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Fire Effect on Concrete Containing Red Clay (Homra) as a Partial Replacement of Both Cement and Sand

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Abstract- The partial replacement of cement and sand with red clay (called also homra) in the concrete is investigated in this study, with reference to fire resistance. As a natural pozzolanic material commonly found in desert areas, homra is extensively used in brick manufacturing. As a waste material from this industry, homra is hazardous for the environment, and using homra in concrete production may reduce its environmental impact, with the plus that homra reacts with the lime resulting from the hydration of ordinary Portland cement (OPC). In this study, replacing OPC and sand (15%, 20 %, 25 and 30% by mass) with homra has been investigated to have information on the mechanical behavior of homra-modified concretes after being exposed to fire for half- an- hour or one-hour. After heating, the specimens were either quenched in water or cooled in air. The tests show that the optimal replacement rate is 15% for the cement and 25% for the sand, in terms of enhanced compressive, tensile and flexural strength.

Keywords: cement replacement; sand replacement; red clay/ homra (as a pozzolanic material) fire resistance (of homra-modified concretes); water quench; residual mechanicals properties after heating.

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Strictly as per the compliance and regulations of:

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I. Introduction

The increasing world population is increasing the amount and type of the waste generated by human activities. Many wastes produced today will remain in the environment for hundreds and perhaps thousands of years. One solution to this crisis lies in recycling wastes into useful products [1].

The production of cement has diminished the limestone reserves in the world and requires a great consumption of energy. River sand has been the most popular choice for the fine aggregate component of concrete in the past, but overusing the material has led to the depletion of river-sand deposits and to a concomitant cost increase of the material. Therefore, it is desirable to obtain cheap, environmentally friendly substitutes for cement and river sand that are preferably by products [2].

Sukesh et al. [3] found that replacing sand with quarry powder improves concrete strength in compression, but the greater the replacement ratio, the lesser the workability of concrete, because of water absorption by the powder itself.

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The main objective in using very fine red clay in concrete and mortar production is the reduction of the amount of cement, thanks to the pozzolanic activity of red clay [4]. Using red clay in concrete and mortars brings in, therefore, at least three benefits: less energy consumption, less environmental impact and more recycling of waste materials, as red clay is partly a waste material.

Kunavat and Sonawane [5] studied the use of brick waste as a replacement of cement and sand in cement mortar. The results indicated that richer mixes gives lower value of bulk density and higher values of compressive strength for sand replacement with brick waste up to 40%.

When the building materials are exposed to fire, some deterioration takes place. This deterioration can often reach a level at which the structure may have to be thoroughly renovated or completely replaced. Cement has been used for the immobilization of low and intermediate level radioactive wastes. Compared to other materials, which are used to stabilization of radioactive wastes, cement is a rather cheap raw material [6]. The Portland Cement containing 20 - 30 wt. % fly ash thus possesses good fire resistance and dimensional stability when exposed to high temperature and then high humidity or wetting [7]. The replacement of OPC by 20 wt. % of thermally activated kaolinite in cement paste increases its thermal stability against temperature up to 600 °C [8].

The compressive strength increases with the addition of homra up to 400 °C then decreases. The higher compressive strength of pozzolanic cement pastes containing 10 and 20 wt. % homra than OPC cement pastes at 300 °C is due to the pozzolanic reaction of homra with the free lime to produce additional amounts of calcium silicate and aluminosilicate hydrates [6].

The cracking of cementitious materials that exposed to a high temperature develops during the post cooling period as a result of rehydration of CaO associated with a significant increase in volume by about 44 % [9]. The enhancement of the thermal stability of concrete and the reduction of post cooling cracking have been achieved by the

Global Journal of Researches in Engineering (E) Volume XVII Issue I Version I Year 2017

addition of pozzolana that consumes ($Ca(OH)_2$) liberated from the hydration of OPC forming additional calcium silicate hydrates [10]. The replacement of OPC by silica fume, fly ash, metakaolin and homra [11] was found to improve the physico mechanical properties, microstructure, and thermal stability of cementitious materials as well as reduce the extend of cracking when exposed to high temperatures.

II. Research Significance

The main objective of this study is to determine the suitable ratio of homra as a partial replacement of cement and sand to increase fire resistance. As well as the treatment type (quenched in water or cooled in air) will be studied.

III. Experimental Program

In this investigation, 108 cubes (100 x 100 x100 mm), 108 cylinders (100 mm in diameter and 200 mm in length), and 108 prisms (100 x 100 x 400 mm) as shown in Fig. 1 were tested using 2500 KN capacity testing machine to investigate concrete compressive strength, tensile strength by splitting tensile test and flexural strength, respectively. The main variables taken into consideration in this study were the replacement ratio of cement and sand with homra, where homra was used at ratios 15 %, 20 %, 25 % and 30 % as a partial replacement of cement then homra was used as a partial replacement of sand at the same ratios in addition to control specimens without homra. Furthermore, part of specimens were exposed to the fire for half-an-hour and the other part for one-hour as shown in Fig. 2. Then some specimens were allowed to cool down to room temperature in air and some specimens were quenched in water.

Figure 1: The test specimens

Figure 2: Fire effect

IV. Properties of Materials

a) *Cement*

The cement used in this investigation was Ordinary Portland (OPC) that has been partially replaced by homra at ratios of 15 %, 20 %, 25 % and 30 wt. %. The tests were carried out to determine its physical properties according Egyptian code of Practice [12].

b) *Aggregates*

Dolomite with 10 mm nominal maximum size was used as coarse aggregate and the fine aggregate was the natural sand free from impurities that has been partially replaced by homra at ratios of 15 %, 20 %, 25 % and 30 wt. %.

c) *Red Clay (Homra)*

Homra is a solid waste material produced from the manufacture of clay bricks and consists mainly of quartz, aluminosilicate, anhydrite, and hematite. Therefore, it acts as a pozzolanic material. These crushed portions of homra are not for commercial use and may be considered as a solid waste to the environment. Homra was collected from brick plant sites and was obtained by grinding the solid shards to produce fine material as shown in Fig. 3.

Figure 3: Homra

d) *Admixture*

In this study, a super plasticizer Sikament NN, was used to improve the workability of concrete.

V. Mix Proportions and Casting Procedure

For this study, the same cement content was adopted for all specimens (i.e. 400 kg / m^3). Homra blended with cement and sand was prepared by a partial replacement of OPC (Type I mixes, i.e. only a share of OPC was replaced with homra) and sand (Type II mixes, i.e. only a share of sand was replaced with homra) with previous mentioned ratios of homra to obtain eight mix proportions more over the control mix without any homra as shown in Table 1. The composition of the control mix is shown in Table 2, the remain mix compositions were adopted by replacement of cement and sand with homra by percentage as shown in Table 1. For each mix proportion, 12 cubes, 12 cylinders and 12 prisms were cast to obtain 324 total specimens. Cement, coarse and fine aggregates were weighed and placed into the concrete mixer for one minute then the mixing water containing super plasticizer was added. The slump test was carried on the fresh concrete as shown in Fig. 4. Fresh concrete was cast in molds then these molds were vibrated for one minute to remove any air bubbles and voids. After 24 hrs, specimens were demolded and cured under water until the desired curing time. After 28 days of curing under water, the hardened specimens were dried and some were exposed to fire for half-an-hour and some for one-hour. After heating, the specimens were partly left to cool in air and partly were quenched in water.

Table (1): The replacement ratios (by mass) of the cement and of the sand with red clay (homra).

Mix No. *	Type I mixes (homra / cement) %	Type II mixes (homra / sand) %
1	-	-
2	15 / 85	-
3	20 / 80	-
4	25 / 75	-
5	30 / 70	-
6	-	15 / 85
7	-	20 / 80
8	-	25 / 75
9	-	30 / 70

* *For each mix, 12 cubes, 12 cylinders and 12 prisms were cast*

Table (2): Mix design

Cement content	(Kg /m^3)	400 *
Coarse aggregate	(Kg /m^3)	1286
Fine aggregate	(Kg /m^3)	551*
Water content	Kg(/m^3)	180
Super plasticizer	(Kg /m3)	5
W / C ratio		0.45

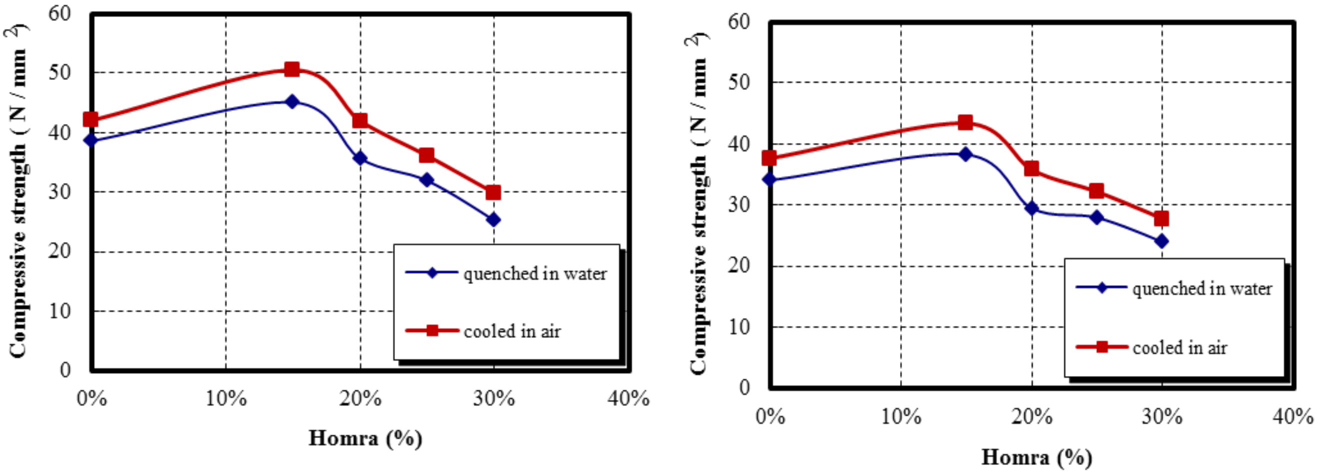
* The quantities of homra is used as the replacement of cement and sand (fine aggregate) content by percentage as shown in table (1)

Figure 4: The slump test

VI. Test Results and Disscusion

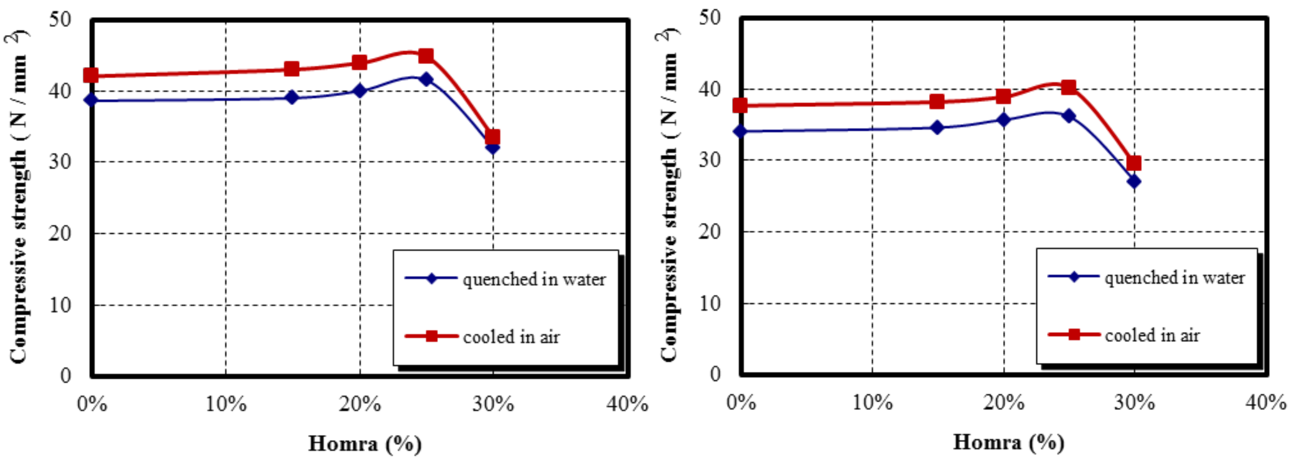
a) Concrete Compressive Strength

The values of concrete compressive strength according to different replacement of cement and sand with homra are shown in Figs. 5 and 6, respectively. These figures indicate that, in Type I mixes, the highest value of concrete compressive strength was obtained from replacement of cement by 15 % of homra. One may note (Fig. 5(a)) that replacing 15 % of cement (by weight) with homra brings an increase in concrete compressive strength equal to 16.8 % and 20.14 % with respect to the control specimen, after quenching the specimens in water or cooling them in air, respectively (half-an-hour of fire exposure). However, after one-hour fire exposure the increase in the compressive strength was lower (equal to 12.33 % and 15.18 %, after quenching in water or cooling in air, respectively). The compressive strength of pozzolanic cement pastes containing wt. 15 % homra was higher than that of OPC pastes at high temperature due to the pozzolanic reaction of homra with the liberated lime to produce additional amounts of calcium silicate and aluminosilicate hydrates. These hydrates deposit within the pore system as shown from scanning electron microscopy (SEM) micrographs (Fig. 7). The decrease of the compressive strength with higher percentage of homra is due to the decrease of the clinker content. In Type II mixes, the higher the percentage of homra the higher the values of compressive strength up to 25 %, after that the increase in the percentage of homra leads to decrease in values of concrete compressive strength. It can be notice that specimens of Type I mixes with 15 % of homra as a replacement of cement give higher values of concrete compressive strength than those of Type II mixes with 25 % of homra as a replacement of sand. Fig. 8 (a) and (b) gives the effect of fire duration on concrete compressive strength in case of Type I and Type II mixes, respectively. The more prolonged the fire, the lower the values of the compressive strength whether specimens quenched in water or cooled in air after fire. The cement pastes made with pozzolanic materials as a partial replacement of Portland cement are more sensitive when exposed to fire. In case of Type I mixes with 15 % homra, the value of compressive strength decreased by 14.13 % when cooled in air and by 15.16 % when quenched in water. However, these values for Type II mixes with 25 % homra were estimated by 10.27 % when cooled in air and 12.92 % when quenched in water. Also, These figures demonstrate, therefore, that the specimens cooled in air exhibit a residual compressive strength greater than that exhibited by the specimens quenched in water, for both Type I and Type II mixes containing homra.



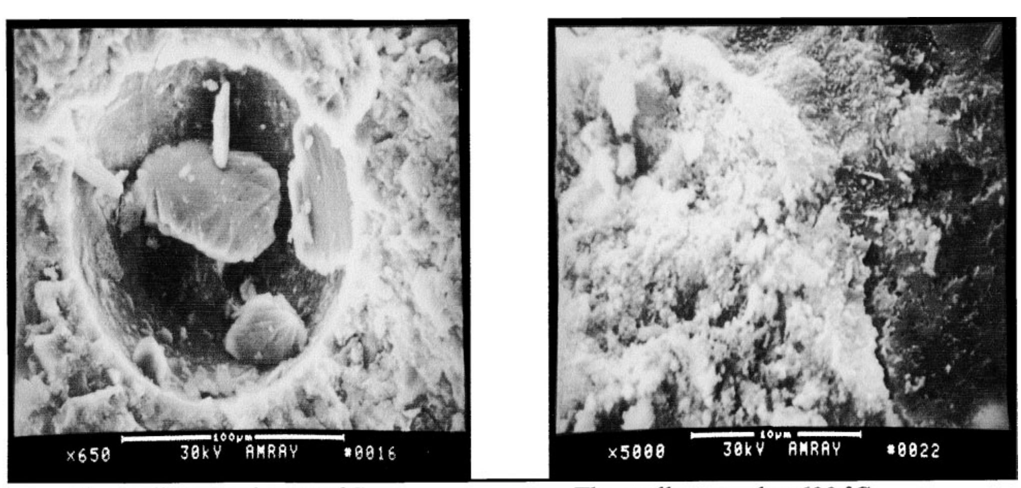
(a) (b)

Figure 5: Compressive strength for Type I mixes: (a) fire duration = half-an-hour ; (b) fire duration = one-hour.



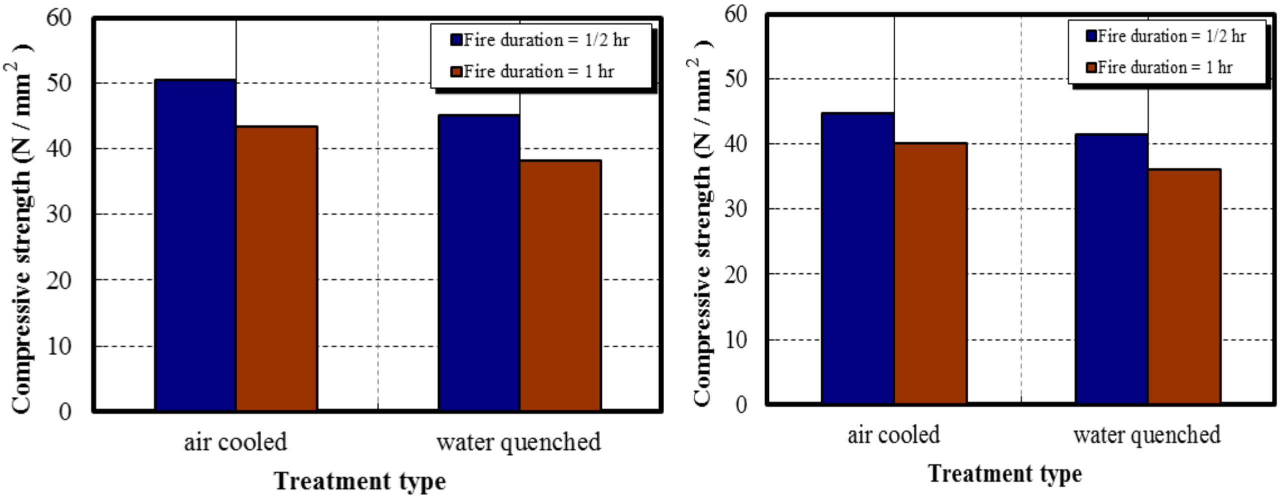
(a) (b)

Figure 6: Compressive strength for Type II mixes: (a) fire duration = half-an-hour ; (b) fire duration = one-hour



Thermally treated at 300 °C Thermally treated at 600 °C

Figure 7: SEM micrographs of thermally treated pozzolanic cement paste containing Homra [6]

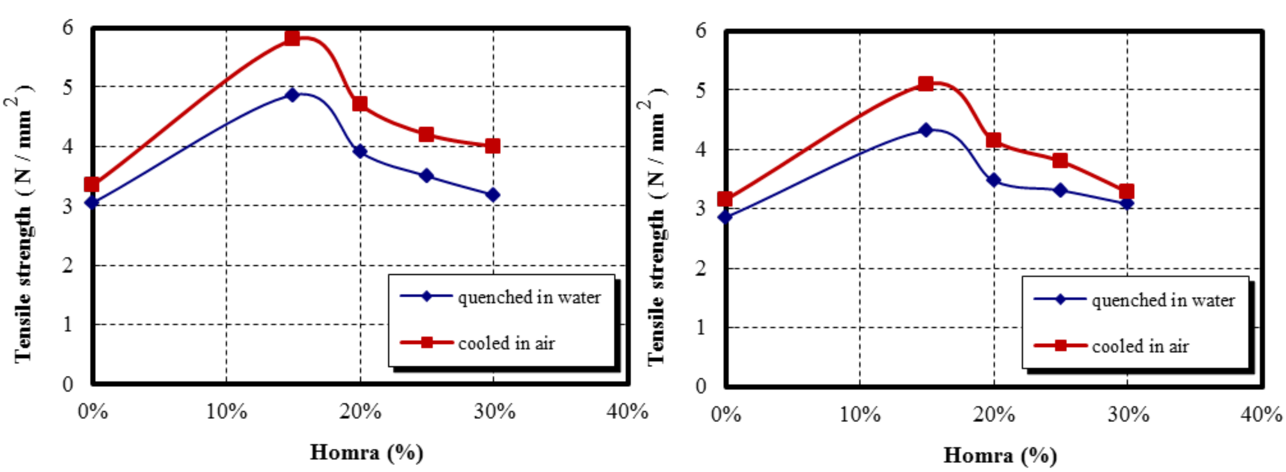


(a) (b)

Figure 8: Effect of fire duration on compressive strength : (a) Type I mixes ; (b) Type II mixes

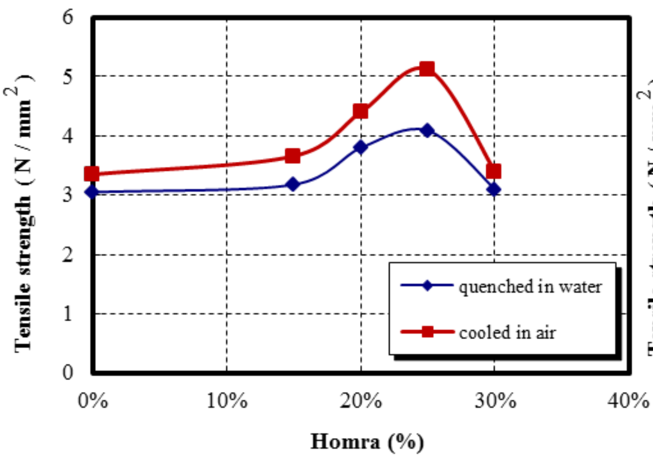
b) Tensile Strength

The values of tensile strength according to different ratios of homra from both cement and sand are plotted in Figs. 9 and 10 for Type I and Type II mixes, respectively. The replacement of cement by 15 wt. % of homra leads to an increase in tensile strength by 61.4 % and 51 % when specimens cooled in air and quenched in water, respectively for time exposer to fire = one-hour. However, when fire duration = half-an-hour these values were estimated by 73.13 % and 59.7 %. The highest value of the tensile strength for Type II mixes was at replacement of sand by 25 wt. % of homra, where the tensile strength was increased by 38.92 % and 33.9 % when specimens cooled in air and quenched in water, respectively for fire duration = one-hour. For fire duration = half-an-hour, the increase in tensile strength was estimated by 52.8 % and 34.1 %. The relation between treatment type and tensile strength is plotted in Fig. 11 (a) and (b) for Type I and Type II mixes, respectively. One can see that for Type I mixes and fire duration = 1 hr when specimens cooled in air, the tensile strength was increased by 18 % than that quenched in water at replacement 15 % by homra and by 19.1 % for fire duration = half-an-hour. For Type II mixes, at replacement 25 % by homra, the tensile strength was increased by 14.65 % when exposed to fire for 1 hr and by 25.18 % when fire duration = half-an-hour. These figures indicate that the tensile strength of air – cooled specimens decreased by 12.1 % and 14.26 % for Type I and Type II mixes, respectively when the fire exposure increased from half-an-hour to one-hour. A similar trend is exhibited by water - quenched specimens, whose tensile strength decreases by 11.3 % and 6.38 % for Type I and Type II mixes, when the fire exposure is increased.

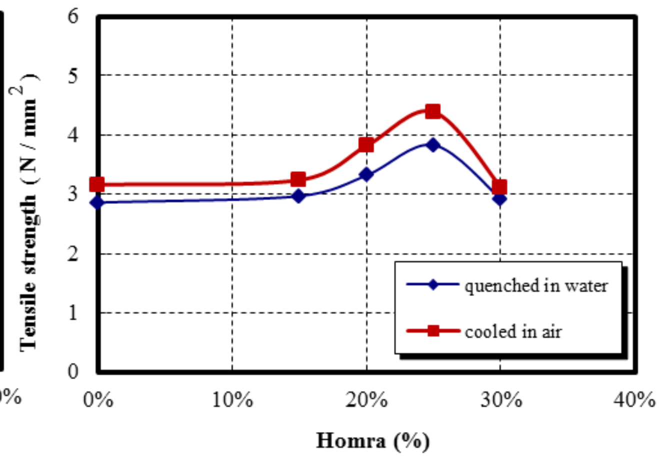


(a) (b)

Figure 9: Tensile strength for Type I mixes: (a) fire duration = half-an-hour; (b) fire duration = one-hour



(a)

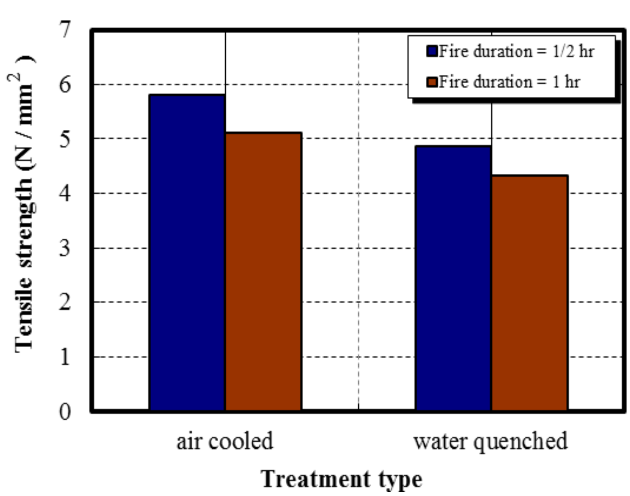


(b)

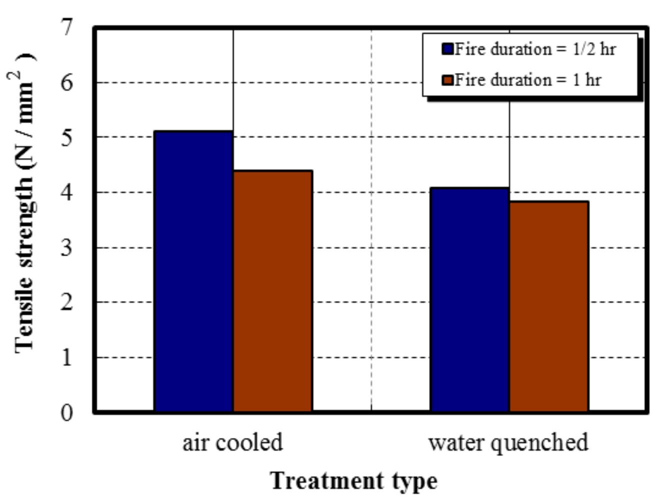
Figure 10: Tensile strength for Type II mixes: (a) fire duration = half-an-hour ; (b) fire duration = one-hour

c) *Flexural Strength*

As the same in compressive and tensile strength, the highest value of flexural strength was obtained in Type I mixes at percentage of homra = 15 % and in Type II mixes at percentage of homra = 25 %. Figs. 12 and 13 show the values of flexural strength according to different percentages of homra for Type I and II mixes, respectively. These figures indicate that the increase in flexural strength for Type I mixes was estimated by 60.7 % and 55.6 % when cooled in air for fire duration = half-an-hour and one-hour, respectively and by 49.1 % and 46.7 % when quenched in water. For Type II mixes, the increase when cooled in air was estimated by 36.1 % for fire duration = half-an-hour and 29.6 % for fire duration = one-hour and by 27.3 % and 24 % when quenched in water. The effect of fire duration on flexural strength are shown in Fig. 14 (a) and (b) for Type I and Type II mixes, respectively. The figure indicate that for Type I mixes at percentage 15 % of homra and fire duration = one-hour when specimens cooled in air the flexural strength was increased by 18.3 % than that quenched in water and by 19.5 % for fire duration = half-an-hour. For Type II mixes at percentage 25 % of homra, the increase was estimated by 16.7 % for fire duration = one-hour and by 18.6 % for fire duration = half-an-hour. The increase the time that specimens exposed to fire the decrease the value of flexural strength. For Type I mixes, the decrease equals to 14.3 % and 13.4 % when specimens cooled in air and quenched in water, respectively. In similar conditions, for Type II mixes exhibit a decrease in the flexural strength equals to 15.7 % and 14.3 %, respectively.

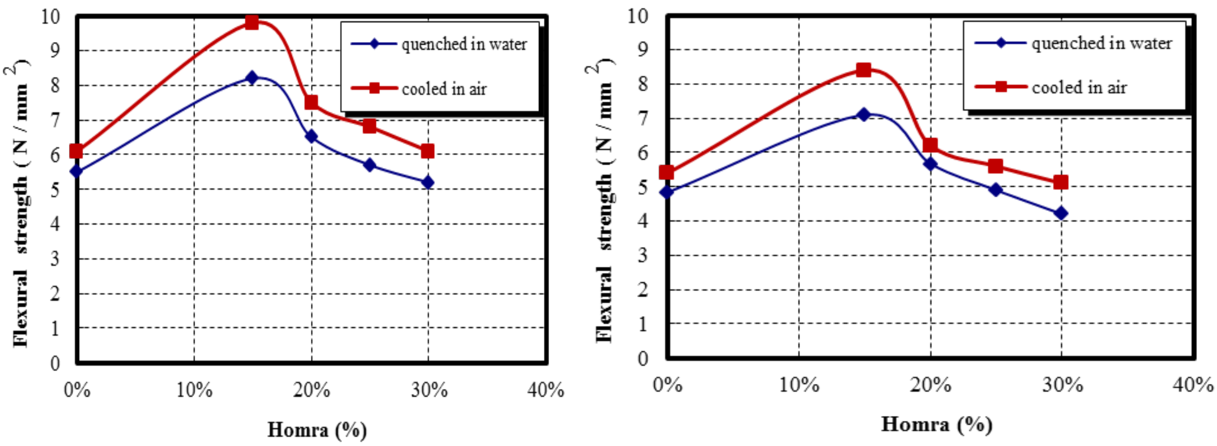


(a)



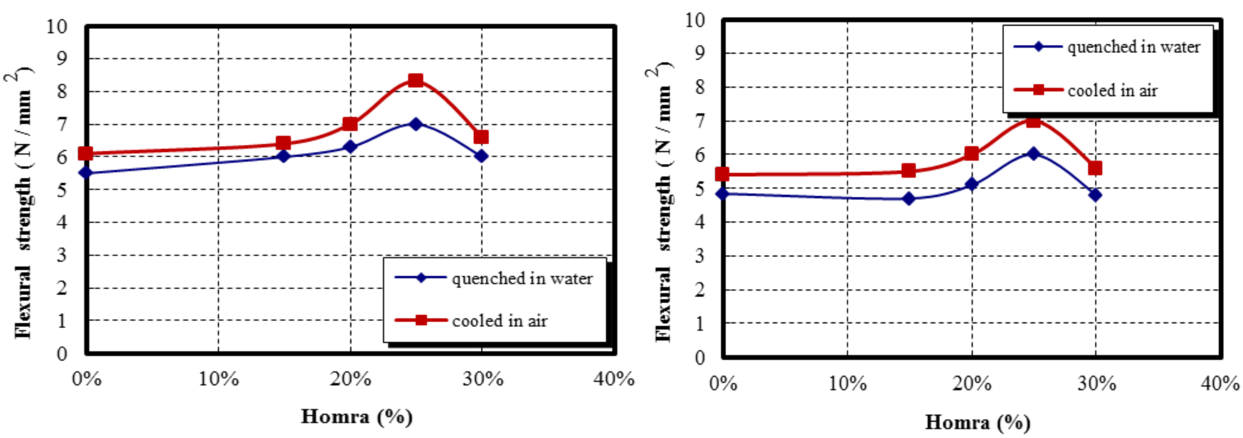
(b)

Figure 11: Effect of fire duration on tensile strength : (a) Type I mixes ; (b) Type II mixes



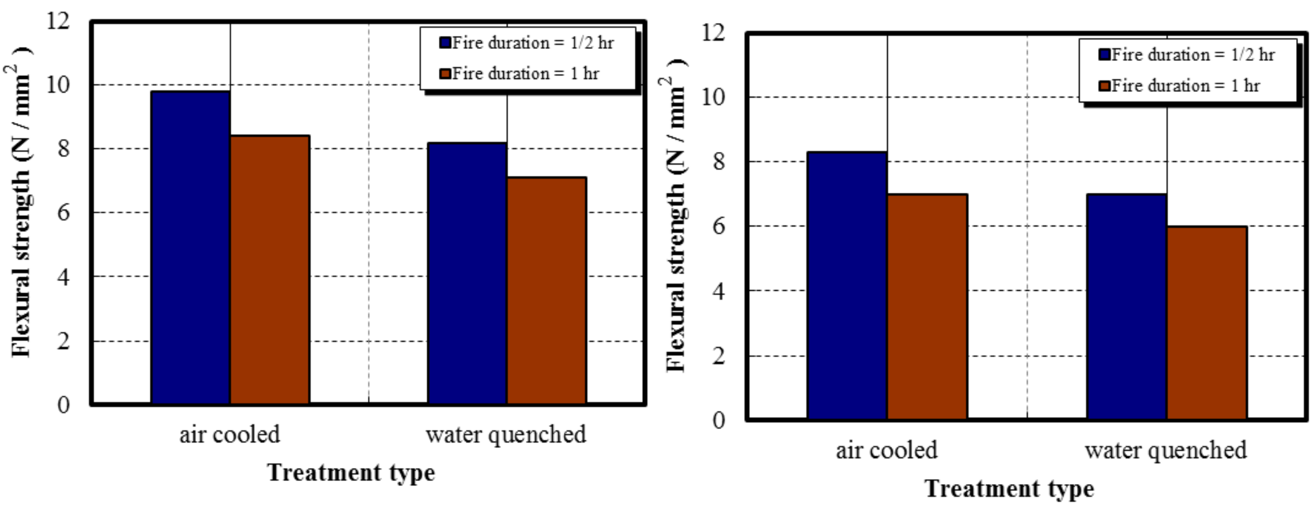
(a) (b)

Figure 12: Flexural strength for Type I mixes: (a) fire duration = half-an-hour ; (b) fire duration = one-hour



(a) (b)

Figure 13: Flexural strength for Type II mixes: (a) fire duration = half-an-hour ; (b) fire duration = one-hout



(a) (b)

Figure 14: Effect of fire duration on flexural strength : (a) Type I mixes ; (b) Type II mixes

VII. Conclusions

An experimental campaign is presented in this paper about the effect of fire on a number of concretes, whose cement and sand have been partially replaced with red clay (homra). The focus is on concrete strength in compression, tension and bending. The following main conclusions can be drawn:

- Using red clay in concrete not only contributes to ecology, but improves concrete mechanical properties in fire, when ordinary Portland cement or sand are partially replaced with red clay.
- Replacing 15% of cement and up to 25% of sand – by mass - with red clay improves all the mechanical properties of concrete.
- Replacing 15% of cement with red clay improves concrete mechanical properties more than replacing 25% of sand.
- Cooling the specimens in air after heating significantly increases concrete mechanical properties with respect to quenching the specimens in water; however, the longer the fire duration, the lower the residual mechanical properties, either after cooling in air or quenching in water.
- Replacing 15% of cement with red clay increases concrete compressive strength by 15.18 % and 20.14 % after one-hour and half-an-hour fire duration, respectively, provided that the specimens are cooled in air.
- In the same conditions as in the previous point, concrete tensile strength by splitting increases by 61.4 % and 73.13 % after one-hour and half-an-hour fire duration, respectively.
- In the same conditions as before, concrete flexural strength increases by 55.6% and 60.7 % after one-hour and half-an-hour fire duration, respectively.

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