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BEHAVIOUR OF THERMOSTONE BLOCKS WITH AND WITHOUT CEMENT MORTAR PLASTERING EXPOSED TO HIGH TEMPERATURES

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Autoclaved aerated concrete (called Thermostone in Iraq) is one of the popular building materials that are used in various purposes in construction industries. It is factory-made material that can be moulded into blocks which can be used in framework buildings. However, these buildings are under the risk of fire since it has different cusses such as arson and electrical short circuit. It is important to find ways to improve counter such phenomenon. Therefore the objective of this paper is investigating the fire resistance performance of Thermostone with and without plastering. Five different samples were used for the test, four of them were covered with different types of plastering. Three tests were employed for this study: Compressive, absorption, and density test. For all tests, the samples were exposed to elevated temperatures from 250°C to 900°C. It was shown that the compressive strength are reduced when exposed to high temperature by up to 75%, however the air-cooled samples are less affected by approximately 15%. Furthermore, plastered samples has lower absorption rate than non-plastered ones. Finally, density decrease with heat by up 10% approximately.

Key words: autoclaved aerated concrete, thermostone, fire resistance, compressive strength

INTRODUCTION

Composite material, as the name suggests, is a material which is manufactured by combining two or more different materials together, resulting in a new one that has enhanced characteristics and better performance than its individual constituents [1]. What distinguishes a Composite material is that each constituent retains its physical, chemical and mechanical properties, unlike metallic alloys. However, its prime advantage is that it combines high strength and stiffness with low density, thus resulting in a strong product with reduced weight [2].

Employing composite materials in construction can be traced back to the Mesopotamian and Egyptians civilizations in the 1500 B.C. where strong buildings were created using a mixture of clay and mud [3]. However, it was not until 1824 that the composite materials industry took a huge leap forward with the introduction of portland cement by Joseph Aspdin, which was later used to make the all-we know product called “concrete”.

Since then, numerous experiments were conducted in order to produce enhanced or new types of concrete. One of these new types is Autoclaved aerated concrete (Called Thermostone in Iraq), an eco-friendly product that is produced using natural raw materials such as cement, sand (or fly ash), gypsum, lime, aluminium powder and water. It was first discovered in 1924 by Dr Johan Axel Eriksson while trying to speed up the curing process for one of his aerated concrete samples by placing it in a laboratory autoclave. His discovery attracted commercial interest and its production started in 1929, and since then it became one of the most popular products in the domestic, commercial and industrial construction [4]. It has various advantages:

- It has sound and thermal insulation.
- It has a lightweight which makes it easy to handle
- It is easy to cut hole and grooves for plumping and electoral lines.
- More economical in the matter of shipping and handling when compared to casted concrete.

Numerous and various researches were conducted regarding Thermostone. Some studies have investigated the types of failures which may occur during and after the manufacturing process [5]. While others have considered the possibility of employing waste Autoclaved aerated concrete as a replacement to coarse and fine aggregates in concrete mixtures [6, 7], or as raw material to create nano-scale materials [8]. Others have suggested inspecting the influence of glazing (for architectural purposes) on the physical properties [9], and researchers have also suggested improving the efficacy of Thermostone waste using class waste [10]. Furthermore, the possibility of producing Thermostone blocks using recycled damaged Thermostone as raw materials was also investigated [11]. Recent studies have suggested using alternative materials (Blast-furnace granulated slag, graphite tailings, or low silicon) in producing

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Theromstone [12-15]. However, most of these studies have inspected the physical properties of Autoclaved aerated concrete under the temperature lab. It is rare to find studies that considered elevated temperatures. Fire is considered a dangerous phenomenon that affects all solid, liquid, and gasses substance. Therefore, it is imperative that all Thermostone components can resist fire for a specific period of time. One suggested method is covering Thermostone with Plaster, a building material that is used to cover and decorate outer an inners walls. Until the 19th century, the plaster components were basically gypsum, lime, and clay. It was not until the 1920s that portland cement was employed in plasters. Cement plasters are effective not only it corrects the joints and reduces the roughness of inner and outer walls, but it can also be used as a protective material, which enhances the humidity, heat and sound insulations. Therefore, the purpose of this papers is inspecting the influence of elevated temperature on the compressive and absorption ratios on Thermostone (with and without plastering).

Research significance

Fire is one of the most hazardous elements that should be carefully considered in building construction. Thus, it's important to conduct studies that shall improve the fire resistance performance of structures while maintaining the cost at the same time. Therefore, this research provides an improved understanding on the fire resistance performance of thermostone with and without plastering. Furthermore, this study inspects whether using crushed bricks (as an alternative to sand) in plastering material would have a great impact on the behaviour of thermostone under high temperatures.

Samples and plastering materials preparation

Thermostone blocks with 651 kg/m^3 density were employed for this study according to Iraqi standard No. 1441 in 2013 [16]. Cubic samples with dimensions of 100mmx100mmx100 mm were prepared by cutting the blocks using an electric circular saw. The samples were divided into two groups: non-plastered and plastered. A grit disc was used to polish the surface of the samples with no plastering (SNPL). Whereas the rest were left with their rough surfaces and were covered 2 cm layer of plastering. The plastered samples can be divided into four depending on the type of plastering. The first is the sample with cement-sand mortar plastering (SCSM), the second is the sample with cement-sand mortar plastering and 4% superplasticizer (SCSM-SP). The third is with cement-crushed bricks mortar plastering (SCCBM), and the final one is with cement-crushed bricks mortar and 4% superplasticizer (SCCBM-SP). Table 1 below display the properties of the mentioned samples.

Table 1: Properties of the employed samples

Sample	Plastering material				
	Cement	Sand	Crushed bricks	SP	w/c ratio
SNPL	-	-	-	-	-
SCSM	1	3	-	-	0.6
SCSM-SP	1	3	0	4%	0.37
SCCBM	1	-	3	-	0.72
SCCBM-SP	1	-	3	4%	0.51

Materials used for plastering

From Table 1, it can be seen that four cementation materials were used to create different plastering materials in this study: Ordinary Portland Cement (OPS), sand (fine aggregate), crushed bricks, and superplasticizer. OPS type I according to Iraqi standard No. 5 in 1984 [17] was employed and its chemical properties are displayed in Table 2. Sand has a specific gravity equal to 2.65 according to critical standard No. 45 in 1984 [18] and with 0.35% sulphate content, and its grading is shown in Table 3. Crushed bricks have been made from grind waste bricks obtained from the Nihrawan factory. Its specific gravity and sulphate contents are 1.84 and 0.34% and Table 4 displays the grading. Finally, the employed superplasticizer is SP703S according to ASTM494-2004.

Table 2: Chemical properties of cement

Components		Test results	Limit of I.Q.S. No.45-1984
Lime (%)	CaO	61.89	-
Silica (%)	SiO_2	21.37	-
Alumina (%)	Al_2O_3	4.60	-
Iron Oxide (%)	Fe_2O_3	3.35	-
Sulphate (%)	SO_3	2.42	≤ 2.8%
Magnesia (%)	MgO	3.05	≤ 5%
Potash (%)	K_2O	0.36	
Soda (%)	Na_2O	0.27	
Loss of Ignition (%)	L.O.I	2.16	≤ 4 %
Lime Saturation Factor	L.S.F	0.91	0.66 - 1.02
Insoluble Residue (%)	I.R	0.60	≤ 1.5%
Main Compound (Bogue's Equation)			
Tricalcium Silicate	C_3S	46.95	-
Dicalcium Silicate	C_2S	25.85	-
Tricalcium Aluminate	C_3A	6.52	-
Dicalcium Aluminate	C_4AF	10.19	-

Table 3: Grading of fine aggregate

Sieve Size (mm)	Passing %	Limit of I.Q no. 45-1948
4.75	96	90-100
2.36	91	75-100
1.18	72	55-90
0.6	48	35-59
0.3	21	8-30
0.15	4	0-10

Table 4: Grading of crushed bricks

Sieve Size (mm)	Passing %	Limit of 0.5
4.75	97	90-100
2.36	89	75-100
1.18	74	55-90
0.6	53	35-59
0.3	17	8-30
0.15	6	0-10

Experimental tests

Tests were conducted on both Plastering and Therm-stone samples, both will be explained individually:

Plastering materials

Three tests were conducted on the plastering: Oven dry density, compressive strength and absorption. ASTM C 567-05a[19] standard was employed to conduct the Oven dry density test. The samples were cast into 50 mm x 100 mm cylindrical moulds. After 24, the samples were removed from moulds and were submerged into water for 28 days. Thereafter, they were heated in the lab for 24 hours at 105 °C. The dry density has been calculated by dividing the mass over volume, Table 5 displays the results obtained from the test.

As for the compressive strength test, ASTM C 109[20] standard was employed. 50 mm x 50 mm x 50 mm cubes were used to cast the plastering samples. After 24 hours, they were unmoulded and placed in the water tub until the day of testing (28 days). Table 5 shows the recorded data.Finally, Water absorption test has been conducted accord to ASTM C 1403 (2005)[21]. 50 mm cubes were used to cast the plastering. After being immersed in water for 28, they were dried in the oven (110 °C) for 24 hours. After cooling, the samples were placed in the water tub for 24 hours and the absorption values were obtained from the percentage of the wet weight to the oven-dried weight (see Table 5).

Thermostone samples

Three types of experimental tests were conducted on cement mortars. Compressive strength, absorption, and density. The compressive strength of samples was tested at the lab's temperature (25°C) and after being exposed to 250°C, 500°C, 700°C, and 900°C temperatures (1.5 hrs for each heating temperature) at the lab's furnace. Furthermore, two different methods of cooling were used: first is slow cooling in which the samples were left to cool in the air, and the second is fast cooling where the heated samples were submerged for 1 hr. in water. Figures 1 & 2 display the samples and compression test.

As for the Absorption test. The samples were subjected to 1.5 hrs heating period at different temperatures (250°C, 500°C, 700°C, and 900°C). After weighting the heated samples they were submerged in water for 1 hour. After

Figure 1: Thermostone samples

Figure 2: Compression test

Table 5: Plastering materials properties

Plastering	Dry Density (kg/m^3)	Absorption %	28 days Compressive strength (MPa)
cement-sand	1980	13.4	22.4
cement-sand + SP	2378	11.1	31.1
cement-crushed bricks	1680	16.7	15.3
cement-crushed bricks + SP	2080	14.8	23.7

drying their external surface, they were weighted once again and the absorption rate was obtained by calculating the percentage of the wet weight to the dry weight. Finally, Density test has been conducted by measuring the density of sample after heat exposure to 250°C, 500°C, 700°C, and 900 °C and comparing them with the density at 25°C (lab temperature). Only air-cooled samples were employed for this test. Figure 3 displays the research flowchart.

RESULTS AND DISCUSSION

Figure 4 demonstrates the compressive strength-temperature relationship for the air-cooled and water-cooled SNPL models, and it shows that the former ones have higher compressive strength than the latter ones at the room temperature (25°C). After exposing to heat, the loss of evaporated water has resulted in an increase of strength for the air-cooled samples by 20% at 250°C [22] (Sakr et al. 2005). However, it started to decrease by 18.9%, 30.3%, and 39% at 500°C, 700°C, and 900°C respectively. This is because the thermal expansion is uneven between the Thermostone surface and interior, which is due to internal air gaps that cause thermal isolation and hinder the expansion, thus resulting in the occurrence of microcracks [23] (Kodur 2003). The water-cooled, on the other hand, start to lose their strength by approximately 5.26%, 23.7%, 36.8% and 68.4% at 250°C, 500°C, 700°C, and 900°C respectively. This is due to the thermal shock of hot models during the heating and cooling cycle which is known to have a detrimental impact on the concrete [24] (Sarhar and khoury 1993), thus accelerating the microcracks appearance and weakening the strength.

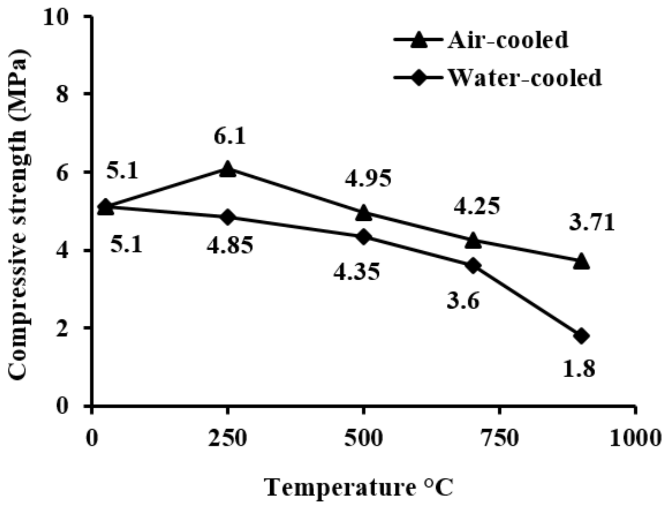

Figure 4: compressive strength-temperature relationship for the air-cooled and water-cooled SNPL models

Figure 5 & 6 illuminate the effect of elevated temperature on the compressive strength of the different Thermostone samples under air-cooling and water-cooling respectively. It was found that the samples plastered with cement mortar have higher fire-resistance than the non-plastered ones regardless of the cooling method (air or water). This is to be expected since cement mortars have a higher density than Thermostone, and due to the thinness of plastering (20mm). In addition, employing superplasticizer has reduced the w/c ratios of cement mortar, thus increasing compressive strength [25].

Furthermore, it can be seen that the strength of the samples has significantly dropped at 700°C and 900°C. For

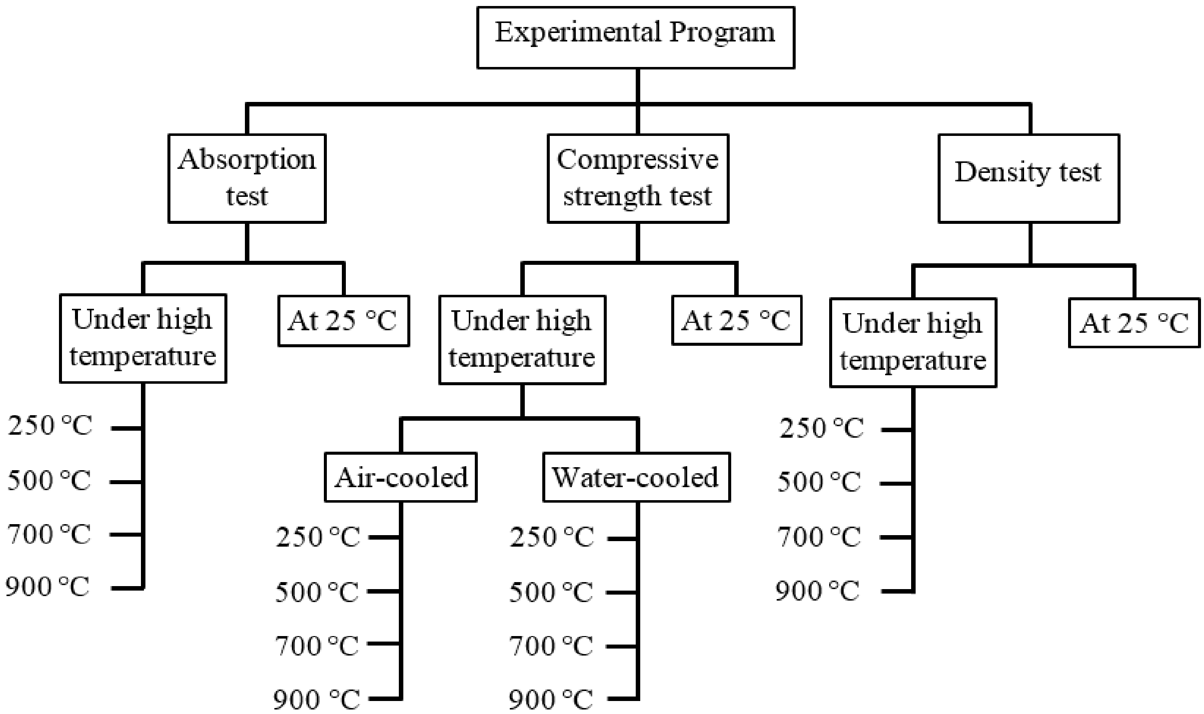

Figure 3: Flowchart of the research

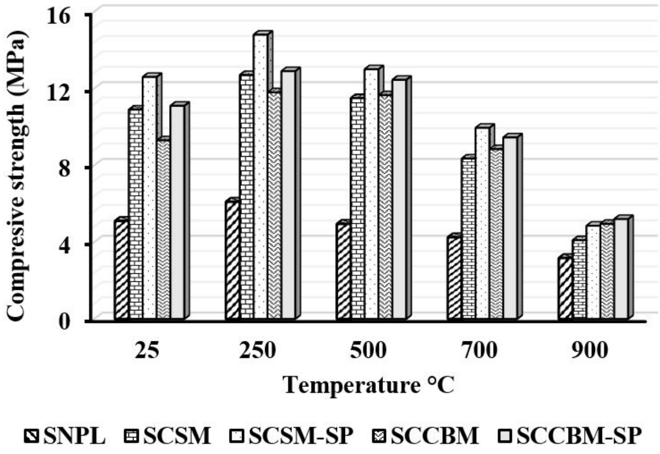

Figure 5: compressive strength-temperature relationship for the air-cooled Thermostone models

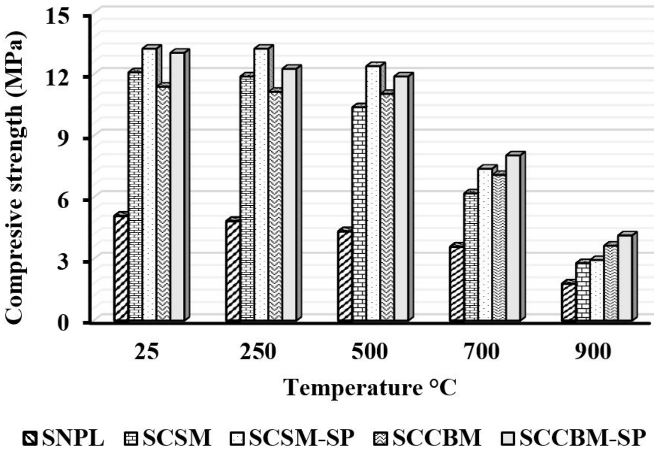

Figure 6: compressive strength-temperature relationship for the water-cooled Thermostone models

example, the compressive strength for air-cooled SCSM-PL has decreased by 21% and 69.5% respectively, while the strength for water-cooled SCSM-PL has decreased by 44.2% and 75.5% accordingly. This is due to the interconnection deterioration between the cement paste and other components, and due to the inhomogeneous change in size during the heating, cooling, and dehydration of calcium hydrate[26-28]. Moreover, the compressive strength at 900 °C for water-cooled samples are lower than the air-cooled ones. That is because water-cooling is rapid which produce high tensile stress and creating cracks in the plastering cover and Thermostone, thus weakening their connection and physical characteristics, and reducing the strength as a result [29, 30].

Absorption test

The results obtained from the absorption test are illuminated in Figure 7 below and it can be seen that the absorption rate for SNPL has increased by approximately 18%, 45%, 59%, and 77% at 250°C, 500°C, and 700°C, 900 C respectively when compared to the absorption rate at 25°C. This is due to the appearance of cracks which increase as the heat rises, and consequently, causing water percolating through them into the SNPL, which adds

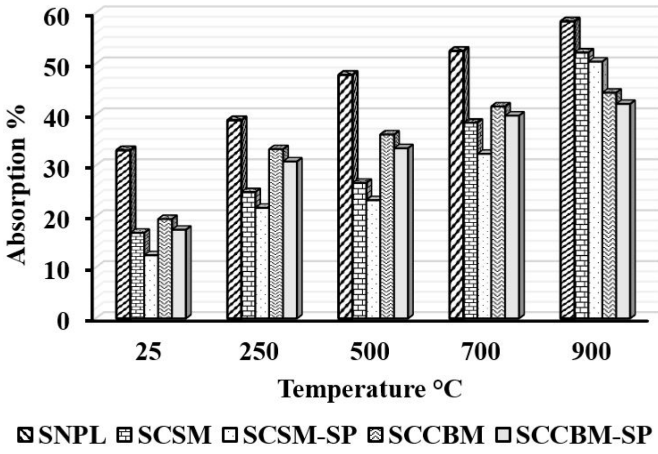

Figure 7: Absorption rate for samples under elevated temperatures

to the water absorbed by the pores of the sample.

On the other hand, the plastered samples have demonstrated a lower absorption rate values at all temperatures when compared to SNPL. This is because the density of the plastered samples is between 1650-2200kg/m^3 which is higher than the non-plastered ones by 3 or 4 times, and also due to the employment of SP which has reduced the percentage of internal voids. Moreover, the sample where crushed bricks were used as plastering component instead of sand (SCCBM and SCCBM-SP) has the lowest absorption rates, which is due to the specific gravity of crushed bricks which is higher than sand.

Figure 8 displays the results obtained from the density test and it is shown that density has dropped by 4.3%, 5.21%, 6.7%, and 9.7% at 250°C, 500°C, and 700°C, 900 °C accordingly when compared to the density at 25°C. This is to be expected since the inner moisture of the blocks decreases as the heat rises.

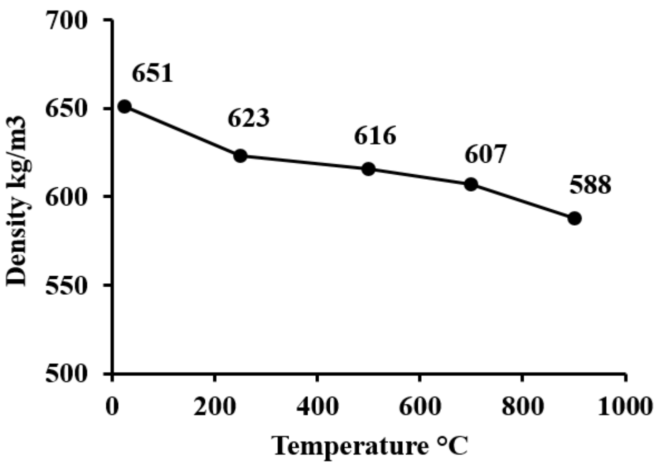

Figure 8: Density for non-plastered samples under elevated temperatures

CONCLUSION

This research was conducted in order to investigate the performance of non-plastered and plastered cement mortars under the influence of elevated temperatures.

The samples have been tested for compressive strength and absorption rate. For both tests, the samples were exposed to different temperature from 25°C to 900°C, and two cooling methods were used: air-cooling and water-cooling. And the samples were examined according to the Iraqi standard No. 1491 in 1989. From the conducted tests, several conclusion can be drawn:

1. Employing plastering cover has greatly influenced the compressive strength and absorption rate.
2. The compressive strength has significantly decreased under high temperature (500 C° - 900 C°) for both plastered and non-plastered samples without exception.
3. Plastering cover has decreased the heat transferred to Thermostone, and consequently, increasing fire resistance duration.
4. Applying superplasticizer in plastering can enhance the compressive strength and reduce the absorption ratio.
5. The impact of high temperature on the compressive strength of water-cooled samples is higher than the air-cooled ones.
6. Covering Thermostone with plastering shall decrease the absorption ratio when compared to the non-plastered ones.
7. A lower absorption ratio can be obtained when employing crushed bricks instead of sand in plastering.

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