Effect of Gypsum Plaster on Hardened Concrete after Exposure to High Temperature: Analysis of Compressive Strength

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Abstract

This study investigated the effects of gypsum powder in concrete after its exposure to high temperature. Concrete with percentage of gypsum samples were prepared and induced to 100° , 300°,500°C, and 700°C elevated temperatures. These were used to evaluate the behavior in compressive strength. The results showed that heating caused significant losses in compressive strength. The findings indicated further that percentage increase of gypsum powder had an effect on the compressive strength of ordinary concrete.

Keywords: *gypsum , compressive strength, elevated temperature*

1. Introduction

Most building structures are seen everywhere in rural places which serve as a shelter from weather, security, living space, to store belongings, and to comfortably live and work. For human beings, it is a place of comfort and safety. But human safety cannot be guaranteed when an unavoidable circumstances occur in buildings such as a natural phenomenon. A natural phenomenon is not a man-made event which includes sunrise, weather (fog, hurricanes, tornadoes), biological processes (decomposition, germination), physical processes (wave propagation, conservation of energy, erosion), tidal flow, and include natural disasters such as electromagnetic pulses, volcanic eruptions, earthquakes etc. Another factor that cause damages in a building is due to fire or exposure to high temperature. Fire is the rapid oxidation of a material in the exothermic chemical process of combustion, releasing heat, light, and various reaction products. Fire in its most common form can result in conflagration, which has the potential to cause physical damage through burning. Due to modern inventions and development of new technologies in construction industries, there are fire-resistant building materials used. Fire resistant material is one that is designed to resist burning and withstand heat, and is designed to burn slowly such as proplex sheets, rock wool, asbestos cement, gypsum board and others which are very expensive. Concrete must therefore be properly formulated in order to hinder failure at high temperature in case of fire by introducing gypsum plaster as additive to concrete.

Section 1201 of the Fire Code states that " Buildings proposed for construction shall comply with all the regulations and specifications herein set forth governing quality characteristics and properties of materials, methods of design and construction ,type occupancy and classification. All other matters relative to the structural design of the building and other structures provided for in this Chapter shall confirm with provisions of the Engineering pursuant to Republic Act Number 544, amended, otherwise known as the " civil engineering Law." In this study, the researcher would like to learn and prove if there is an effect in adding gypsum to concrete mix to withstand fire in comparison with controlled samples with no additive. To measure the capability of the material and its strength, compression test shall be applied and evaluate the results.

Fire resistive assemblies for protection of openings and fire-retardant roof coverings. During fire, prolonged exposure of structure may cause damage on the structure and weakening of the material strength which may cause threat to the safety of occupants. In this case people may choose to simply abandon the place, which is costly. So the researcher has been motivated to conduct a study on how to protect the structure from gradual exposure to fire. The researcher will introduce a fireproofing construction material, a concrete with gypsum plaster. It will assess its compressive strength if it can withstand after exposure to high temperature.

1.1. Overall Aim

This study aims to investigate the compressive strength of a hardened concrete with gypsum as an additive if it can withstand exposure to high temperature in comparison with the standard composition of concrete. The general objective of the project is to produce a fire proofing concrete by adding a required percentage of gypsum to the mixture. Furthermore it has the purpose of finding out whether the utilization of this additive concrete will be beneficial to the construction industry and to the country as well. In order to achieve the major concern of the study, the researcher sought to answer the questions: What percentage of gypsum plaster is added to hardened concrete mixture? What desired temperature of constant time is to be applied to produce a favorable compressive strength?

1.2. Objectives

Below are the specific objectives of the study. 1. To determine the weight of each of the specimen before and after placing each into a conventional furnace 2. To compare the compressive strengths of the concrete samples between the controlled hardened concrete and samples with percentage increase of gypsum added to the concrete mixture. 3. To understand the effects of gypsum present in concrete under fire condition

1.3. Scope

This research will develop a proportions of gypsum and concrete as fireproofing agents. It will also determine the compressive strength of a hardened concrete with different percentage of gypsum with different levels of temperature.

2. Methodology

2.1 Research Design

Setting of this study is purely experimental research. The researcher prepared 48 samples of hardened concrete of which 36 of them have gypsum with different percentage in the field. The samples were induced at elevated temperature from 100°C to 700°C for 20 minutes each with the aid of electrical furnace. After the cooling phase of the specimen in air, compressive strengths were measured using the Universal Testing Machine (UTM) at Mapua Institute of Technology in Manila.

The researcher's primary source was through internet, textbooks, published and unpublished journals. The researcher got additional information at the University of the Philippines Diliman library as part of its local studies and literatures. The series of experiments performed were based on ASTM and standard methods. All data gathered were recorded, tabulated and analyzed to support the researcher's objective to prove if gypsum when added on hardened concrete affects the compressive strength when exposed to different temperatures.

2.2 Preparation and Evaluation of a Concrete Mixture

This laboratory exercise will be broken into two separate components. The first part involves concrete mixing and subsequent evaluation of the fresh concrete properties. The second part will examine hardened concrete properties. The purpose of this laboratory exercise is to introduce the proper concrete mixing procedures, the evaluation of fresh concrete properties and the determination of hardened concrete properties. An emphasis will be placed on the W/C ratio and its effect on concrete strength.

2.3. Reduction of Data

2.3.1. Statistical Treatment

This study will focus on the result of the compressive strength of the samples with different percentage of gypsum by weight of Portland in the concrete mix. The levels of temperature applied in concrete mix samples are also taken into considerations. Two-sample tests are appropriate for comparing two samples, typically the experimental results between the samples with gypsum percentage and the samples from a scientifically controlled experiment.

2.3.2. Material

To ensure the quality of the each of the materials, test was set forth based on the guidelines of ASTM, which are shown in the appendices. The ingredients of the concrete are assured to be free from foreign matters to maintain consistency and desirability of the samples. Cement - Type I Portland cement , Holcim brand, confirming ASTM C150 (standard specification of Portland cement),were used in the preparation of concrete samples. The cement contained admixture Gypsum - Plaster of Paris Aggregates - The aggregates used in the study were a calareous type. The fineness modulus and grading of the fine and coarse aggregates were identified in accordance with the requirement described in the ASTM C136, referred to as standard specification for sieve analysis of fine and coarse aggregates, (see in Appendix P.) The specific gravity and absorption were also determined according to ASTM C127 and ASTM C128 respectively. The coarse aggregate unit weight was obtained using ASTM C29 test method. Aggregates used for sampling were free from organic impurities. The physical property test results are listed in Table .1.

Table 1. Aggregates Physical Properties

Aggregates	Maximum Size	Specific gravity		
	(mm)			
Type		Dry	SSD	Apparent
coarse	20	2.477	2.54	2.645
fine		2.171	2.23	2.313

Table 2. Physical property of Gypsum and Portland cement

Material	Density	Specific gravity
Portland	1506 kg/m3	3.15
Gypsum	2798 kg/m3	2.31

2.4. Testing Equipment

2.4.1. Universal Testing Machine (UTM)

The UTM is a mechanical device which can perform many standard tensile and compression tests on materials, components, and structures. The equipment has a maximum capacity to carry 1000kN, and manufactured by Shimadzu Corporation, see Figure 1 .The UTM, which is interfaced with a computer was used to measure the compressive strength where test results were automatically registered and recorded.

Figure 1. Hydraulic Type UTM with computer interfaced

2.4.2. Electrical furnace

An electrical furnace has been designed to use for heating samples up to 1000° C temperature seen in Figure 2. (a). It is equipped with temperature controls and monitor, to measure the apparent temperature of concrete samples, see in Figure 3 (b)

(a) (b)

Figure 2. (a) Electrical furnace, (b) Temperature control panel

2.5. Experimental Test Procedures

2.5.1. Preparation of samples

Supply of all materials needed in the study were locally available in the market. Several tests of the constituents such as specific weight, density, porosity etc were conducted at Universal Resting Laboratory in Brgy. Turbina, Calamba City Laguna. Procedures in handling the samples were based from the set guidelines of the ASTM C172 and ASTM C31 presented in this chapter .The cylindrical mold dimension used is in accordance with ASTM C39.

2.5,2.Mixture preparation

The concrete mixture was proportioned according to the American Cocnrete Institute design procedure maintained at water cement ratio of 0.60. There were thirty-six (36) samples with percentage increase of gypsum by weight of Portland Cement and twelve (12) samples with no additives as the controlled specimen and basis of the results. The slump for all concrete mix was maintained for all batches a slump that is ranging from 60 mm to 75 mm.

2.5.3. Mixing and casting of concrete mix

All materials by batches were segregated according to their design mix proportion before placing them to the mixer. The aggregates were washed thoroughly to remove dust or other coating from the surface, and were dried, and likewise for the sand used. Coarse aggregates, cement and gypsum powder were placed first in the mixer and run for thirty (30) seconds. Then followed by adding the fine aggregates and run the mixer again for thirty (30) seconds. Water was added and allowed to run for three (3) minutes , followed by a three (3) minute rest period, and another two (2) minutes mixing period. After mixing is complete, slump testing was done ranging from 60mm to 75mm as prescribed by ASTM C143. Afterwards, casting of the fresh concrete was done by batches in a total of 48 – 6"x 12" cylindrical moulds and placing them concrete in 2 layers. Consolidation was ensured in each layer by rodding them for 25 times . The top surface of each specimen was flattened as possible by striking off with the rod. For proper identification, marking of all cylindrical molds were done and afterwards covered the molds with polyethylene sheet to prevent water evaporation.

2.5.4. Curing of samples

Curing of samples was based on ASTM standards. After 24 hrs, the specimen were removed from the molds, and immersed in a ponding bin filled with water .At the end of

28 days, all the specimens were removed and kept in a room temperature for another 7 days and covered with plastic to prevent excessive drying prior to testing. Samples" weights were also measured before they were subjected to testing , the details were presented in Appendix A to E.

2.5.5. Heating Samples

In the testing process, the samples were transported from Calamba Laguna to Mapua Institute of Technology . Before oven-drying proceeds for the first batch samples at 100 °C thru electric furnace, the equipment was first heated for 5 minutes to obtain the desired constant temperature of 100 °C. After a while, the samples by batches were placed in the oven with a drying time of 20 minutes each. The specimen were then removed from the oven after cooling for 5 minutes .The remaining batches at 300°C, 500 °C, and 700 °C were also observed with the same procedure as in the 100 °C batches . On the following day, after 24 hours of cooling, the samples were brought to the testing laboratory. Details are shown in Appendix A to G.

2.5.6. Compressive Testing

Before compressive testing proceeds, weight of oven-dried samples were recorded. Height and diameter of the cylinders were recorded as well.. With the aid of the Universal Testing Machine, compressive strength of concrete by batch were performed.

3. Results and Discussion

Table 3 shows the variations of weight, density and compressive strength of concrete mixes with water cement ratios. It was observed that the weight ,density and compressive strength of the concrete cylinders decreases with uniform water-cement ratio. However the compressive strength was observed to increase at 5% gypsum plaster between 100°C and 300°C but decreases continuously as gypsum plaster increases by weight of cement. This shows that the water–cement ratio is a determinant of the weight, density and compressive strength of the concrete cylinders.

Table 3. Variation of Weight, Compressive Strength with Uniform Water-Cement Ratio

Sample	Temperature	Water Cement Ratio	Saturated Weight (g	Weight in Air (g)	Sample	Compressive Strength (kN/m_2)
at 0% Gypsum						
C1	100°C	0.5	13.23	12.8	12.78	30.1

C2	100°C	0.5	13.34	12.85	12.8	29.04
C3	100°C	0.5	13.13	12.65	12.61	28.78
at 5% Gypsum						
C1	100°C	0.56	12.84	12.3	12.27	30.6
C2	100°C	0.56	12.92	12.6	12.57	29.36
C3	100°C	0.56	12.89	12.5	12.46	29.02
at 10% Gypsum						
C1	100°C	0.65	12.76	12.42	12.32	28.25
C2	100°C	0.65	12.74	12.4	12.3	28.49
C3	100°C	0.65	12.82	12.3	12.17	26.57
at 20% Gypsum						
C1	100°C	0.75	12.43	12.2	12.11	10.81
C2	100°C	0.75	12.42	12.15	12.06	10.83
C3	100°C	0.75	12.56	12.2	11.85	12.91

3.1. Heating Procedure and Effect

The 48 cylindrical samples were weigh before placing them to oven to determine the moisture loss after oven-dried. Samples were heated to the desired temperature of 100°C , 300°C,500 °C, and to a maximum of 700°C and allowed them to cool down inside the furnace for 5 minutes. Later, the specimens were brought out from the furnace and were weighed before and after exposure to elevated temperature. It can be described that the concrete sample with gypsum decreases its weight because gypsum is a lightweight material.

The graphs show a decrease in weight of the samples after exposure to 100 °C to 700 ° C temperature. It is evident that hydration occurred during heating, The equivalent moisture loss of each batch has also been determined using the formula below :

$$\mathbf{M = (A - B) / A * 100\%} \quad (1)$$

Where :

A = air-dry weight (kg)

B = Oven-dry weight (kg)

M = Moisture loss

In Figure 3 shows the equivalent moisture loss of each samples to the desired temperature The graph illustrates that on the sample with 5% gypsum , a consistent increase in moisture loss as temperature increases. The complete tabulated results of the moisture loss is shown in Appendix Q.

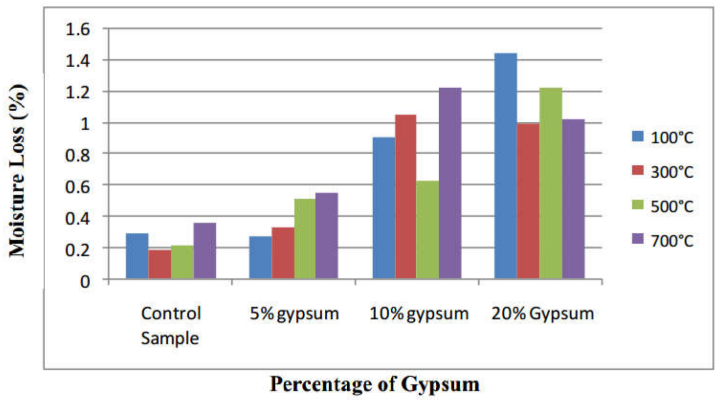

Figure 3. Moisture Loss Chart

In Figure 3.8 shows the equivalent moisture loss of the samples on the desired temperature. The graph illustrates that the samples with 5% gypsum , shows a consistent increase in moisture loss as temperature increases. The remaining samples show a pattern of consistency except for the samples with 20% gypsum.

3.2 Compressive Test Results

On table 4, showing the summary of average compressive strength of the samples group according to percentage gypsum applied and the desired temperature. On figure 4 shows the graphical relation between compressive strength and the temperature induced to controlled sample without gypsum and with the percentage increase of gypsum .It is shown from the graph that compressive strength decreases significantly with exposure to elevated temperature.

Table 4. Summary on Average Compressive Test Results

Temperature	Average Compressive Strength with Percentage Gypsum			
	@ 0%	@ 5%	@ 10%	@ 20%

100°C	**29.31**	29.66	27.77	11.52
300°C	27.52	27.65	24.47	12.24
500°C	26.87	29.48	26.97	12.16
700°C	26.66	26.68	24.75	12.15
Average	**27.90**	**28.93**	**26.41**	**11.97**

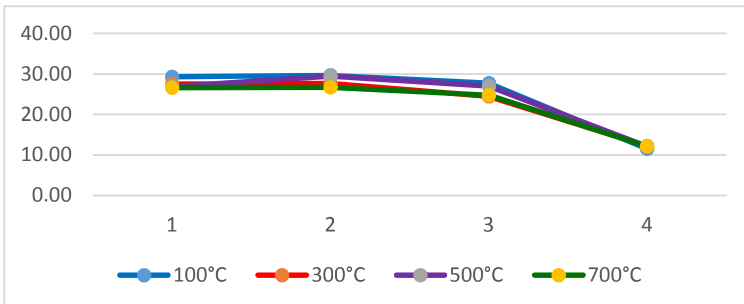

Figure 4. Effect of Gypsum on the Compressive Strength

Result on t-Test between the compressive strength and the controlled concrete sample of 0% ,5%,10%, and 20% gypsum by weight of Portland cement respectively at 100 °C. The remaining results can be seen in Appendix Y . The computed t-test, interpretation, and decision. At 100°C, there is no significance in the compressive strength when concrete is added with gypsum between 5% to 10% at a temperature of 100°C. On the other hand, there is significance on the increase in gypsum by 20% at 100°C temperature the same results were found at 300°C. However, between 500°C and 700°C, there is significance to this level, which means that dehydration or loss of water begins to take place. A sizeable degradation in compressive strength has been observed at this temperature rise. The strength reduction is in the range of 11 to 40 percent. Table 5 shows the summary on Percent Reduction of Strength. It can also be interpreted from the result of compressive strength that it affects the presence of gypsum wherein the molecular structure of gypsum contains nearly 50 per cent water, which accounts for gypsum's plaster fire resistance, which the concrete is thoroughly saturated.

Table 5. Summary on Percent Reduction of Strength

Temperature	**Percent Reduction Strength**						
	@ 0% as Control	**@ 5%**		**@ 10%**		**@ 20%**	
		% Difference					

100°C	**29.31**	29.66	-1.21	27.77	5.24	11.52	60.70
300°C	27.52	27.65	-0.47	24.47	11.07	12.24	55.52
500°C	26.87	29.48	-9.70	26.97	-0.38	12.16	54.73
700°C	26.66	26.68	-0.06	24.75	7.18	12.15	54.41

4. Conclusion

The results carried out from the experiment conducted in the previous chapter have brought clear understanding about the effect of gypsum as an additive to concrete exposed to elevated temperature. The following conclusions can be drawn from the results: The hydration occurs when moisture evaporates from concrete which decreases the concrete weight ranging 0.2%, 0.30%, 1.0%, and 1.50% by weight at temperature rise from 100°C, 300°C, 500°C, and 700°C respectively. As it has been implied saturation of the concrete when a percentage increase of gypsum is added to the concrete mixture. The rate increase in temperature and the number of percentage increase of gypsum also have a bearing on the effects sustained by the concrete. The 10% and 20% with gypsum on concrete shows a reduction in compressive strength by 9% and 60% respectively. However in the concrete sample with 5% gypsum there is a positive increase of 1.45% and 0.40% higher in compressive strength as compared with the controlled sample at 100°C. and 300°C temperature respectively. This is in contrast to the performance of the concrete mixes when exposed to temperature increases beyond 300°C which has a reduction strength by 14.5% to 38% at 500°C and 700°C. From the results observed in the experiment, the correlation between the elevated temperature and residual compressive strength is inversely proportional.

5. Recommendation

Based on the results obtained from this study, the presence of gypsum in concrete mixture between 5% to 10% by weight of Portland Cement , can acts as an additive to concrete as heat resistant agent between temperature change of 100°C to 300°C. The use of gypsum as a fire resistant should be discouraged because strength decreases significantly when exposed to higher temperature beyond 300° C. The following recommendation can be improved by future researchers. Since this study had focused on a single period of time exposing samples in conventional oven at 20 minutes, the researcher would recommend to consider different exposure intervals periods of time of 15, 30, and 45 minutes. to differentiate and compare the effect of induce thermal stress on the concrete. The cooling process may be taken into consideration to compare and evaluate between cooling and in air and water. Since the researcher has maintained a uniform water cement ratio, it is best recommended to take different level of water added to concrete with gypsum at 0.05 intervals.

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