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Mechanical Properties of Concrete Made of Crushed Concrete Subjected to Different Fire Durations.

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MECHANICAL PROPERTIES OF CONCRETE MADE OF CRUSHED CONCRETE SUBJECTED TO DIFFERENT FIRE DURATIONS

الخواص الميكانيكية للخرسانة المصنعة من كسر الخرسانة المعرضة للحريق لفترات زمنية مختلفة

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خلاصة:

تلاحظ في الأونة الأخيرة الزيادة المطردة في المخلفات الناتجة عن تكسير الخرسانة حيث يتم التخلص منها عن طريق تجميعها في مدافن صحية خاصة مما يمثل ضررا بيئيا من حيث اهدار الموارد الطبيعية و المتمثلة في الركام الطبيعي و من ثم بدأ التفكير في أنحاء متفرقة من العالم في استغلال هذه المخلفات عن طريق اعادة استخدامها في انتاج الخرسانة بحيث تحل محل الركام الكبير بنسب معينة و ذلك بعد تكسير مخلفات الخرسانة باستخدام الكسارات للوصول الي التدرجات المطلوبة. و رغم وجود العديد من الأبحاث التي من خلالها قد تم دراسة الخصائص الميكانيكية للخرسانة التي تستخدم كسر الخرسانة كنسبة من الركام الكبير الا أنه حتي الأن لم يتم دراسة تأثير تعرض هذه المخلفات للحريق علي خواص الخرسانة و لذلك فان هذه الدراسة تعني بدراسة تأثير مدة تعرض المخلفات للحريق علي خواص الخرسانة التي يشكل فيها كسر المخلفات نسبة من الركام الكبير حيث تم دراسة تأثير تعرض مخلفات الخرسانة للحريق عند درجة حرارة ٦٠٠ درجة مئوية لفترات زمنية متغيرة لمدة ساعة و ساعتين و ثلاث ساعات و ذلك لخلطات خرسانية مختلفة (٣٠ خلطة خرسانية) من حيث محتوي الأسمنت (٣٠٠ , ٣٥٠ و ٤٠٠ كجم/م٣) و نسبة استبدال الركام الطبيعي بناتج كسر الخرسانة (٠ و ٢٥ و ٥٠ و ١٠٠ %) و قد تم استعراض مقاومة الضغط و الشد و الانحناء للخلطات المختلفة.

ABSTRACT

The amount of construction and demolition waste has increased considerably over the last few years. The heaviest materials found in construction and demolition waste are rocks, concrete and ceramic residues. Nowadays, almost all demolished concrete has been mostly dumped to landfills. From the viewpoint of environmental preservation and effective utilization of resources, the interest in using recycled materials derived from construction and demolition waste is growing all over the world. Crushing concrete to produce coarse aggregate for the production of new concrete is one common means for achieving a more environment-friendly concrete. This reduces the consumption of the natural resources as well as the consumption of the landfills required for waste concrete. From the durability point of view, the performance of recycled concrete exposed to fire or high temperatures is not a very well-known subject since this property has been widely studied on conventional concretes. Such performance is related to the temperature level reached at the surface and interior of the material, the time of exposure. Also, the concrete's own characteristics such as w/c ratio, type of natural aggregate used. In the experimental work, the fresh properties (slump test) and the hardened properties,(compressive strength, splitting tensile strength, and flexural strength) were carried out. A total of thirty concrete mixes with different cement contents (300, 350, and 400 Kg/m3) at w/c ratio (0.5) were made and the percentag of substitution of natural coarse aggregate by the

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recycled concrete aggregate subjected to fire temperature 600°C for (1, 2, and 3 hours) was (0%, 25%, 50% and 100%). In the process of mixing, equal consistence among all concrete mixes was achieved. The obtained results indicate that the recycled coarse aggregate subjected to fire can successfully be used for making structural concrete.

1. INTRODUCTION

Shortage of natural aggregate in urban environments and increasing distance between the sources of quality natural aggregate and construction sites compelled the constructors to consider substituting the natural aggregate by recycled material (construction ceramics, slag, concrete). On the other hand, large quantities of old concrete often occur in urban environments, whose removal and disposal presents an environmental problem. Many authors from different countries study this point: Solomon L. and Paulo H. (Brazil), and Poon C, Kou S. and Lam L. (China) in their research papers [1] marked an aggregate which is brought from demolished masonry and concrete structures as potentially good for use in new concrete. Scope of usage of recycled materials is determined by their quality. In general, the quality of recycled aggregate depends on the quality of the original concrete it was obtained from, so prior to the design of mixture, aggregates must be examined in detail. Tabsh and Abdelfatah in [2] conclude that the percentage loss in compressive or tensile strength due to the use of recycled aggregate is more significant in a weak concrete than in stronger one. The use of coarse aggregate made from recycled concrete with strength equal to 50 MPa will result in concrete compressive and tensile strengths comparable with that achieved when using natural coarse aggregate. Recycled concrete mixes require more water than conventional concrete to maintain the same slump without the use of admixtures, regarding that it is a relatively new material [3].

Concrete is a composite material consisting of aggregates and matrix as its basic components. The effect of heating on both these components individually as well as their interaction control the behavior of concrete at high temperatures. Purkiss [4], Concrete is a porous material with its pores filled with water and air, surface heating of the concrete at elevated temperatures during fire not only results in deterioration of its properties like elastic modulus, tensile and compressive strength, but also in moisture migration in the presence of liquid water, heat evolved from fire to the concrete, causes the evaporation of liquid water. With the rise in temperature, the aggregate expands, the expansion of the matrix, on the other hand, is substantially offset of sometimes completely negated by shrinkage due to the evaporation of water. The resultant expansion differential causes internal cracking in the concrete and reduction in its stiffness. The extent of this phenomenon differs considerably with the type off aggregate and is most pronounced in the case of concrete with siliceous aggregate. Which at very high temperatures (575 °C or above) aslo undergoes physical changes accompanied by a sudden expansion in volume, thus sometimes causing aggregate splitting and / or spalling. Concrete is a poor conductor of heat, but can suffer considerable damage when exposed to fire. Unraveling the heating history of concrete is important to forensic research or to determine whether a fire-exposed concrete structure and its components are still structurally sound [5]. Making of concrete with recycled aggregate subjected to fire has still been inadequately researched field. So the effect of using aggregate obtained from demolished concrete has been studied previously in several researchers, while in the current study the recycled aggregate resulting from concrete subjected to fire will be used and its effect on the properties of concrete will be studied.

2.EXPERIMENTAL PROGRAM

2.1. Materials

2.1.1. Cement

The cement used in this investigation was CEM I 42.5 N. Testing of cement was carried out as per the Egyptian Standard Specifications ESS 2421/2005 [6]. Mechanical and physical properties and the chemical analysis of the used cement are given in Tables (1) and (2) respectively.

2.1.2. Fine aggregates

Natural sand composed of siliceous materials was used as Fine Aggregate (FA) in this study. Testing of sand was carried out according to the ESS 1109/2002 [7]. Table (3) shows the physical properties of the sand.

2.1.3. Coarse aggregates

2.1.3.1 Natural coarse aggregates

Natural crushed stone (dolomite) was used in this study. Testing of natural coarse aggregate (NCA) was carried out according to the ESS 1109/2002 [7]. Mechanical and physical properties of the NCA comply with both ESS 1109/2002 [7] and the Egyptian Code ECCS203-2007 [8]. Table (4) show the physical and mechanical properties of the Natural crushed stone (dolomite).

2.1.3.2 Recycled coarse aggregates

The recycled coarse aggregate used in this study were produced by crushing the concrete elements subjected to fire. Jaw crusher type (BB300) was used to gash the fined elements into wise recycled aggregate with fraction size 10 – 12 mm.

Testing of (RCA) was carried out according to the ESS 1109/2002 [7]. The physical and mechanical properties of the RCA are shown in Table(5).

It was observed that the density, water absorption ratio and Los Angeles abrasion having lower values in comparison with natural aggregate, mainly due to the adhered mortar as reported by many other researchers [9-10-11].

2.1.4. Mixing water

Drinking water was used for mixing.

2.1.5. Super Plasticizer

In this study, In order to obtain same workability without increased water, super plasticizer admixture ADDICRETE BV was used. ADDICRETE BV is a superplasticizer and flowing concrete admixture. (Complies with ASTM C 494 – 80 type A, DIN 10045, BS 5075PART 1).following properties, base material was lingo sulphonates, density was 1.18± 0.01/1 at 25°C and it was combatable with types of Portland cement.

2.2. Test setup of fire furnace and the Jaw crusher type BB300

The fire furnace was designed for the purposes of fire; the fire furnace system consists of three main components the fire chamber the fire lighter, and temperature control system as shown in Figure (1).The crusher used in this study was jaw crusher (type BB300) was shown in Figure (2).

2.3. Concrete mixes

The concrete mixes were prepared in the laboratory of Housing and Building National Research Center. A total of thirty concrete mixtures were made with different cement contents (300,350, and 400 kg/m3) at w/c = (0.5), the amount of water was adjusted according to cement content ,the superplasticizer dosage varied from 1% to 2.9% of cement content to achieve the required level of workability defined by a slump value of 10± 2cm. The percentage of substitution of natural coarse aggregate by the recycled concrete aggregate subjected to fire temperature 600°C for (1, 2, and 3 hours) was (0%, 25%, 50% and 100%). Control mixes ma. e with the natural aggregate, and the other concrete mixes were made using a recycled concrete aggregates subjected to fire, the ratio of fine to coarse aggregate was about 1:2. Composition of designed mixtures has been shown in Table (6).

2.4. Concrete tests

All the concrete mixes were mixed in the laboratory of Housing and Building National Research Center (HBRC). The slump test was conducted on fresh concrete to determine the slump value. For each concrete mix, six 150*150*150 mm cubes were cast for the determination of compressive strength at 7 and 28 days. Three 150mm * 300mm cylinders were cast for the determination of indirect tensile strength at 28 days. Three beams of dimensions 100 * 100 * 500 mm were cast for the determination of flexural strength at 28 days. After casting, all the cast specimens were covered by plastic sheets and water saturated burlap and left in the laboratory at 20 ± 3 °c for 24 h. the specimens were then demoulded and transferred to a saturated water curing tank at 25°c until the age of testing.

3. *RESULTS AND DISCUSSION*

3.1 Fresh concrete properties

The dosage of superplasticizer added to different concrete mixes to maintain a constant slump of 10 ± 2 cm was shown figure (3). It was found that in comparison between concrete groups (G1,G2, and G3) it can be noticed that dosage of superplasticizer was increased significantly by increasing the percentage of replacement of (RCA), fire temperature and fire duration. In general, recycled concrete needed more superplasticizer dose than the control concrete (without recycled materials) regardless of fire temperature and fire duration, and this agree with [12], who found that recycled concrete needed more superplasticizer dosage than the control concrete (without recycled materials) regardless of w/c ratio or type of recycled materials.

At fire temperature 600°C and fire duration 1 hour the dosage of superplasticizer for all mixes was adjusted to be 0.6% to 2.6% of cement content at replacement ratios 0%, 25%, 50% and 100% and cement content 300, 350 and 400 kg/m^3 .

At fire temperature 600°C and fire duration 2 hours the dosage of superplasticizer for all mixes was adjusted to be 0.6% to 2.8% of cement content at replacement ratios 0%, 25%, 50% and 100% and cement content 300, 350 and 400 kg/m^3 .

At fire temperature 600°C and fire duration 3 hours the dosage of superplasticizer for all mixes was adjusted to be 0.6% to 2.9% of cement content at replacement ratios , 25%, 50% and 100% and cement content 300, 350 and 400 kg/m^3.

3.2 Hardened concrete properties

The compressive strength results at 7 and 28 days of concrete mixtures subjected to fire temperature 600°C and fire durations 1, 2, and 3 hours were presented in Table (7).

It was observed that the compressive strength of concrete mixtures with percentage of replacement of RCA (0% , 25% ,50 % and 100%) were increased by (21%,26%,20% and 23 %) , (22%,24%,18%and 17%) and (28%, 27%, 23 and 20%)at cement contents 300,350 and 400 kg/m^3, from 7 to 28 days, respectively.

Figure (4-a) shows the concrete mixtures subjected to fire temperature 600°C for 1 hour, it can be noticed that at replacement ratio 25%, there is a slight increase in the compressive strength of concrete by (2%and 1%) at cement contents (300 and350 kg/m^3), respectively while the compressive strength decreased by 2% at cement content 400 kg/m^3 comparing to control mixtures , this agree with [13] who found that up to 25% coarse RCA has no major effect on compressive strength, and also with [14] who reported that there is an increase in the compressive strength of concrete replacement ratio 25% by 4%, and 2% at cement contents 350, and 400 kg/m^3 respectively, comparing to control mixtures. (Knowing that the RCA used in the previous studies was not exposed to fire). This may be attributed to the absorption capacity of the adhered mortar present in the recycled aggregate and the effectiveness of the new interfacial transition zone of the recycled aggregate concrete. Rough texture of recycled aggregates provided better bonding and interlocking between the cement paste and the recycled aggregates themselves compared with those of natural aggregates. A stronger bond between the cement and the recycled coarse aggregate may be able to compensate to some degrees the negative effect due the use of a weaker aggregate. While at replacement ratios (50% and 100%) RCA, there is a reduction in the compressive strength the by (10% and 17%) , (13% and 21%) and (13% and 20%) at cement contents 300,350 and 400 kg/m^3, respectively comparing to control mixtures at 28 days , this agree with [15] who found the results that up to 50% coarse RCA decrease the compressive strength by (5% to 10%), who found the results that full replacement 100% natural coarse aggregate by RCA decrease the compressive strength between by (8% and 24%), comparing to control mixtures. (Knowing that the RCA used in the previous studies was not exposed to fire).

Figure (4-b) shows the concrete mixtures subjected to fire temperature 600°C for 2 hours, it can be noticed that at replacement ratio 25%, there is a slight decreased in the compressive strength of concrete by 3% at cement contents 300, and 350 kg/m^3, while the compressive strength decreased by 4% at cement content 400 kg/m^3. At replacement ratios (50% and 100%) RCA, there is a reduction in the compressive strength the by (18% and 24%), (19% and 30%) and (18% and 28%) at cement contents 300,350 and 400 kg/m^3 respectively, comparing to control mixtures at 28 days.

Figure (4-c) shows the concrete mixtures subjected to fire temperature 600°C for 3 hours, it can be noticed that as fire temperature and fire duration increased there is a significant disintegration of the calcium silicate hydrate as well as partial disintegration occurs in the aggregate. Where at replacement ratio 25%, there is a decrease in the compressive strength of concrete by 7% at cement contents 300, and 350 kg/m^3 and decreased by 10% at cement content 400 kg/m^3.While at replacement ratios (50% and 100%) RCA, there is a reduction in the compressive strength by (20% and 34%) , (23% and 35%)

and (23% and 36%) at cement contents 300,350 and 400 kg/m^3, respectively. So as the fire duration increase the cohesion between the cement matrix and aggregate is starting to release, leads to the predominance of microcracks where the space between the cement matrix and aggregate increased intermingled with voids due to increase in porosity, the dehydration of calcium hydroxide is take place Ca(OH)2, and C-S-H gel. So we can concluded that is the duration of recycled concrete aggregate exposed to fire increased the loss in compressive strength increased at different cement contents and different percentage of replacements.

It can be noticed from fig (5-a) that at replacement ratio 25%, there is decrease in the tensile strength of concrete by (5%, 4%and 2%) at cement contents (300,350 and 400 kg/m^3) when subjecting to fire temperature 600°C for 1 hour respectively, comparing to control mixtures . While at replacement ratios (50% and 100%) RCA, there is a reduction in the tensile strength the by (14% and 22%), (12% and 23%) and (12% and 21%) at cement contents (300,350 and 400 kg/m^3), respectively comparing to control mixtures at 28 days .This agree with Hansen, [16]. Who stated that full replacement 100% natural coarse aggregate by RCA, the tensile splitting strength of recycled aggregate concretes produced with both fine and coarse aggregate to be reduced by 35%. (Knowing that the RCA used in the previous studies was not exposed to fire).

It can be noticed from fig (5-b) that at replacement ratio 25%, there is decrease in the tensile strength of concrete by (7%,5% and 5%) at cement contents (300,350 and 400 kg/m^3) when subjecting to fire temperature 600°C for 2 hours respectively, comparing to control mixtures . While at replacement ratios (50% and 100%) RCA, there is a reduction in the tensile strength the by (17% and 27%), (15% and 25%) and (15% and 26%) at cement contents (300,350 and 400 kg/m^3), respectively comparing to control mixtures at 28 days.

It can be noticed from fig (5-c) that at replacement ratio 25%, there is decrease in the tensile strength of concrete by (10%,10% and 7%) at cement contents (300,350 and 400 kg/m^3) when subjecting to fire temperature 600°C for 3 hours respectively, comparing to control mixtures. While at replacement ratios (50% and 100%) RCA, there is a reduction in the tensile strength the by (19% and 30%), (17% and 29%) and (19% and 31%) at cement contents (300,350 and 400 kg/m^3), respectively comparing to control mixtures at 28 days.

It can be noticed from fig (6-a) that at replacement ratio 25%, there is a slight increase in the flexural strength of concrete by 1% at cement content 300 kg/m^3, comparing to control mixtures and decreased by (1% and 6%) at cement contents (350 and 400 kg/m^3) respectively comparing to control mixtures at 28 days. While at replacement ratios (50% and 100%) RCA, there is a reduction in the flexural strength the by (13% and 27%), (18% and 27%) and (14% and 25%) at cement contents (300,350 and 400 kg/m^3), respectively comparing to control mixtures at 28 days. This agree with Akash Rao, [17] who stated in his literature that, that full replacement 100% natural coarse aggregate by RCA, the flexural strength of RCA produced with both fine and coarse aggregate reduced by 26%.(Knowing that the RCA used in the previous studies was not exposed to fire).

It can be noticed from fig (6-b) that at replacement ratio 25%, there is decrease in the flexural strength of concrete by (5%,4% and 9%) at cement contents (300,350 and 400 kg/m^3) respectively comparing to control mixtures at 28 days. While at replacement ratios (50% and 100%) RCA, there is a reduction in the flexural strength the by (18% and 30%), (20% and 31%) and (18% and 30%) at cement contents (300,350 and 400 kg/m^3), respectively comparing to control mixtures at 28 days.

It can be noticed from fig (6-c) that at replacement ratio 25%, there is decrease in the flexural strength of concrete by (6%,8% and 5%) at cement contents (300,350 and 400 kg/m^3) respectively comparing to control mixtures at 28 days. While at replacement ratios (50% and 100%) RCA, there is a reduction in the flexural strength the by (24% and 36%), (22% and 34%) and (24% and 37%) at cement contents (300,350 and 400 kg/m^3), respectively comparing to control mixtures at 28 days.

4. CONCLUSION

(1) The workability (slump test) of recycled aggregate concrete subjected to fire is lower than natural aggregate concrete because the rate absorption of RAC is higher than NAC.

(2) In comparison between concrete groups (G1, G2, and G3) it can be noticed that the dosage of superplasticizer was increased significantly by increasing the percentage of replacement (RCA) and fire duration.

(3) In general, the compressive strength, splitting tensile strength and flexural strength significantly decreased as the recycled aggregate content increased.

(4) The increase in the fire duration leads to considerable decrease of the compressive strength, splitting tensile strength and flexural strength.

(5) Replacement of natural aggregate by 25% recycled concrete aggregates subjected to fire temperatures 600°C at fire duration 1, 2 & 3hours respectively has a very minor effect on both of compressive and tensile strength.

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Table (1): Mechanical and Physical Properties of Cement

Property		Results	Specifications Limits*
Compressive Strength of Standard Mortar (MPa)	2 days	21.4	Not less than 10
	28 days	47.7	Not less than 42.50 Not more than 62.5
Soundness (La Chatelier) (mm)		1	Not more than 10
Setting Time (min)	Initial	135	Not less than 60
	Final	180	----------

*Limits of ESS 4756-1 / 2007 [6]

Table (2): Chemical Properties of Cement

Property	Results
Silicon Oxide SiO2	21.0
Aluminum Oxide Al2O3	6.10
Ferric Oxide Fe2O3	3.00
Calcium Oxide CaO	61.5
Magnesium Oxide MgO	3.8
Sulfur Oxide SO3	2.5
Sodium Oxide Na 2O	0.4
Potassium Oxide K2O	0.3
Loss on Ignition (L.O.I)	1.0
Insoluble Residue	0.9

Table (3): Physical Properties of Fine Aggregate

Property	Results	Limits*
Specific Weight	2.63	-----
Bulk Density (t/m3)	1.78	-----
Clay and Fine Dust Content (% By Volume)	1.4	Not more Than 4

*Limits of ESS 1109 /2002 [7]

Table (4): Physical and Mechanical Properties of Natural Coarse Aggregate

Property	Results	Limits
Specific Weight	2.61	-----
Bulk Density (t/m3)	1.56	-----
Water Absorption %	2.05	Not more than 2.5**
Clay and Fine Dust Content %	2.4	Not more than 4*
Flakiness Index %	36.8	Not more than 40*
Elongation Index %	9.6	Not more than 25**
Abrasion Index %	17.8	Not more than 30*
Impact Value %	12.60	Not more than 45*

*Limits of ESS 1109/2002 [7]
**Limits of ECCS203-2007 [8]

Table (5): Physical and Mechanical Properties of Recycled Coarse Aggregates

Property	Results			Limits
	600°C - 1hr	600°C -2hrs	600°C -3hrs	
Specific Weight	2.18	2.20	2.15	-----
Bulk Density (t/m3)	1.25	1.51	1.31	-----
Water Absorption %	4.93	6.67	7.67	Not more than 2.5**
Clay and Fine Dust Content %	7	10	13	Not more than 4*

*Limits of ESS 1109/2002 [7]
**Limits of ECCS (203-2007) [8]

Table (6): Concrete mix proportions at fire temperature 600°C and fire durations 1, 2, and 3 hours

Mix NO.	Designation	W	SP			C	FA	NCA	FRCA
			1hr	2hr	3hr				
Control	M1 (M-0% -300)	150	1	1	1	300	659	1317	-
G1 (1,2 and 3 hrs) 9 mixes	M2 (M-25%-300)	150	1.15	1.2	1.3	300	638	957	319
	M3 (M-50%-300)	150	1.7	1.9	1.95	300	618	618	618
	M4 (M-100%-300)	150	2.6	2.8	2.9	300	582	-	1164
Control	M5 (M-0%-350)	175	0.8	0.8	0.8	350	623	1246	-

G2 (1,2 and 3 hrs) 9 mixes	M6 (M-25%-350)	175	1	1.1	1.2	350	604	906	302
	M7 (M-50%-350)	175	1.35	1.45	1.6	350	585	585	585
	M8 (M-100%-350)	175	2.3	2.45	2.55	350	550	-	1100
Control	M9 (M-0% - 400)	200	0.6	0.6	0.6	400	588	1176	-
G3 (1,2 and 3 hrs) 9 mixes	M10 (M-25%-400)	200	0.9	1	1.1	400	569	854	285
	M11 (M-50%-400)	200	1.25	1.3	1.45	400	551	551	551
	M12 (M-100%-400)	200	1.7	1.9	2	400	519	-	1038

W= Water (Litre/m3)
SP%; Superplasticizer percentage of cement content
C (kg/m3)= Cement content
FA (kg/m3)= Fine aggregates (sand)
NCA (kg/m3)= Natural coarse aggregates
FRCA (kg/m3)= Fired Recycled coarse aggregates

Table(7) Compressive strength of concrete mixtures at fire temperature 600°C and fire duration 1, 2, and 3 hours at 7 and 28 days.

Group	Designation	Compressive strength at 7 days (N/mm^2)			Compressive strength at 28 days (N/mm^2)		
		1-hr	2-hrs	3-hrs	1-hr	2-hrs	3-hrs
G1	M1(M-0%-300)	22.9	22.9	22.9	28.95	28.95	28.95
	M2(M-25%-300)	21.8	20.05	19.5	29.45	28	27
	M3(M-50%-300)	20.90	19.05	17.15	26.15	23.95	23
	M4(M-100%-300)	18.4	16.5	14.65	24	22.05	19.5
G2	M5(M-0%-350)	25.55	25.55	25.55	32.8	32.8	32.8
	M6(M-25%-350)	24.5	22.05	22	32.15	31.7	30.6
	M7(M-50%-350)	23.3	20.90	19.2	28.5	26.5	25.5
	M8(M-100%-350)	21.6	19.15	17.45	26	23	21.5
G3	M9(M-0%-400)	28	28	28	37.75	37.75	37.75
	M10(M-25%-400)	27.7	. 23.1	23.5	37.9	36.4	33.9
	M11(M-50%-400)	25.4	22.65	20.45	33	31	29
	M12(M-100%-400)	24.1	21.35	19.2	30.2	27.2	24.1

Table(8) Splitting tensile and flexural strength of concrete mixtures at fire temperature 600°C and fire duration 1, 2, and 3 hours at 28 days.

Group	Designation	Splitting tensile strength at 28 days (N/mm^2)			Flexural strength at 28 days (N/mm^2)		
		1-hr	2-hrs	3-hrs	1-hr	2-hrs	3-hrs
G1	M1(M-0%-300)	2.9	2.9	2.9	5.75	5.75	5.75
	M2(M-25%-300)	2.75	2.7	2.6	5.85	5.43	5.4
	M3(M-50%-300)	2.5	2.4	2.35	4.95	4.7	4.37
	M4(M-100%-300)	2.25	2.1	2.05	4.2	4	3.7
G2	M5(M-0%-350)	3.25	3.25	3.25	6.25	6.25	6.25
	M6(M-25%-350)	3.12	3.1	2.9	6.1	6.025	5.76
	M7(M-50%-350)	2.85	2.75	2.7	5.15	4.95	4.85
	M8(M-100%-350)	2.5	2.45	2.3	4.55	4.3	4.13
G3	M9(M-0%-400)	3.55	3.55	3.55	6.85	6.85	6.85
	M10(M-25%-400)	3.5	3.35	3.3	6.48	6.2	6.49
	M11(M-50%-400)	3.15	3	2.85	5.94	5.6	5.22
	M12(M-100%-400)	2.8	2.6	2.45	5.13	4.8	4.34

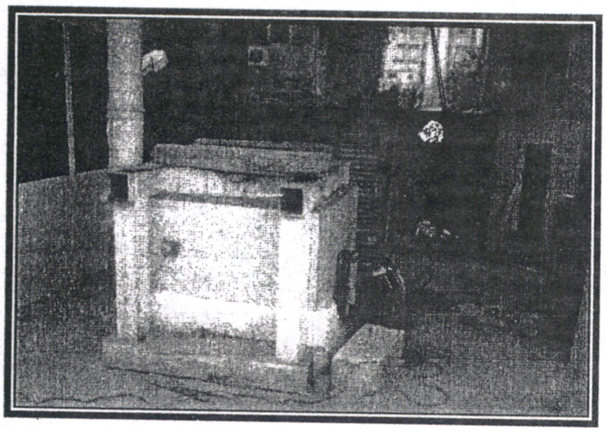


Fig (1) Test setup of fire furnace

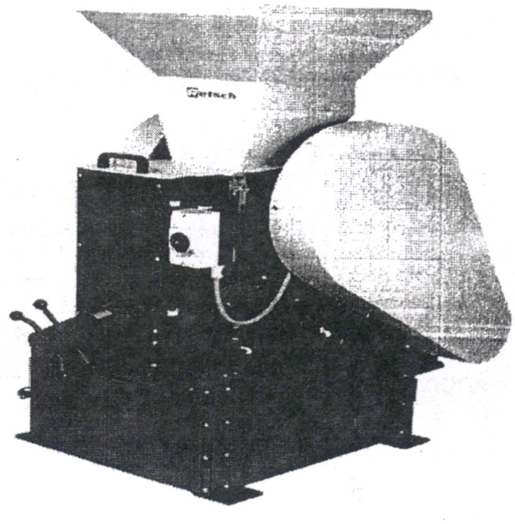


Fig (2) Jaw crusher BB300

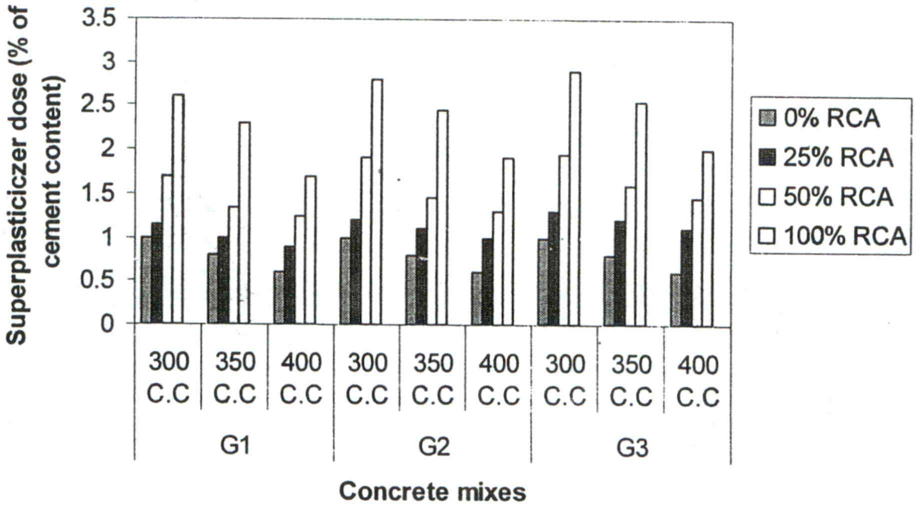
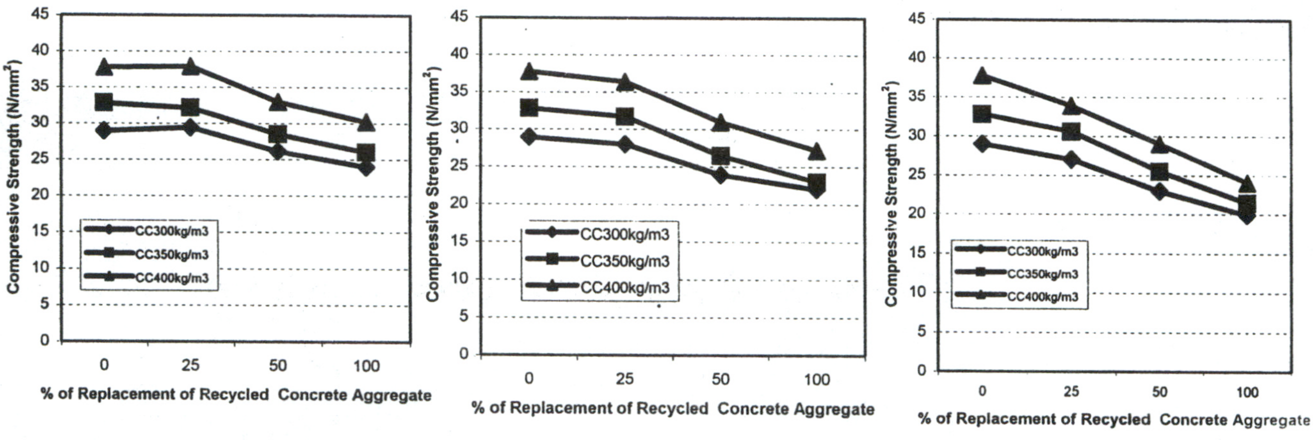
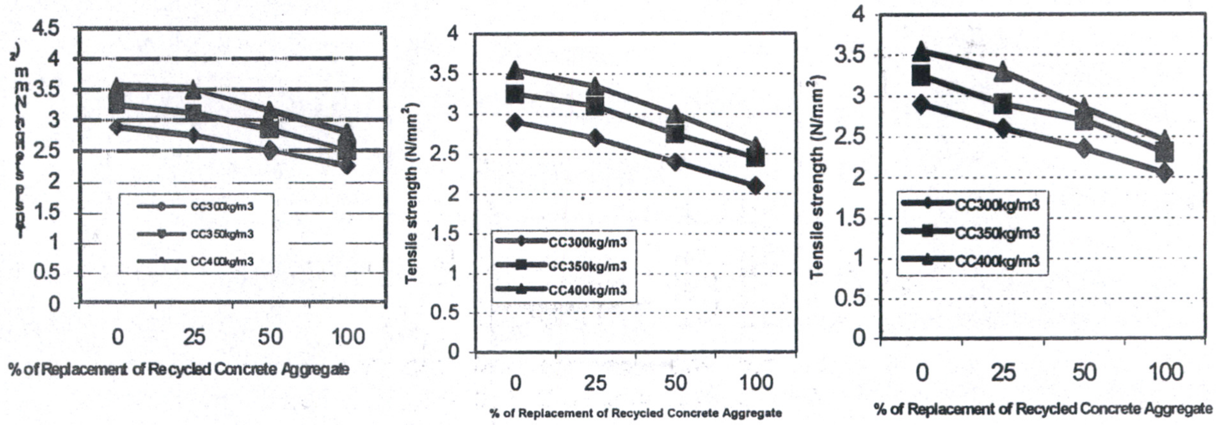


Fig (3) Superplasticizer dosage for concrete mixes



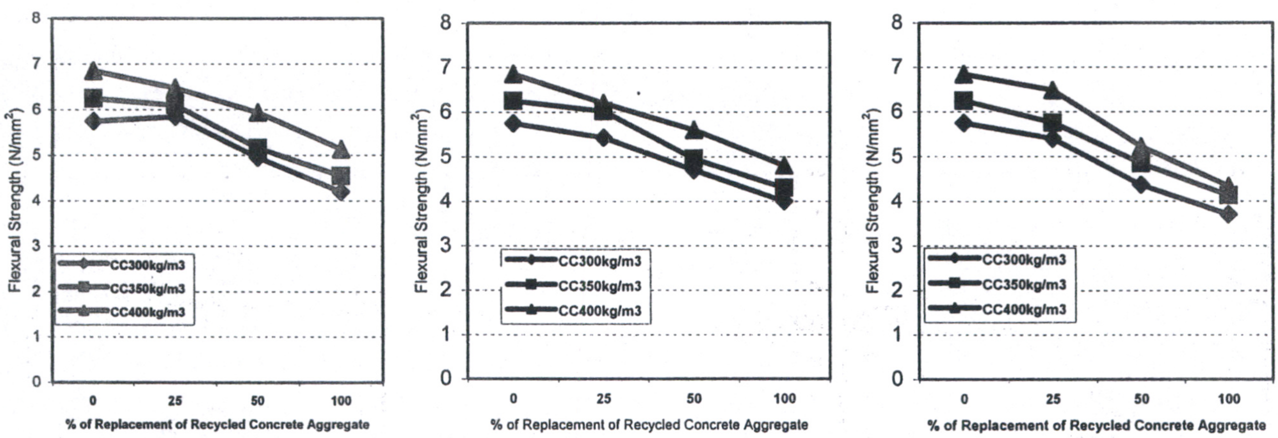
a - Duration - 1hr **b - Duration – 2hr** **c- Duration – 3hr**

Fig. (4) Relationship between Compressive Strength and % of Replacement of (RCA) for Different Cement Contents at Fire Temperature 600°C at 28 Days



a - Duration - 1hr b - Duration – 2hr c- Duration – 3hr

Fig. (5) Relationship between Tensile Strength and % of Replacement of (RCA) for Different Cement Contents at Fire Temperature 600°C at 28 Days



a - Duration - 1hr b - Duration – 2hr c- Duration – 3hr

Fig. (6) Relationship between Flexural Strength and % of Replacement of (RCA) for Different Cement Contents at Fire Temperature 600°C at 28 Days