Effect of high temperature and type of cooling on some mechanical properties of cement mortar

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Abstract. Mortar of cement as construction materials subjected sometimes to high temperature. Some of properties of this mortar being studied after this effect. The effect of high temperature 100, 200, 400 and 700 °C (exposed for two hrs.) on some mechanical properties (compressive and flexural strength) of two groups of cement mortar samples (with and without the addition of crushed bricks and superplasticizer as modifying materials) has been studied. Two methods of cooling samples by air and by water for 1/2 hr. was used, then tested after 3, 7 and 28 days. The results showed that the compressive and flexural strength for reference mix exposed to 700°C and water cooling decreased by 65.3 % and 64.7%, respectively, compared with their reference mix tested at 20°C in 28 days. While mixes containing 100% of crushed brick as an additive and air cooling decreases by 12.3% and 9% of their compressive and flexural strength, respectively compared with the mixes tested at 20°C in 28 days. Also showed that the decreases in flexural strength for no sand mixes containing 100% of crushed brick and 4% of superplasticizer exposed to 700°C and then water cooling was 28.2% compared to those for reference mixes tested at 20°C.

1 Introduction

Cement mortar as a material in service is exposed to high temperatures during fire. The main properties of cement mortar after such an exposure to fire are of great importance in terms of the serviceability of the materials.

Fire represents one of the most sever risks to buildings and structures. To find the resistance of construction materials for fire, test is performed torch for each country according to fire-fighting systems in place there. It has been found through experiments that cement mortar had bad properties in fire resistance; so many researches had been done to limit and improve the ability to withstand high temperatures.

Aydin [1] studied the effect of high temperature up to 900°C on the compressive strength of cement pumice mortars containing different amounts of ground granulated blast furnace slag (GGBFS). Aydin concluded that at 900°C, the mortar containing 80% GGBFS exhibited only 23% 23% and 28% compressive strength loss when cooled in air and water, respectively, whereas mortars without GGBFS lost almost 70% of their strength.

Aydin and Baradan [2] investigated the effects of different high temperatures on the mechanical properties of cement pumice mortars containing fly ash. They concluded that the cement pumice mortar containing 60% of fly ash revealed the best performance particularly at 900°C. This mixture did not show any loss in compressive strength at all test temperatures when cooled in air.

Hossain, Islam and Karim [3] studied the effect of high temperature during fire on the bond and compressive strength of cement mortar containing high volume fly ash without using any water reducing admixtures. They indicated that the mortar containing 50% fly ash as a replacement of cement exhibits greater resistance to high temperature. Also, compressive and bond strengths of mortar containing different percentages of fly ash initially increase with the increase in temperature but after 200°C they decrease with the further increase in temperature.

2 The objective

Studying the effect of high temperature on compressive and flexural strength of cement mortar, and how to decrease these effects by replacing with crushed bricks as waste materials.

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3 Experimental works

3.1 Materials

3.1.1 Cement

Ordinary Portland cement type (I) manufactured in Iraq with trade mark of (AL. MASS) has been used. The test results show that the cement conforms to provisions of (I.Q.S. No. 5 / 1984) [4]. Tables 1 and 2 show the chemical analysis and physical properties of cement.

3.1.3 Crushed bricks

The bricks that have been used in this research were waste material from Iraqi factory in Al-Nahrwan. The waste bricks were crushed to get same grading as fine aggregate used as partial or complete replacement of sand. The grading of crushed brick was shown in Table 4. It was shown that the grading of crushed brick within the same zone of sand. Also, the chemical test results indicated that specific gravity was 1.84, sulfate content in crushed bricks was 0.34% and fine materials less than 0.075 was 3.8%.

3.1.2 Fine Aggregate (sand)

Sand used after it has been sieved by sieve size (4.75 mm) with specific gravity of 2.64, sulfate content is 0.35%, and percentage of fine materials less than 0.075 mm was 3.4%. The grading of fine aggregate was shown in Table 3. It conformed to (I.Q.S.NO. 45 – 1984) [5].

3.1.4 Superplasticizer

Superplasticizer SP 703S type A according to (ASTM C494 – 2004) [6] was used as a high range water reducing admixture by weight of cement of (1%, 2%, and 4%). Table 5 shows the chemical properties of the super plasticizer used according to manufacturer.

3.1.5 Water

Drinking water was used for all the mixes and for the curing process of samples.

Table 1. Chemical analysis of cement*.

Components		Test Result	Limits of I.Q.S. No. 5 / 1984
Lime (%)	CaO	61.89	-
Silica (%)	SiO_2	21.37	-
Alumina (%)	Al_2O_3	4.6	-
Iron Oxide (%)	Fe_2O_3	3.35	-
Sulfate (%)	SO_3	2.42	≤ 2.8%
Magnesia (%)	MgO	3.05	≤ 5%
Potash (%)	K_2O	0.36	
Soda (%)	Na_2O	0.27	
Loss on Ignition (%)	L.O.I	2.16	≤ 4%
Lime Saturation Factor	L.S.F	0.91	0.66 – 1.02
Insoluble Residue (%)	I.R	0.6	≤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	-
Tetracalcium Aluminoferrite	C_4AF	10.19	-

Table 2. Physical properties of cement*.

Physical Property	Test Result	Limits of I.Q.S. No. 5 / 1984
Specific Surface Area (m^2/kg)	369	230 (min)
Setting time Initial (hrs. : min.) Final (hrs. : min)	 2:00 3:35	 0:45 (min.) 10:0 (max.)
Compressive strength (N/mm^2) 3 days 7 days	 24.9 29.7	 15 (min.) 23 (min.)

*Test done at NCCL.

Table 3. Grading of fine aggregate (sand).

Sieve Size (mm)	% passing	Limit of I.Q.S. No. 45 – 1984 - Zone 2
4.75	98	90 – 100
2.36	83	75 – 100
1.18	65	55 – 90
0.6	47	35 – 59
0.3	18	8 – 30
0.15	6.0	0 – 10

Table 4. Grading of crushed bricks

Sieve Size (mm)	% passing	Limit of I.Q.S. No. 45 – 1984
4.75	100	90 – 100
2.36	88	75 – 100
1.18	70	55 – 90
0.6	61	35 – 59
0.3	19	8 – 30
0.15	7	0 – 10

Table 5. Properties of superplasticizer SP 703S

Appearance	Dark brown / black liquid
Specific gravity	1.235 @ 25 ± 2 °C
Chloride content	Nil
Flash point	N / A

3.2 Mix Proportioning

The flow of the mortar was considered to mix design so that the w/c ratio was determined according to ASTM C1437-04 [7]. The reference mortar mix was designed to have flow 80 ± 5 mm, the cement: sand ratio was 1:3 by weight and w/c ratio was 0.6. Seven mortar mixes were prepared. Its details are shown in Table 6.

3.3 Preparation, Casting and Curing of Specimens

The mix of the raw materials was done according to ASTM C 305 – 99[8]. After conducting flow test, the specimens were prepared by casting in different standard molds. The standard molds were cleaned and oiled before casting to avoid the adhesion to sides of the molds. The mortar was placed in the molds with layers according to the standard specifications for each test and compaction by means of vibration table. The top layers of mortar specimens had been smoothed by steel trowel, and then the specimens were covered with nylon sheets for 24 hours to prevent the evaporation of water. After that the specimens were demolded and fully immersed in tap water for 28 days. At age 28 days the specimens subjected to different constant temperatures (100, 200, 400 and 700 °C (exposed for two hrs.) in two ways. First one when the samples were oven dry and second one where the samples were fully saturated.

Table 6. Mixes proportion details (by weight)

Mix Symbol	Cement	Sand	Crushed bricks	SP % from cement	w/c to give flow of 80 ± 5 mm	Oven Dry density kg / cm^3 at 28 days age
B_0	1	3	-	-	0.6	1980
B_1	1	2.25	0.75	-	0.62	1840
B_2	1	1.5	1.5	-	0.66	1760
B_3	1	-	3	-	0.72	1680
B_4	1	2.25	0.75	1	0.58	2080
B_5	1	1.5	1.5	2	0.55	2120
B_6	1	-	3	4	0.52	2180

4 Results and Discussion

4.1 Oven dry density

This test was done according to ASTM C 567-05a [9] using 50×100 mm cylindrical specimens. The results of dry density for different mortars demonstrated in Table 6 and Fig. 1. From the results, it is clear that the replacement of sand by crushed brick with (0.25%, 50% and 100%) reduce the dry density of mortars with (7.07%, 11.11% and 15.15), respectively. The reasons of these reductions may be due to the use of supplementary material (crushed brick) which has a specific gravity much lesser than that of sand and its coarse grains. Also, the results indicated that the use of superplasticizer increase the dry density. These may be due to reduction in the w/c which needs to give flow of 80 ± 5 mm.

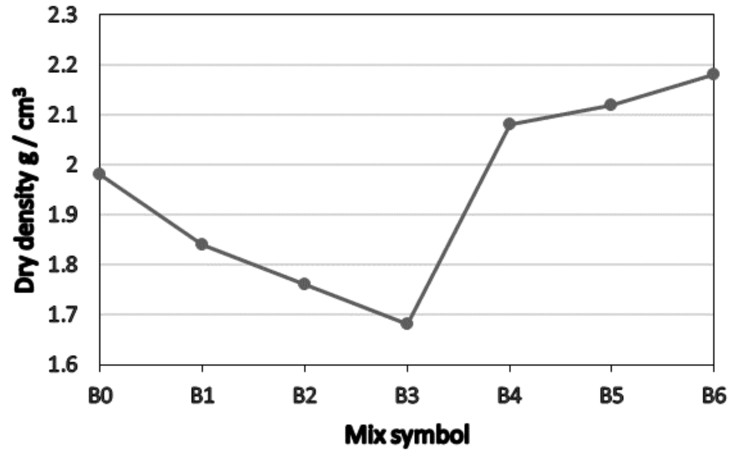

Fig. 1. Oven dry Density for different mixes tested at (28) day and curing in water at 20 ^{0}C

4.2 Compressive Strength

This test was done according to ASTM C 109-02 [10] using 50 mm cube specimens. From the results, it's clear that the use of water curing is better than air curing methods and this is in conformity with the findings of the earlier researchers. The use of super plasticizer for specimens (B_4, B_5 and B_6) with percent of (1%, 2% and 4%), respectively reduces the ratio of (w/c) which increases the compressive strength to ensure good workability (Shirkavand and Baggott, R,1995[11]) (Fig. 2. & 3.). Also, the results indicated that the compressive strength of specimens without replacement of sand by crushed bricks when exposed to 700°C dropped by (37.1%) (Mix B_0), while this drop reduced to (19.5%) when the total sand was replaced by crushed bricks (Mix B_6). This reduction of drops referred may be related to the use of refractory materials (crushed bricks) which had stability when exposed to high temperatures compared with sand.

From Fig. 3, the values of compressive strength were achieved when tested at age of (28) days for specimens (B_6) and exposed to heating of (700) $^{\circ}$C which represents an increase of (163.15%) compared to reference mortar specimens (B_0) when exposed to heating of (700) $^{\circ}$C and tested at age (28) days. These results are the same researchers results of (Ahmed, A. H and Abdul Kaream, O.M,2010[12]) and these may be due to reduction of required water which increases strength and reduces voids.

The results showed there is a big loss in compressive strength for the reference mortar specimen (B_0) when exposed to high temperature tested at (28) days as shown in Fig. 2 & 3 and this suits the result archived by the researcher (Aydin & Baradan , ,2007[2]) which included "The loss of the mortar exposed to high heating temperature treated with water is greater than the loss in compressive strength for the mortar at the same condition treated with air".

Fig. 4 represents the relationship between compressive strength with dry density for cement mortar for different mixes tested at (28) days and cured in water at 20^{0}C. It's clear to observe that the relations between compressive strength and dry density are positive.

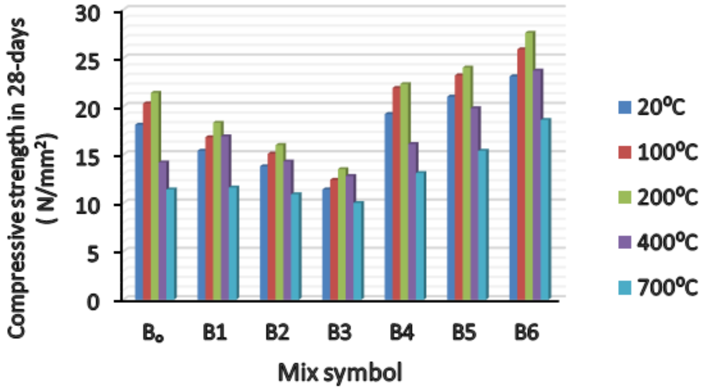

Fig. 2. Compressive strength in 28-days for different mixes of mortars cooled with air and exposed to different temperature

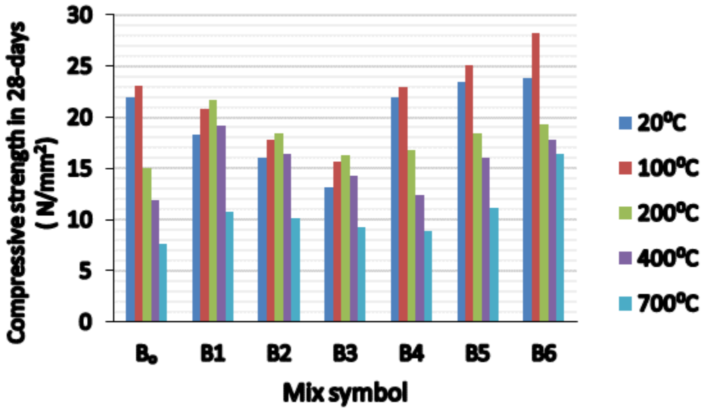

Fig. 3. Compressive strength in 28-days for different mixes of mortars cooled with water and exposed to different temperature

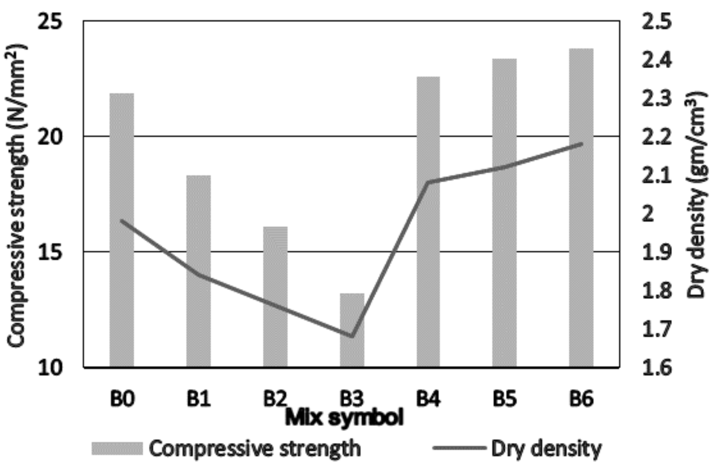

Fig. 4. The relationship between compressive strength and the dry density for different mixes tested at (28) day and cured in water at 20^0C

4.3 Flexural Strength

This test was done according to ASTM C348-02 [13] using 40×40×160 mm prism specimens. The result values for flexural strength for all mixes exposed to different heating temperatures for half hour after treatment with air or water and then tested are shown in Fig. 5. & 6.

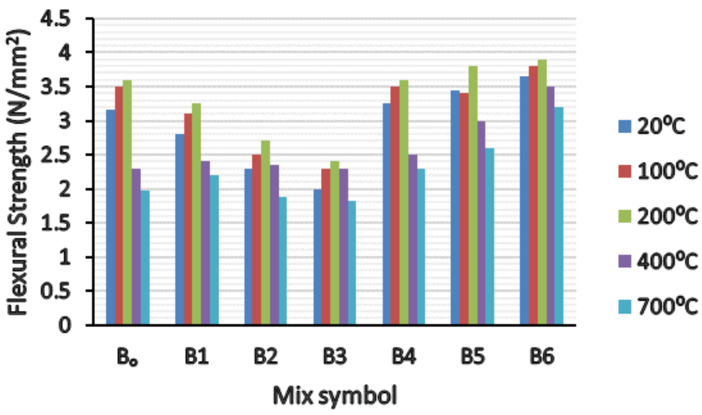

Fig. 5. Flexural Strength in 28-days for different mixes cooled by air and exposed to different temperature

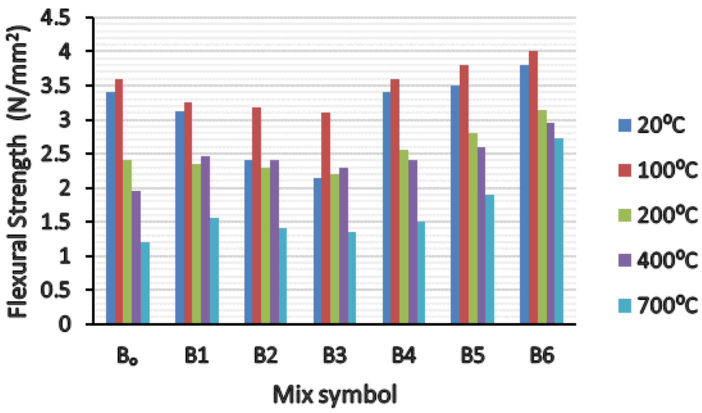

Fig. 6. Flexural Strength in 28-days for different mixes cooled by water and exposed to different temperature

From the results, it's clear that the use of water curing gives good results compared with air curing methods and this is also in conformity with the findings of the earlier researchers as for compressive strength.

For the specimens exposed to different heating temperatures for half hour after being treated with water and tested, the results showed the loss in flexural strength was huge (between 28.2% - 64.7%), especially for those specimens exposed to (700)°C and tested at (28) days for specimens B_0 to B_6 respectively, which was about double the loss for the same specimens treated with air after being exposed to heating degree as shown in Fig. 5 & 6 this result doesn't counter the research (Aydin, 2007[2]) .Many authors (Georgali B. ,and Taskiridis P. E,2005[14], Fu Y.F. ,et all ,2004[15], Serdar A. ,et all ,2008 [16]and Fares , Noumoure ,and Remond,2004[17]) agree on the fact that strength decreases with increasing temperature of exposure.

From Fig. 6, the values of compressive strength were achieved when tested at age of (28) days for specimens (B_6) and exposed to heating of (700) °C which represents increase by percent of (127. 5%) compared to reference mortar specimens (B_0) when exposed to heating of (700) °C and tested at age (28) days. These may be due to reduction of required water which increases strength and reduces voids.

Fig. 5 shows the loss of strength at highest heating degree of temperature (700) °C tested at age (28) days with percent of (37.3%, 9% and 12.3%) for specimens (B_0 , B_3 and B_6), respectively compared to the same specimens when tested at the same age with heating degree of (20)°C, while Fig. 8 showed the relation of the percentage of loss of strength at highest temperature (700)°C between the specimens treated with air and others treated with water.

5 Conclusions

From the experimental results presented in this research, the following conclusions can be drawn:

1- All specimens exposed to a temperature of 700°C showed a decrease in their compressive and flexural strengths. The difference in the strength decrease was relatively different between specimens treated with water and those left in air to dry compared to the reference specimens tested at 20°C after (3, 7 and 28 days).

2- The decrease in both compressive and flexural strength was more obvious in specimens subjected to

700°C than that treated in water and for all references tested at 20°C.

3- The minimum compressive strength loss was achieved when specimens (B_3) were exposed to 700°C and air treated then tested after 28 days, the decrease in strength was (9.1%) compared to that of reference specimens tested at 20°C and the percentage loss in flexural strength was (9%) for the same above case.

4- The minimum loss in compressive and flexural strength for specimens (B_3) was (29.6%, 37.3%), respectively for the specimens at 700°C by water treated and tested after 28 days when comparing those results relative to the reference samples at 20°C.

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