with the addition of a combination of (gum Arabian + rosin), (gum Arabian+ ferric oxide) and (rosin+ ferric oxide) to Al-Ahliyah plaster, slight changes in the setting time of the samples was occurred; however, these changes were statistically not significant. While in other combinations, any formulas added to Al-Ahliyah plaster containing borax showed an increase in the setting time, and any formulas contain potassium sulfate showed reduction in the measured setting time when compared to that recorded with the control sample. Changes in setting time also has been occurred when additives are added to Plaster of Paris.

Duncan's multiple range test showed that there is no statistical differences present after the addition of gum Arabian or ferric oxide, whereas as a significant reduction occurred with the addition of both rosin or potassium sulfate to Plaster of Paris (2.4 and 2.3 minute) respectively. On the other hand, the setting time of Plaster of Paris was increased significantly (9.5 minute) when borax is added to it.

It was revealed that the addition of these combinations lead to changes in the setting time of Plaster of Paris. However, these changes are not significant except that combinations, which consisted of borax, plus other additive, which showed a significant increase in the setting time or that, contain potassium sulfate plus other additive, which showed a significant decrease in their setting time when compared to the control sample.

Table 12. Duncan's Multiple Range Test for the Setting Time of the Experimental Group (one additive)

Chemical Additive	N	Al-Ahliyah Plaster		N	Plaster of Paris	
		Mean(min) ± SD	DMRT		Mean(min) ± SD	DMRT
Gum Arabic	5	8.1 ± 0.41	C	5	3.1 ± 0.41	BC
Rosin	5	7.5 ± 0.35	B	5	2.4 ± 0.22	AB
Potassium Sulfate	5	4.2 ± 0.27	A	5	2.3 ± 0.27	A
Borax	5	12.6 ± 0.41	E	5	11.0 ± 0.93	D
Ferric Oxide	5	9.5 ± 0.35	D	5	3.1 ± 0.41	BC
Control	5	9.2 ± 0.75	D	5	3.3 ± 0.67	C

N: number of sample., DMRT: Duncan's multiple range test. (Different letters mean that the groups were significantly statistically different).

Table 13. Duncan's Multiple Range Test for the Setting Time of the Experimental Group (two additives)

Chemical Additives	N	Al-Ahliyah Plaster		N	Plaster of Paris	
		Mean(min) ± SD	DMRT		Mean(min) ± SD	DMRT
Gum Arabic + Rosin	5	9.6 ± 0.47	BCD	5	3.2 ± 0.28	BC
Gum Arabic + Potassium Sulfate	5	4.8 ± 0.25	A	5	2.3 ± 0.47	A
Gum Arabic + Borax	5	14.3 ± 1.10	EF	5	10.1 ± 0.25	E
Gum Arabic + Ferric Oxide	5	9.7 ± 0.86	CD	5	3.3 ± 0.47	BC
Rosin + Potassium Sulfate	5	4.2 ± 0.28	A	5	2.3 ± 0.47	A
Rosin + Borax	5	15.0 ± 0.40	F	5	9.5 ± 0.40	DE
Rosin + Ferric Oxide	5	8.7 ± 0.95	B	5	3.6 ± 0.25	C
Potassium Sulfate + Borax	5	10.2 ± 0.28	D	5	9.5 ± 0.40	DE
Potassium Sulfate + Ferric Oxide	5	4.2 ± 0.28	A	5	2.7 ± 0.50	AB
Borax + Ferric Oxide	5	14.0 ± 0.40	E	5	9.3 ± 0.25	D
Control	5	9.2 ± 0.75	BC	5	3.3 ± 0.67	BC

DMRT: Duncan's multiple range test. (Different letters mean that the groups were significantly statistically different).

4. Discussion

Calcium sulfate hemihydrate occupies an important role in the fabrication of dental prostheses. Dental cast that is poured in plaster or stone should be accurate in every respect, dimensionally stable over time and hard enough to withstand the fabrication processes [17]. It was found that additives play an important role in altering the properties of gypsum materials merely by changing the forms of their crystals [18].

4.1. Effect of Additives on the Physical and Mechanical Properties of Gypsum Products: Effect of Additives on the Water/Powder Ratio

It was indicated that surface interaction plays an appreciable part in determining the water requirement, and the effects produced by additives are due to changes in the strength of the surface forces [19].

The results of water/powder ratio test showed that the addition of either Arabian gum or rosin to the plasters lead to increase in the water required for mixing. This is mainly due to that these chemical materials act as emulsifying agents i:e withdrawn the water from the mixture and necessitates the addition of more water to reach the workable mix. While the addition of salts (potassium sulfate, borax and ferric oxide) showed the least changes in the water/powder ratio of the materials. This is in agreements with Carige *et al.* (1996) [20]. Potassium sulfate and borax act by providing additional crystals and these necessitates a slight increase in the water required for mixing [21].

The addition of combination of additives required an additional increase in the amount of mixing water. This is in agreement with Craig and Power [22] who revealed that variations occurred in the surface of hemihydrate crystals after the addition of chemical materials have a great influence on the values of the water/powder ratios of the materials.

4.2. Effect of Additives on the Setting Temperatures

The criteria for selection of a particular gypsum product depend–on its use and on the physical and chemical properties necessary for that particular use [22]. Many salts and colloids are known to alter the setting characteristics of the α- and β-hemihydrate powders by their effect on the chemical composition of the crystals and by the way on their setting reactions [23].

The results showed that the type of the chemical additives bear a direct effect on the degrees of setting temperatures test. However, all additives added to either types of plaster lead to changes in the temperature of reaction. Potassium sulfate gave the maximum rise in the temperature of setting; this is in agreement with previous study [24].

The surface temperatures in all of the tested samples were less than that of the inner temperature. This is mainly due to the insulating effect of the outer layers of the plaster. In addition, the loss of heat from the water molecules present in the inner part of the sample were more slower than that molecules present in the outer surface of the sample, this is in agreement with Anderson, [25].

As the temperatures of the plaster's surface increase after the addition of additives, also the temperature of wax (that is attached to the plaster) increased. However, the deformation of the type II wax started from 45°C when flows are taken place [22]. Al-Ahliyah plaster with additives showed to have a suitable temperature with the wax that is not exceeded 44°C in most cases, while Plaster of Paris showed to have a higher wax temperature and this is due to its higher inner and surface setting temperature [22].

Stone showed to produce higher temperatures of setting and this is in agreement with Prombonas and Vlissidis [26]. Accordingly, the temperature of wax placed in contact with the stone surface also increased more than that placed against plaster. The less water that is used in mixing the stone, in addition to different additives present in it by the manufacturer contributes to this increase in temperature. This is, in fact, increased the chance of deformation of the waxed trial denture flasked with dental stone more than that flasked with plaster. In addition, the time and temperature affect the residual stress that is present in wax that is surrounding and holding the teeth. So that the waxed dentures should be flasked soon after completion to maintain the greatest accuracy of tooth relations [27].

4.3. Effect of Additives on the Setting Time

The control of setting time can be affected either by the physical or chemical properties of the gypsum products or by the method of manipulation that the dentists used [28]. However, the setting time measurements and manipulation of gypsum products used in this study were all conducted according to ADA specification No. 25. The results revealed that the addition of gum Arabian or rosin would decrease the setting time of plasters. As these additives act as emulsifying agents and they decrease the available water in the media, so the resultant thick mixes will set faster. This agrees with Kotsiomiti *et al*. [29], who stated that, the less water/powder ratio the faster setting would be the mix.

The results also showed that the addition of potassium sulfate lead to the highest reduction in the setting time, while the addition of borax in all concentrations lead to the highest increase in the setting time of the studied samples. Indeed, accelerators and retarders worked on the principle of changing the solubilities of the hemihydrate and dehydrate crystals. For example, accelerators cause the hemihydrate crystals to be much more soluble than dihydrate crystals and this would increase the nuclei of crystallization and fasten the setting [22]. On the other hand, borax acts by nuclei poisoning, by reducing the rate of solution of hemihydrate or inhibiting the growth of dihydrate crystals and this will retard the set [30]. Ferric oxide showed non-significant changes in the setting time of plasters. This is mainly because this material is a pigment and it is inert which act by coloring the crystals only without any changes in their chemistry [24].

Mauri and Moret [31] found that dyes only adsorb on the surface of the crystals (especially when added in small concentrations) whenever added alone or in combination with other additives.

Generally, the setting time of Plaster of Paris showed to be less than that recommended by the ADA specification No.25 for type II model plaster. This is may be due to the presence of accelerator added previously in this type of plaster and also due to the less amount of water needed during mixing in comparison with Al-Ahliyah plaster. The setting time of both types of plaster was shorter than the control sample of stone. Craig *et al*. [32] stated that the manufacturer added many additives to the formula of stone in order to control its setting characteristics.

5. Conclusion

The setting temperatures showed that both Al-Ahliyah plaster and Plaster of Paris have less than of dental stones. Also the setting temperatures of Al-Ahliyah plaster showed less than of Plaster of Paris. The results indicated that Al-Ahliyah plaster have the most convenient temperature (the least degree of softening) during setting against modeling wax (about 44 °C) than that of Plaster of Paris and stone. Additives will increase the setting temperatures of both types of plaster. However, the maximum increase occurs with the addition of more than one additive.

References

[1] Sunitha M Roy, J Sridevi, N Kalavathy, (2010) An evaluation of the mechanical properties of Type III and Type IV gypsum mixed with two disinfectant solutions Indian journal of dental research, 21,(3), pp. 374-379.

[2] Moslehifard, E. and Nasirpouri, F. and Mahboub, F. and Salehjou, M. and Ghasemzadeh, S. and Bahari, M.(2012), Influence of chemical disinfection on mechanical and structural properties of type III and IV dental stones, Advances in Applied Ceramics, 111(8): 450-458.

[3] Amer A. Taqa, Mohammed NZ. Alomari AW. (2012); The Effect of DifferentWater Types on The Water Powder Ratio of Dental Gypsum Products. Al–Rafidain Dent J. 12(1): 142-147.

[4] Amer A Taqa ,Nada Z. Mohammed,Tariq Y. Kassab Bashm(2015), The Effect of adding some chemical materials on the compressive strength and surface hardness of dental stone, Eastern Academic Journal. Accepted for publication.

[5] Craig RG, Powers JM, Wataha JC (2000) Dental Materials: Properties and Manipulation. 7th ed, Mosby Company, pp: 209-218.

[6] Anderson JN (1972) Applied dental materials. 4th ed, BlackWell Scientific Publications, pp: 157-169.

[7] Sebbahi S, Chameikh ML, Sahban F, Aride J, Benarafa L, Belkbir L (1997) Thermal behavior of Moroccan phosphogypsum. Thermochemica Acta.; 302(1-2): 69-75.

[8] Faraj SA and Al-Sabbagh AK (1987) Iraqi plasters as investing material. Iraqi Dent J.; 13: 38-43.

[9] Peyton FA, Anthony DA, Asgar K, Charbeneau GT, Craig RG, Myers GE (1964) Restorative dental materials. 2nd ed, Mosby Company, pp: 230-265, 266-290.

[10] Zhang Q, Kasai E, Saito F (1996) Mechanochemical changes in gypsum when dry ground with hydrated minerals. Pow Tech.; 87(1): 67-71.

[11] Peng J, Qu J, Zhang J, Chen M, Wan T (2005) Adsorption characteristics of water-reducing agents on gypsum surface and its effect on the rheology of gypsum plaster. Cem & Con Res.; 35(3): 527-531.

[12] Prombonas A and Vlissidis D (1994) Compressive strength and setting temperatures of mixes with various proportions of plaster to stone. J Prosthet Dent.; 72(1): 95-100.

[13] Hisatsune K, El-Araby AM, Iwanuma K, Tanaka Y, Udoh K, Yasuda K (1995a) Abnormal behavior in adiabatic calorimetry of set dental stone. J Prosthet Dent.; 14(1):84-87.

[14] Hisatsune K, Takuma Y, Shibuya M, Ohsawa M, Yasuda K (1995b) Quantitative analysis of unreacted hemihydrate in set dental stone by adiabatic calorimetry. J Mater Sci.; 6: 284-287.

[15] Harris PE, Hoyer S, Lindquist TJ, Stanford CM (2004) Alterations of surface hardness with gypsum die hardeners. J Prosthet Dent.; 92(1): 35-38.

[16] Mohammed NZ (2005) The effect of adding some chemical materials on the physical and chemical properties of dental stone. MSc Thesis, University of Mosul.

[17] Harris PE, Hoyer S, Lindquist TJ, Stanford CM (2004) Alterations of surface hardness with gypsum die hardeners. J Prosthet Dent.; 92(1): 35-38.

[18] Mahmoud MH, Rashad MM, Ibrahim IA, Abdel-Aal EA (2004) Crystal modification of calcium sulfate dihydrate in the presence of some surface-active agents. J.Coll & Int Sci.; 270: 99-105.

[19] Ridge MJ and Boell GR (1962) Physical properties of calcined gypsum. J Appl.Chem.; 12: 437-444.

[20] Craig RG, O'Brien WJ, powers JM (1996) Dental Materials:Properties and manipulation. 6fh ed, Mosby Company, pp: 183-213.

[21] Zhang Q, Kasai E, Saito F (1996) Mechanochemical changes in gypsum when dry ground with hydrated minerals. Pow Tech.; 87(1): 67-71.

[22] Craig RC and Powers JM (2002) Restorative dental materials. 11th ed, MosbyCompany, pp: 392-421, 426-430.

[23] Breeding LC and Dixon DL (2000) Accuracy of casts generated from dual-arch impressions. J Prosthet Dent.; 84(4): 403-407.

[24] Ray (1998) Dental Materials Science. Pp: 18-35.

[25] Anderson JN (1972) Applied dental materials. 4th ed, BlackWell Scientific Publications, pp: 157-169.

[26] Prombonas A and Vlissidis D (1994) Compressive strength and setting temperatures of mixes with various proportions of plaster to stone. J Prosthet Dent.;72(1): 95-100.

[27] Diwan R, Talic Y, Omar N, Sadiq W (1997b) The effect of storage time of removable partial denture wax pattern on the accuracy of fit of the cast frame work. JProsthet Dent.; 77: 375-381.

[28] Phillip's RW (1982) Skinner's science of dental material. 8th ed, WB Saunders Company, pp: 10-28, 63-69, 382-392.

[29] Kotsiomiti E, Diakoyianni-Mordohai I, Kaloyannides A (1995) Effect of the addition of ammonium salts on improved dental stone's surface hardness. Hell Dent J.; 5:45-50.

[30] O'Brien WJ (2002) Dental materials and their selection. 2nd ed, Quintessence books, pp: 56-60.

[31] Mauri A and Moret M (2000) Growth of potassium sulfate crystals in the presence of organic dyes: in situ characterization by atomic force microscopy. J Crys.Grow.; 208(1-4): 599-614.

[32] Craig RG, Hanks CT, Kohn DH, O'Brien WJ, Powers JM, Wagner WC, Wataha JC (1997) Restorative dental materials. 10th ed, Mosby Company, pp: 333-360.