Residual Compressive Strength of Iraqi-Gypsum Subjected to Elevated Temperature Exposure

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Abstract

The effect of elevated temperate exposure on the compressive strength of ordinary gypsum and plaster of Paris has been studied in this research. The gypsum test specimens were subjected to six temperature levels of 100, 200, 300, 500, 700 and 900 ^{o}C with three different exposure periods of 0.25, 0.5 and 1 hour. Results of 111 specimens for two types of gypsum with two cooling conditions having compressive strength ranging from 15 to 0 MPa were presented. These results showed that, the compressive strength of the specimens at temperature up to 100 ^{o}C exhibited a slight increase as compared with reference values. But all gypsum specimens suffered a significant decreases in compressive strength when exposed to 500 ^{o}C and above. After a period of 0.50 hour, the exposure period was seen to have a slight effect on the residual strength of ordinary gypsum except at 900 ^{o}C. The results also show that no residual strength was observed at 500 and 900 ^{o}C for the plaster of Paris and ordinary gypsum specimens respectively. On the other hand, water cooling was adversely affects on strength as compared with air cooling.

Keywords : Compressive strength, elevated temperature, gypsum, water cooling

الخلاصة

يتضمن هذا البحث دراسة تأثير درجات الحرارة العالية على مقاومة انضغاط الجص الاعتيادي والبورق. عرضت النماذج المفحوصة إلى ست درجات حرارة (١٠٠، ٢٠٠، ٣٠٠، ٥٠٠، ٧٠٠ و ٩٠٠ م˚) ولثلاث فترات زمنية (٠,٢٥، ٠,٥، ١ ساعة). وتم اعتماد نتائج ١١١ نموذج ذات مقاومة انضغاط تراوحت بين ١٥ إلى ٠ نت/مم^{2}. أظهرت هذه النتائج بان مقاومة الانضغاط للنماذج أبدت زيادة طفيفة عند تعرضها إلى ١٠٠م˚. لكن كان هناك تدهور واضح لمقاومة الانضغاط عند تعرض النماذج إلى درجات حرارة ٥٠٠ م˚ فما فوق. بعد فترة ٠,٥ ساعة من التعرض، فان الاستمرار في تسليط درجات الحرارة له تأثير طفيف على انخفاض مقاومة الجص عدا النماذج التي تعرضت إلى ٩٠٠ م˚. كما أظهرت النتائج أيضا بان مقاومة الانضغاط تصبح معدومة عند تعرض النماذج إلى ٥٠٠ و ٩٠٠ م˚ لكل من البورك والجص على التوالي. من جهة أخرى فان التبريد المفاجئ للنماذج قد اثر سلبا على المقاومة إذا ما قورنت بالنماذج التي تم تبريدها في الهواء.

Introduction

Gypsum is a good construction material used for various building purposes because of its low cost and its availability with good and suitable types. The products of gypsum are suitable for the environment and usage such as light weight, thermal and sound isolation, fire resistance and other uses.

In Iraq, the major application of gypsum is as a binder, finishing materials, precast units, gypsum boards, partitions and sound isolations in various buildings. Many walls and internal roofs were finished by ordinary gypsum plaster, then coated by plaster of Paris layer to get smooth surface. Also, gypsum is a useful material used for jointing the brick units as a mortar in masonry walls.

In the structural design of buildings, in addition to the normal gravity and lateral loads, it is, in many cases, necessary to design the buildings to safely resist exposure to fire (**Shettey 1988**). It is also necessary to protect the building members such as beams, columns, slabs and walls by plaster materials (cement mortar and gypsum mortar) as finishing to decrease the structural deterioration for certain period of fire exposure. Such deterioration can be decreased if good finishing materials were used in the building. This attributed to the fact that, fire initially causes damage to member surface and then affects the core of the structural member.

There are many ways of exposing buildings to fire. One of the most common types of exposure is by accidental fire. Normally such fires are of short duration but at high intensity with the temperature reached up to 1000 ^{o}C. Another type of heat

exposure may be found in places exposed to sustained elevated temperatures ranging from 100-1000 ºC.

According to the available literature, few investigations were carried out on gypsum material. Several recent and past studies were conducted on using some types of additives to improve and control the setting time, hydration, strength development, water resisting property and volume change characteristics of gypsum (**Faiyadh et al 1987, Al-Taee 1988, Al-Aubaidi 2004, Al-Qaisi 2004, Fraih et al 2005**). Another research presented good performance in tensile strength when studied the theoretical and experimental behavior of fiber reinforced gypsum plate (**Al-Ramadhani 1994**). The effect of addition some chemical admixtures to gypsum was also studied to product suitable composition matrix for application on external brick walls exposed to weathering conditions (**Al-Sudani 2001**).

A new study on plaster of Paris materials showed that the addition of gypsum to concrete mix, produce matrix of structural concrete-gypsum planks to create a smooth, monolithic floor surface that delivers superior strength, sound control and fire resistance. This product set quickly, allowing foot traffic within two hours and continued construction activities the next day (**Deely 2006**).

In this study there is an attempt to investigate the influence of elevated temperature and exposure periods on the compressive strength of ordinary gypsum and plaster of Paris. However, still limited amount of published literature is available about gypsum material.

Experimental Program

Two Types of locally produced gypsum (ordinary gypsum and Al-Ahliyah plaster of Paris) were used in this work. The physical properties of these materials are shown in **Table (1)**. For these two types, the (water/gypsum) ratios used were 0.43 and 0.56 respectively. The test procedure given by (**ASTM C473-73**) was adopted for measuring the setting time of gypsum mixtures using the vicat apparatus.

After mixing, the paste was cast into 50 mm molds corresponding to (**ASTM C472-73**). The specimens were demolded after the setting took place and they were exposed to laboratory environment under polyethylene cover up to the age of 14 days. The compressive strength was measured on gypsum specimens before and after heat exposure.

Table (1): Physical properties of ordinary gypsum and plaster of Paris.

Materials	Physical properties	Test results	Limits of Iraqi specification No.28/1988
Local gypsum	Initial setting time (Min.)	4.5	8 - 25
	Fineness (%) remaining on sieve No.16	5	≤ 8
	Compressive strength (N/mm^2)	6.87	Not less than 3
Plaster of Paris	Initial setting time (Min.)	7.5	8 - 25
	Fineness (%) passing on sieve No.16	100	100
	Compressive strength (N/mm^2)	15.2	Not less than 5

Conditions of Exposure

Electrically heated oven designed for temperature up to 1200 ^{o}C was used**.** The dimensions of heating chamber are 20×20×30 cm. The temperature were selected to be 100, 200, 300, 500, 700 and 900 ^{o}C and the period of exposure were 0.25, 0.50 and 1.00 hour. When the target temperature was reached, the specimens were kept at that temperature for the required periods. Some of the specimens were quick cooled (water cooling) after removed from the oven. The other specimens were kept beside the oven to cool down at a laboratory temperature as shown in **Pictures (1 and 2)**.

Compressive Strength of ordinary gypsum

The test results of compressive strength for all ordinary gypsum specimens (50 mm) exposed to different temperatures and periods are given in **Table (2)** and shown graphically in **Figures (1, 2 and 3)**.

Initially, as the temperature increased to 100 ^{o}C, the specimens showed a slight increasing in compressive strength of an average of 6 percent as compared with reference specimens. This increase in compressive strength may be attributed to the following reasons: 1) The slight increase in the temperature causes additional increasing in the rate of hydration of gypsum paste. 2) The increase in compressive strength may be due to increase the reactivity of unhydrated gypsum particles of the specimens.

Table (2): Compressive strength test results for ordinary gypsum.

Exposure Temperature, ^{o}C	Compressive strength (MPa) at exposure periods of		
	٠,٢٥ hour	٠,٥٠ hour	١,٠٠ hour
27	٦,٨٧	٦,٨٧	٦,٨٧
١٠٠	٧,٣٤	٧,٣٧	٧,٢٢
٢٠٠	٥,٩٢	٤,٣٤	٣,٦٦
٣٠٠	٥,٤٣	٣,٧٥	٢,٨٠
٥٠٠	٣,٢٨	٢,٣٤	٢,١١
٧٠٠	٢,٣٤	١,٦٩	١,٤٠
٩٠٠	٢,١٩	١,٤٠	٠

For comparison, the results of compressive strength are expressed as a percentage of reference values (residual strength). This variation in the residual strength with respect to temperature and period of exposure is plotted in **Figure (2)**. At temperature of 200 ^{o}C, it can be observed that the specimens show decreasing in compressive strength as the temperature increases for all periods of exposure. In temperature range from (200-900) ^{o}C, the results are surmised as follows:

1. At a period of 0.25 hour, the percentages of residual strengths were (86-31) % for a control specimens.
2. More reduction in strength occurs at the 0.50 hour of exposure. The strength of specimens at this period was about (63-20) % for reference value.

3. At a period of 1.00 hour, the reduction in compressive strength of specimens was slightly higher than of 0.50 hour. However, the residual compressive strength varied from (53 to zero) %.

This reduction may be due to dehydration process which occurred through the gypsum matrix according to the following series:

$$CaSO_4.2H_2O\ \textbf{(gypsum)} \xrightarrow{130\text{-}170\ ^oC} CaSO_4.\frac{1}{2}H_2O\ \textbf{(Hemihydrate)} \xrightarrow{250\text{-}400\ ^oC} CaSO_4\ \textbf{(Anhydrate-Soluble)} \xrightarrow{400\text{-}900\ ^oC} CaSO_4\ \textbf{(Anhydrate-Unsoluble)} \xrightarrow{1000\text{-}1200\ ^oC} Cao\ \textbf{(Lime)}$$

Also, higher temperature causes weakening of bonds between the gypsum particles and gradually losing all the specimens properties.

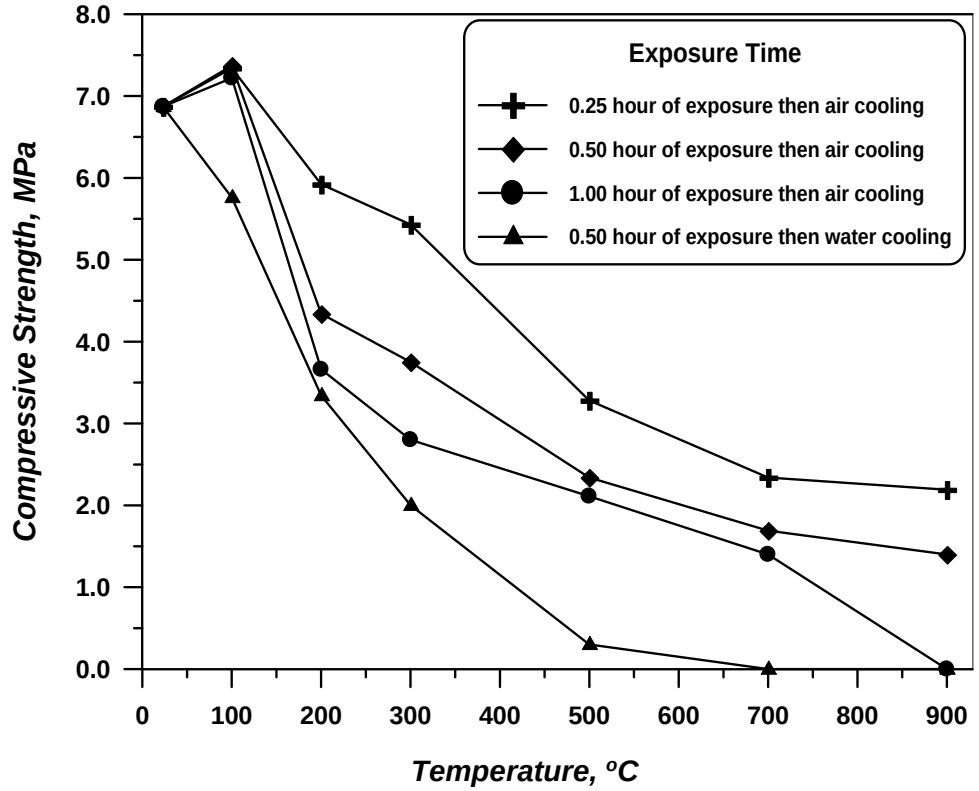

Figure (1): Relationship between the compressive strength of ordinary gypsum and exposure temperatures for different periods

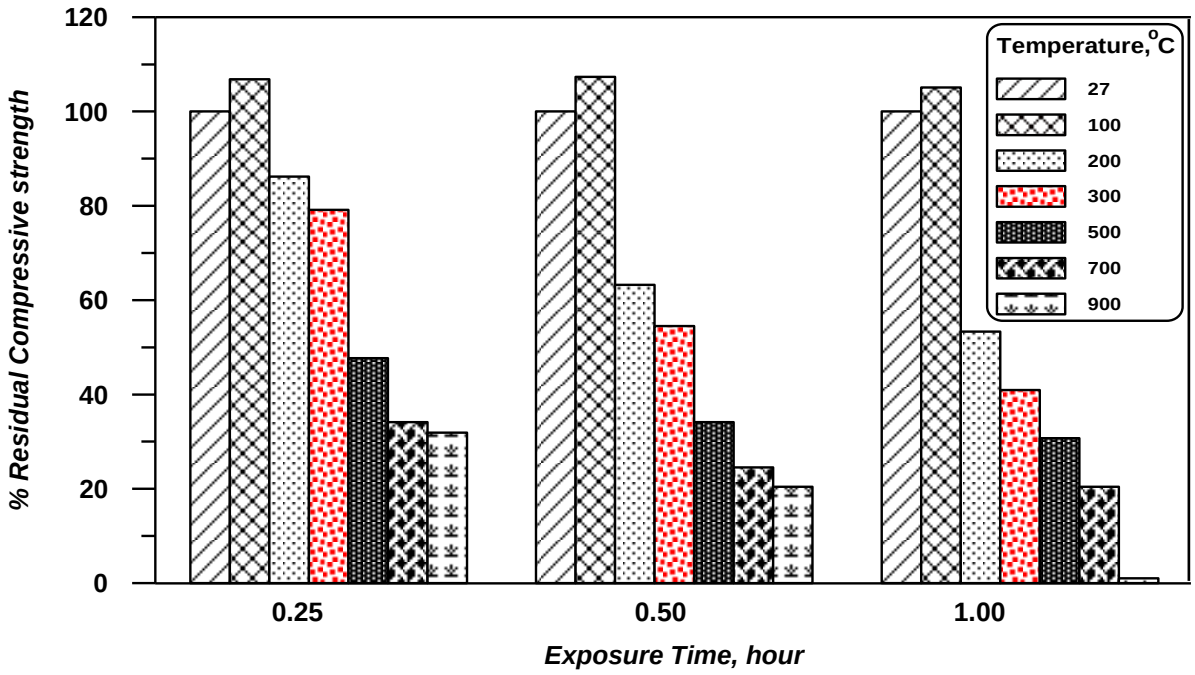

Figure (2): Effect of exposure periods and temperatures on the residual compressive strength of ordinary gypsum.

Generally, the exposure period was seen to have a slight effect on the residual strength after 0.50 hour. **Figure (3)** showed that, the large amount of loss in compressive strength occurs within the first 0.50 hour. After this period, small reduction in strength was observed except at 900 ^{o}C.

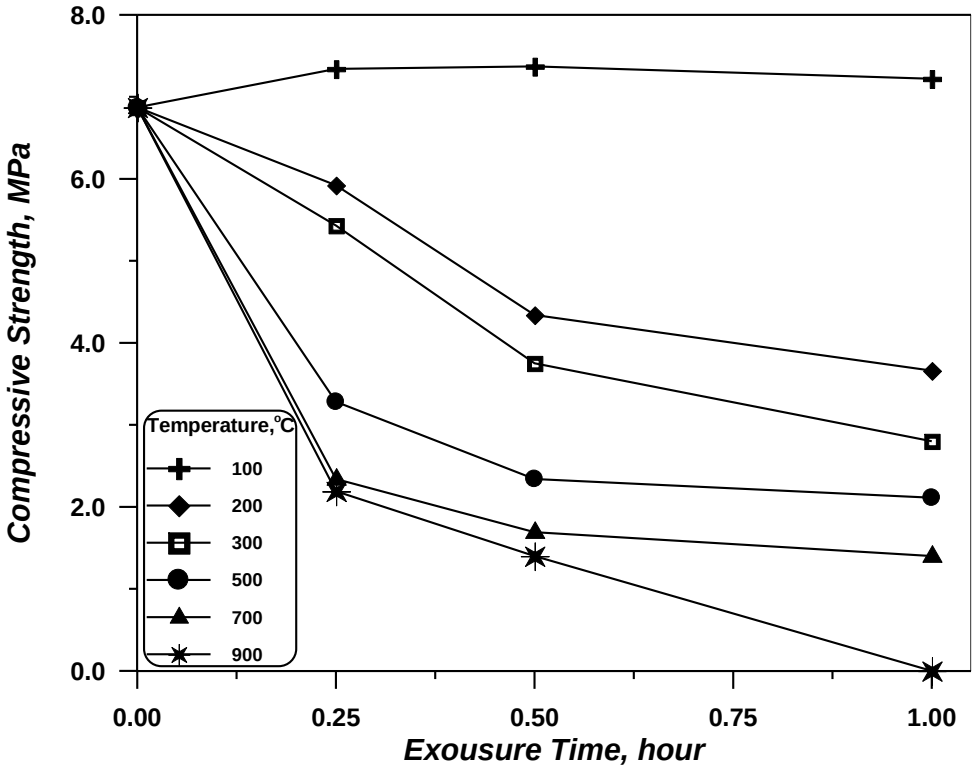

Figure (3): Relationship between the compressive strength of ordinary gypsum and exposure periods for different temperatures.

Furthermore, the tests show that the hair-surface cracks took place on the specimens at 500 ^{o}C and above as shown in **Picture (3)**. The number, depth and length of these cracks were increased and seen clearly especially at the 1.00 hour as shown in **Picture (4)**.

On the other hand, greater deterioration in compressive strength was occurred when the specimens subjected to quick cooled (water cooled) than when slowly cooled (air cooled). This can be observed from **Figure (1) and Picture (5**). This cooling condition may cause thermal shock which giving large thermal gradient within gypsum specimens and therefore a greater reduction in strength may occur.

Compressive Strength of plaster of Paris

The influence of elevated temperature on the deterioration of plaster of Paris compressive strength at different period of exposure is shown in **Table (3)**, **Figures (4, 5 and 6) and Picture (6)**.

At 100 ^{o}C, the compressive strength of specimens show trends somewhat similar to that observed in ordinary gypsum specimens. At 200 ^{o}C and 300 ^{o}C, the percentages of residual compressive strength were (101-50)% and (87-26)% respectively for a period of (0.25 -1.00) hour. As can be seen clearly from **Figures (4 and 6)**, both higher temperature and period of exposure were significantly affect the strength of specimens when subjected to 500 ^{o}C. At this temperature, the residual compressive strength after exposure to 0.25 hour is about 44%. But at period of 0.50 hour, no residual strength was observed and all specimens where damaged. Additionally, the cracks were seen clearly in the specimens as shown in **Picture (6)**.

Table (3): Compressive strength test results for plaster of Paris.

Exposure Temperature, ^{o}C	Compressive strength (MPa)		
	٠,٢٥ hour	٠,٥٠ hour	١,٠٠ hour
٠	١٥,٢٠	١٥,٢٠	١٥,٢٠
١٠٠	15.10	١٥,٦٠	١٦,٤٠
٢٠٠	١٥,٩٠	١٢,٤٠	٧,٦٠
٣٠٠	١٣,٢٠	٦,٤٠	٤,٠٠
٥٠٠	٦,٨٠	٠,٠٠	٠,٠٠

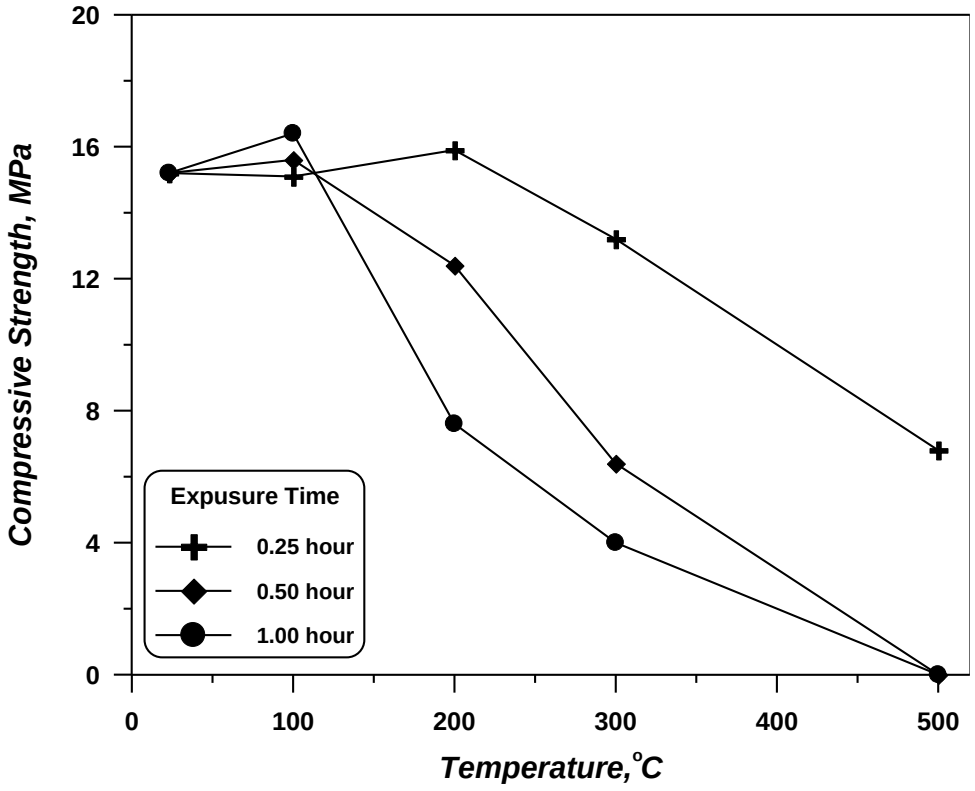

Figure (4) : Relationship between the compressive strength of plaster of Paris and exposure temperatures for different periods .

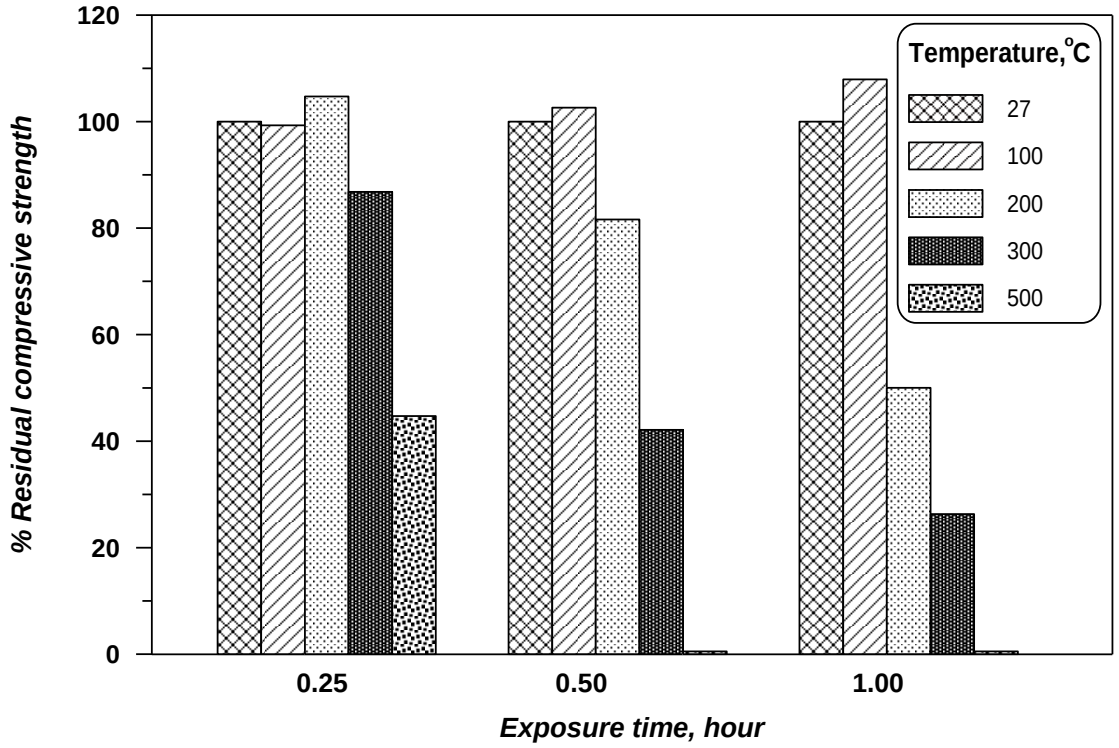

Figure (5): Effect of exposure periods and temperatures on the residual compressive strength of plaster of Paris.

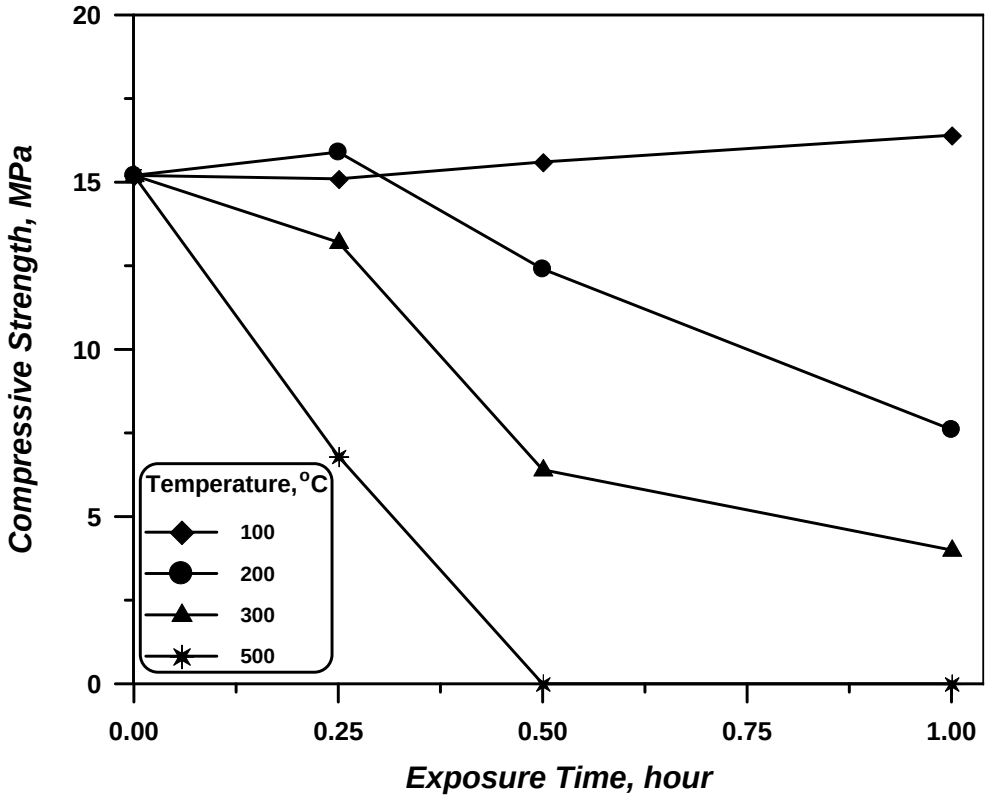

Figure (٦): Relationship between the compressive strength of plaster of Paris and exposure periods for different temperatures.

Conclusions

1. Increasing the temperature to 100 ^{o}C leads to slight increase in compressive strength of ordinary gypsum and plaster of Paris by about 6% as compared with reference value.
2. At 200 ^{o}C and above, the compressive strength of all specimens decreases with increasing both temperature and period of exposure.
3. More reduction in compressive strength of ordinary gypsum occurs between (500-900) ^{o}C and no residual strength was observed at a period of 1.00 hour in 900 ^{o}C. However, surface cracks were took place on the specimens at 500 ^{o}C and above. These cracks were increased at 900 ^{o}C.
4. Large amount of deterioration in compressive strength of ordinary gypsum occurs within the first 0.50 hour. After this stage, the exposure period have a slight influence on the residual strength except at 900 ^{o}C.
5. The compressive strength of plaster of Paris specimens was significantly affected when the specimens subjected to temperature between (300-500) ^{o}C. At 500 ^{o}C of 0.50 hour of exposure, all specimens were damaged and the cracks was observed clearly.

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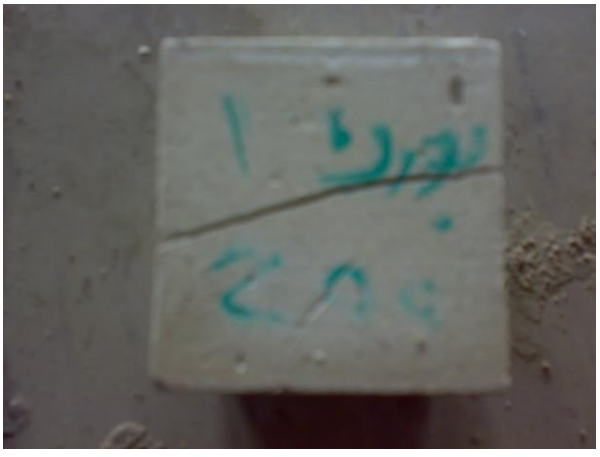
Picture (1): Ordinary gypsum specimens before heating.

Picture (2): Plaster of Paris specimens before heating.

Picture (3): Surface-Cracks of ordinary gypsum specimens.

Picture (4): Cracks of ordinary gypsum specimens at failure.

Picture (5): Failure of ordinary gypsum specimens at water cooling.



Picture (6): Cracks of plaster of Paris specimens at failure.