Influence of Incorporating Construction Building Demolition as Recycled Aggregate on Concrete Behavior

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ABSTRACT

Because of increasing waste production and public concerns about the environment, it is desirable to recycle materials from construction and building demolition. This study aimed to find a technique for producing recycled aggregate concrete obtained from construction and building demolition waste. Laboratory trials were conducted to investigate the possibility of using recycled aggregate from different sources in Iraq, as a partial replacement of both coarse and fine natural aggregates or one of them. Recycled aggregate consists of crushed concrete (CC) or a combination of crushed brick (CB) and crushed concrete (CC). The aggregate in concrete was replaced with 10%, 20%, 30% and 50% by weight of crushed concrete (CC) or crushed brick (CB) and crushed concrete CC. Some of mechanical properties of recycled aggregate concrete as compared to those of conventional normal aggregate concrete are studied. Compressive strength and the splitting tensile strength were determined after curing for 7, 28, and 90 days while density was determined after28 days. From these results, it is reasonable to assume that the use of recycled concrete aggregate does not jeopardize the mechanical properties of concrete for replacement ratios up to 50%. The concrete prepared with the crushed concrete only as a partial replacement of natural aggregate achieved the highest strength values at 7, 28and 90 days. The results suggested that an aggregate that contains 50% recycled aggregate is optimum for producing recycled aggregate concrete The test results showed that the replacement of coarse or fine natural aggregate by recycled brick aggregate at the levels of 10,20,30 and 50% had little effect on the compressive strength of the specimens.

Keywords: concrete; splitting tensile strength; compressive strength; recycled aggregate; demolition

تأثير اضافة بعض مخلفات الابنية الانشائية المهدمة كركام معاد تدويره على سلوك الخرسانة

الخلاصة

بسبب زيادة إنتاج النفايات والمخاوف العامة حول البيئة فانه من المستحسن إعادة تدوير بعض المواد من الابنية و المنشات المهدمة. تهدف الدراسة إلى ايجاد تقنية الهدف هو انتاج ركام يصلح للخرسانةلإنتاج خرسانة الركام المعاد تدويره والتي نحصل عليها من مخلفات الابنية و المنشات المهدمة. أجريت التجارب المختبرية لفحص إمكانية استخدام الركام المعاد تدويره من مصادر مختلفة في العراق، كنسبة تعويضية من كل من الركام الطبيعي الخشن والناعم أو احدهما. يتالف الركام المعاد تدويره من الخرسانة المسحوقة أو خليط من الطابوق المسحوق والخرسانة المسحوقة. تم استبدال الركام الطبيعي في الخرسانة جزئيا بنسبة وزنية ١٠٪، ٢٠٪، ٣٠٪ و ٥٠% من الخرسانة المسحوقة أو من الطابوق المسحوق والخرسانة المسحوقة. تم دراسة بعض الخواص الميكانيكية لخرسانة الركام المعاد تدويره بالمقارنة مع الخرسانة الاعتيادية ذات الركام الطبيعي . تم تحديد مقاومة الانضغاط ومقاومة

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الشد بالانشطاربعد المعالجة بالماء لمدة ٧، ٢٨، و ٩٠ يوما وتم تحديدالكثافة بعمر28 يوم. بينت النتائج بأنه يمكن استخدام ركام الخرسانة المعاد تدويرها بما لا يعرض الخواص الميكانيكية للخرسانة للخطر لنسب استبدال تصل الى ٥٠٪. الخرسانة المحضرة من الخرسانة المسحوقة فقط كتعويض جزئي من الركام الطبيعي حققت أعلى قيمة للمقاومة بعمر ٧، و ٢٨ و ٩٠ يوما. وتشير النتائج أن الركام الذي يحتوي٥٠٪من الركام المعاد تدويره هو الأمثل لإنتاج خرسانة الركام المعاد تدويره . وأظهرت نتائج الاختبار أن استبدال الركام الطبيعي الخشن أو الناعم بركام الطابوق المعاد تدويره وبنسبة استبدال ١٠،٢٠،٣٠ و ٥٠٪ كان تأثيرها قليل على مقاومة الانضغاط للنماذج.

INTRODUCTION

The environmental impact of the production of the raw ingredients of concrete (such as cement, coarse and fine aggregate) is considerable **[1–3]**. The scale of the problem makes it prudent to investigate other sources of raw materials in order to reduce the consumption of energy and available natural resources, and to achieve a more ‘‘green’’ concrete. Crushing concrete to produce aggregate for the production of new concrete is one common mean 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 **[4]**.

For years people have been trying to keep the environment clean. Scientific studies provide us with information on how can maintain the natural balance of life, and recycling has a primary role in these studies. As a result of natural disasters or increasing population and urbanization, great amounts of waste materials are produced. These waste materials include concrete, wood, glass, aluminum, ceramics, PVC, and iron **[5]**.

In Iraq, the possible sources of concrete for reuse as aggregate are that from demolition of existing reinforced concrete structures, and the rejected concrete from ready-mix plants.

Concrete demolition waste has been proved to be an excellent source of aggregate for new concrete production. There are many studies proved that concrete made with this type of aggregate can have mechanical properties similar to those of conventional concrete is nowadays a possible goal for this environmentally sound practice **[1–3]**.

Generally, two typical grades of crushed concrete aggregates can be produced and classified by size gradation. One is the coarse recycled concrete aggregate (CRCA), part of which can be used in new concrete or road base materials. The other is the fine recycled concrete aggregate (FRCA) or recycled mortar from crushed concrete waste whose sizes are smaller than 5 mm [**6,7**].

Clay brick generated from construction and demolition sites is mostly delivered to landfills or reclamation sites for disposal. With the limited landfill space and reclamation areas in Iraq, it is important to explore the possible use of crushed clay brick as a civil engineering material.

The mechanical properties and the durability characteristics of recycled concrete aggregate must be investigated to ensure proper use of the recycled material. Tests have shown that the mechanical properties depend on the properties of the recycled concrete used to produce the aggregate and on the percentage replacement of coarse aggregate in the new concrete. With 100% replacement of coarse aggregate with recycled aggregate for example, Ravindraraj **[8]** measured a 9% decrease in compressive strength while Yamato et al. **[9]** measured a 45% decrease. Similarly, Gerardu and Hendriks**[10]**showed that 15% decrease in the modulus of elasticity of RAC, while Frondistou-Yannas**[11]** reported up to 40% decrease at relatively high water–cement ratio of0.75 and an insignificant difference at a lower ratio of 0.55. Ravindraraj**[12]** suggested equations for the modulus of elasticity that give an average decrease of15% for NAC and RAC of similar cylinder compressive strengths.

Successful application of recycled aggregate in construction projects has been reported in Hong Kong , as reviewed by Poon etal .**[13]** Their study aimed to develop a technique for producing concrete bricks and paving blocks using construction and demolition wastes as recycled aggregate. The test results showed that the replacement of coarse and fine natural aggregate by recycled aggregate at the levels of 25% and 50% had little effect on the compressive strength of the concrete bricks and blocks, but higher levels of replacement reduced the compressive strength.

There have been a number of publications on the use of recycled aggregate in concrete. It was concluded that concrete strength decreases when recycled concrete was used **[6]** and the strength reduction could be as low as 40% **[6,14]**. However, no decrease in strength was reported for concrete containing up 20% fine or 30% coarse recycled concrete aggregate, but beyond these levels, there was a systematic decrease in strength as the content of recycled aggregates increased. The strength characteristics of concrete was not affected by the quality of recycled aggregate at high water/cement ratio, it was only affected when the water/cement ratio is low. The higher the water/cement ratio, the less is the reduction in compressive strength **[6].** On the other hand, the physical properties and the presence of unhydrated cement in recycled concrete aggregate affected the properties of concrete **[14].** For concrete containing recycled brick, the strength was unaffected by the strength of brick **[6]**

Most of the work on using recycled aggregate in concrete has focused on replacing the coarse aggregate. Therefore, Khatib**[6]**reports the effect of replacing the fine aggregate (sand) with either fine crushed concrete or brick on the properties of the concrete. Properties include compressive strength, ultrasonic pulse velocity, and dynamic modulus of elasticity, shrinkage and expansion. The fine aggregate in concrete was replaced with 0%, 25%, 50% and 100% crushed concrete or crushed brick. Generally, there is strength reduction of 15–30% for concrete containing crushed concrete. However, concrete incorporating up to 50% crushed brick exhibits similar long-term strength development to that of the control mix.**[6]**.

Due to the wide variation in the properties of the available resources, properties of concrete using local materials need to be investigated in order to gain the required confidence in the performance of the new material. In Baghdad region, waste concrete from demolished sites constitute the larger resource for recycled aggregate and hence need to be studied. Studies on the properties of recycled aggregate concrete in Iraq and in the Arabian Gulf Region are limited **[15-18]**.

Experimental program

Materials

Cement

Ordinary Portland cement manufactured by AL-Mass cement factory was used throughout this research. It was stored in air-tight plastic containers to avoid the atmospheric conditions and to maintain constant quality. Table (1) and Table (2) show the chemical and physical properties of the cement used in this research. The used cement conforms to Iraqi specification No.5 / 1984 **[19]**.

Natural aggregate

-Fine aggregate:-Natural sand (Al-Ukhaider) was used with maximum size of 5mm .Table (3) shows that the grading and sulfate content which are conforming to the Iraqi specification No. 45/1984 **[20]**.

-Coarse aggregate:- Crushed aggregate of 14 mm maximum size and 2.65 specific gravity were used . It was obtained from AL- Nebaiquarry. The grading of aggregate and sulfate content was within the limit specified by Iraqi standard No. 45 / 1984 [20] as shown in Table (4)

Recycled aggregate

Waste concrete was obtained from two buildings under demolition in the Baghdad area in Iraq. No information was available on the age of the buildings, but most old construction in that area took place 20–40 years ago. Large parts of crushed concrete (CC) and crushed brick (CB) were transported to the laboratories and broken by workers into pieces with size smaller than 70 mm. Those pieces were crushed using a hammer (hand) in the University of Technology Laboratory to produce crushed concrete (CC) and crushed brick CB aggregate with particle size of less than 14 mm and sieving to produce fine aggregate and coarse aggregate according to the particle size requirements. The particle size distribution of crushed concrete (CC) and crushed brick CB is similar to the particle size distribution of normal aggregate. The sulfate content was 0.48% so that it was within the limit specified by Iraqi standard No. 45/1984.

Mix proportions

Different mixes were employed to examine the influence of incorporating building demolition as recycled aggregate on the compressive strength of concrete. Table 5 gives the details of the mix proportions. The control mix (M1) had weight of 1 (cement): 2(sand): 3 (coarse aggregate) and did not include either CC or CB. Inseries1 (mixes M2, M3, M4 and M5), the natural coarse aggregate was replaced with 10%, 20%30% and 50% (by weight) crushed concrete coarse aggregate, respectively while in series 2 (mixesM6, M7, M8, and M9), the fine aggregate was replaced with 10%, 20%30% and 50% (by weight) crushed concrete sand, respectively. On the other hand, in series 3(mixes M10, M11, M12 and M13), the natural coarse aggregate was replaced with 10%, 20%, 30% and 50% (by weight) crushed (concrete and bricks) (CC+CB) coarse aggregate respectively. While in series4 (mixes M14, M15, M16, and M17), the fine aggregate was replaced with 10%, 20%, 30and50% (by weight) crushed (concrete and bricks)(CC+CB) sand, respectively. Finally in series 5(mixes M18, M19, M20,and M21), the fine and coarse aggregate were replaced with 10%, 20%,30% and 50% (by weight) crushed concrete (CC) aggregate, respectively. On the other hand, in series 6(mixes M22, M23, M24,and M25), the fine and coarse aggregate were replaced with 10%, 20%30% and 50% crushed (concrete and brick)(CB+CC) aggregate, respectively.

Results and discussion

Density

Generally speaking, the compressive strength of the normal concrete increases with a rising of the mass density **[23]**. Within the data investigated,(Table6- Table10) show the values of the density. It can be assumed here that there exists approximately a linear relationship between the compressive strength and the mass density**[23]**.

Tables(6-10) present density values in kg/m^3 for all mixes at28 days curing time. The density value ranged from 2285 kg/m^3 to 2372 kg/m^3 for all concretes while the control mix has 2322 kg/m^3 density

A decrease in density can be observed as the replacement of natural aggregate with CB increases as reported by Khatib[6].Recycled brick aggregates present relatively lower density and higher water absorption compared to natural aggregates**[6]**.

A slightly lowered is obtained for concrete containing crushed brick (CB)as compared with those containing crushed concrete (CC) at the same replacement level. A decrease in density for concrete containing CB as compared with those containing CC is not associated with a decrease in compressive strength as suggested by Khatib**[6].**

Furthermore, the density of the mix with recycled coarse aggregate is slightly higher than that of the control mix prepared with natural aggregate.

Compressive strength

The compressive strength of the hardened concrete was determined at the ages of 7, 28 and 90 days on (100*100*100) mm cubes. These cubes were removed from the molds after 1 day and were cured in water before testing. The test results are summarized in Tables (6, 7, 8,9 and 10). The following sections discuss these results of the study, with emphasis on the comparison between the behavior of recycled aggregate concrete RAC and natural aggregate concrete NAC. Figs (1, 2, 3, 4, 5, 6) showed the development of the cube strength at different age ranging from 7 to 90 days .However, the effects of the recycled aggregate on the compressive strength of the concrete were quite different for different percent and type of recycled aggregate.

Laboratory trials were carried out on six series of mixes with recycled aggregate obtained from different sources in Baghdad, as the replacement for coarse or fine or both coarse and fine natural aggregate at levels of up to 50% by weight. The test results showed that the replacement of natural coarse aggregate by recycled concrete aggregate at the levels of, 10%, 20%, 30% and 50% had little effect on the compressive strength. However, the strength of the specimens increased as the percentage of the replacement increased .Using recycled concrete aggregate as the replacement of natural coarse aggregate at the level of up to 50%, concrete with a 90-day compressive strength of not lessthan25.1MPa can be produced as shown in Fig(1). However, the results presented in Table(6) have shown that when recycled concrete aggregate was used as a replacement of natural coarse aggregate the compressive strength of hardened concrete was almost unchanged when compared with concrete prepared with natural aggregate. Tabsh **[21]** reported the strength for the concrete mix made with recycled coarse aggregates from concrete produced almost the same compressive strength as that of the concrete made with natural coarse aggregate.

The test results also showed that the replacement of fine natural aggregates by recycled concrete aggregates at the levels of, 10%, 20%, 30% and 50% had little effect on the compressive strength. However test results of cubic specimens showed that strength was only a little high for concrete containing fine recycled aggregate as a partial replacement of natural fine aggregate but remained almost same. The strength of the specimens increased as the percentage of the replacement increased. Using recycled concrete aggregates as the partial replacement of natural fine aggregates at the level of up to 50%, concrete with a 90-day compressive strength of not less than 23.6MPa can be produced as shown in Fig(2) .

From Table (6) and Table (7) concrete made with recycled concrete aggregate was better than concrete made with natural aggregate. The compressive strength of concrete made by replacing coarse aggregate was significantly better than those concretes made by replacing fine aggregate

The cube compressive strength for all mixes in series 3 and series 4 at 7, 28 and 90 days is presented in Table (8)and Table(9) respectively. In both series3 and 4, the incorporation of crushed clay brick as a partial replacement of coarse or fine aggregate reduced the compressive strength. Generally, compressive strength decreases in concrete containing crushed concrete CC and crushed brick CB as a partial replacement of coarse aggregate or fine aggregate. This observation is similar to that by Poon et al **[13]**.

At 90 days of curing, an increase in crushed concrete CC and crushed brick CB content results reduction in compressive strength. This is best illustrated in Fig. (3) and Fig(4) where compressive strength is plotted against different curing times. The inclusion of crushed brick CB in recycled concrete results in a lower compressive strength as compared with that of recycled concrete incorporating crushed concrete CC only at the same replacement level. Due to the lower performance of concrete with crushed bricks aggregate, structural concrete applications should be limited to low performance concrete such as pavement blocks and manufactured elements.

The test results of series 5 and series 6 are summarized inTable10 and Table 11. Each presented value is an average of two measurements. The results indicated that the incorporation of crushed concrete only and crushed concrete and crushed clay brick as a partial replacement of fine and course aggregate increased the compressive strength has shown in Fig. 5 and Fig 6. As the replacement level increased from 0% to 50%, the compressive strength increased. This might be attributed to further cementing action of unhydrated cement particles in the crushed concrete (CC)**[6]**. In both series5 and 6, the incorporation of recycled fine and coarse aggregate increases the compressive strength. Hence, substitution of both coarse and fine aggregate with recycled brick aggregate should be done with caution as it can adversely affect the compressive strength**[22]**also Khatib**[6]** reported that including brick in concrete causes an increase in long-term strength due to its pozzolanic nature.

Furthermore, at the same replacement level, the compressive strength of the concrete in all Series replacing the fine or coarse aggregate or both of them by crushed concrete was higher than that replacing the fine or course aggregate or both of them by crushed brick and crushed concrete.

Splitting tensile strength

The splitting tensile strength test is often used to obtain the tensile strength of concrete, rather than by a direct tensile strength test because the former is easier to perform. In practical applications, however, the tensile strength of concrete is often estimated from the compressive strength **[23]**. The splitting tensile strength of the recycled aggregate concrete is shown in Fig8 to Fig10. Although the results show a considerable scatter, the tendency that the splitting tensile strength increases with increasing compressive strength can still be recognized.

Compared with normal concrete, splitting tensile strength values showed that strength was only a little high for series1and in series,2 but remained almost the same in series3and in series4. Therefore, it could be concluded that splitting tensile strength remained unchanged. Relations between age and splitting tensile strengths are presented in Table12 to Table17.

The tensile splitting strengths of the mixes in series 4and in series5were higher than that of the control mix. Since the tensile splitting strength is mainly governed by the properties of the interfacial transition zone (ITZ), the improvement of the ITZ can be attributed to two main reasons: firstly the high water absorbability of the particles of crushed concrete and crushed clay brick allowed a better penetration of the cement paste, thus increasing the bond strength, secondly, the lower particle density of crushed brick and crushed concrete compared to that of recycled concrete aggregate represented a higher volume of fine particles in the mixture when recycled concrete aggregate was replaced by either crushed clay brick or crushed concrete. The finer particles of crushed clay brick and crushed concrete may fill the voids and reduce the porosity at the interface. Hence, an enhancement in the properties of the ITZ was achieved**[24]**.

On the other hand, the splitting tensile strength of the mixes in which crushed building demolition was used was comparable to that of the control mix.

CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn:

1-For concrete mixtures prepared with the incorporation of recycled concrete aggregate only as a partial replacement of natural fine and coarse aggregate exhibited the highest compressive strength.

2-The concrete mixtures prepared with the incorporation a combination of recycled concrete aggregate and recycled brick aggregate as a partial replacement of fine or course natural aggregate seemed to impose the largest negative effect on the concrete strength than that mixes prepared with the incorporation of recycled concrete aggregate only as a partial replacement of fine or coarse natural aggregate.

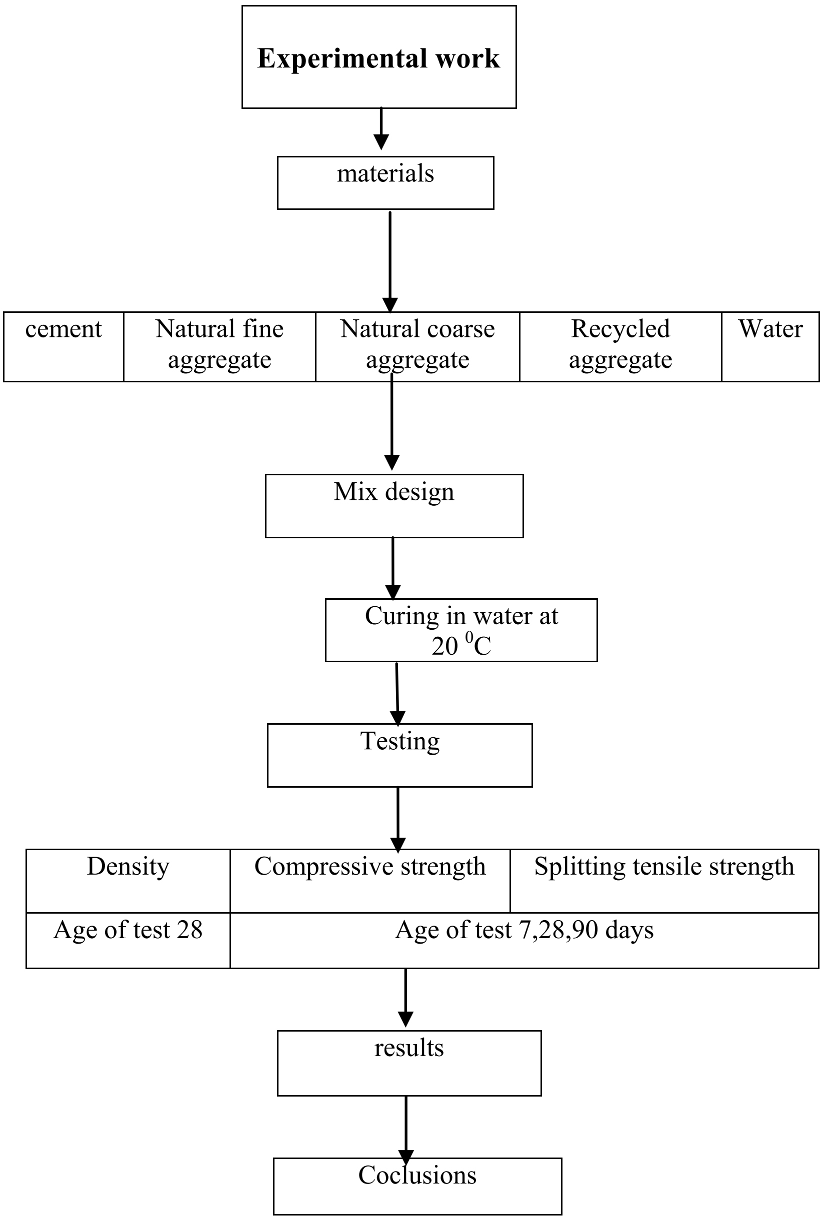
3-The use of crushed clay brick reduced the density of the new concrete.

4- The compressive and tensile strengths of the new concrete decreased as the crushed clay brick content increased.

5- Both compressive strength and tensile splitting strength not reduced with the increase of the replacement ratio; however،the values obtained for both properties are still acceptable, especially for reasonable levels of the replacement ratio (50%).

6- In conclusion, recycling waste concrete aggregate in concrete production may help solve a vital environmental issue.

Testing program



Table(1):Chemical composition and main compounds of the cement

Oxide composition	CaO	SiO_2	AlO_3	Fe_2O_3	MgO	SO3	L.O.I	I.R
Content (percent)	61.89	21.37	4.6	3.35	3.05	2.42	2.16	0.6
Main compounds	C_3S		C_2S		C_3A		C_4AF	
Content (percent)	46.88		26.17		6.53		10.18	

Table (2) :Physical properties of the cement

Physical properties	Specific surface area (m^2/kg) (Blain)	Soundness (mm) (Autoclave)	Setting time Initial setting (hrs:min)	Setting time final setting (hrs:min)	Compressive strength (Mpa)3days	Compressive strength (Mpa) 7days
Test results	321	0.5	1:55	2:24	23	29

Table (3): Grading and physical properties of fine aggregate.

Sieve size	Cumulative % passing	Limits of Iraqi specification NO. 45 /1984
4.75 mm	94	90-100
2.36 mm	90	85-100
1.18 mm	85	75-100
600 μm	65	60-79
300 μm	20	12-40
150 μm	3	0-10
Specifi gravity : 2.6 Sulfate content : 0.5% max 0.5 % Fineness modulus : 2.43		

Table (4): Grading and physical properties of coarse aggregate .

Sive size(mm)	Camulative % passing	Limits of Iraqi specifiction NO. 45 /1984
14	97.8	90-100
10	71.	50-85
5	8.7	0-10
2.36	0	0-5
Sulfate content : 0.041 % max 0.1% Specific gravity : 2.65 Dry density: 1630 kg/m3		

Table (5): Details of mixes used throughout this investigation

Mix No.		Composition								Series No.
		C	NS	NG	RCS	RCG	RBS	RBG	replacement ratio (% by weight)	
1	Mix1	-*	-	-					0%	control
2	Mix2	-	-	-		-			10%of NG	series 1 partial replacement of normal gravel
3	Mix3	-	-	-		-			20% of NG	
4	Mix4	-	-	-		-			30% of NG	
5	Mix5	-	-	-		-			50% of NG	
6	Mix6	-	-	-	-				10%of NS	series2 partial replacement of normal sand
7	Mix7	-	-	-	-				20% of NS	
8	Mix8	-	-	-	-				30% of NS	
9	Mix9	-	-	-	-				50% of NS	
10	Mix10	-	-	-		-		-	10%of NG	series 3 partial replacement of normal gravel
11	Mix11	-	-	-		-		-	20% of NG	
12	Mix12	-	-	-		-		-	30% of NG	
13	Mix13	-	-	-		-		-	50% of NG	
14	Mix14	-	-	-	-		-		10%of NS	series 4 partial replacement of normal sand
15	Mix15	-	-	-	-		-		20% of NS	
16	Mix16	-	-	-	-		-		30% of NS	
17	Mix17	-	-	-	-		-		50% of NS	
18	Mix18	-	-	-	-	-			10%of (NG+ NS)	series 5 partial replacement of normal (gravel+sand)
19	Mix19	-	-	-	-	-			20% of (NG+ NS)	
20	Mix20	-	-	-	-	-			30% of (NG+ NS)	
21	Mix21	-	-	-	-	-			50% of (NG+ NS)	
22	Mix22	-	-	-	-	-	-	-	10%of (NG+ NS)	series 6 partial replacement of normal (gravel+sand)
23	Mix23	-	-	-	-	-	-	-	20% of (NG+ NS)	
24	Mix24	-	-	-	-	-	-	-	30% of (NG+ NS)	
25	Mix25	-	-	-	-	-	-	-	50% of (NG+ NS)	

* :used in mix, blank:not used
Notation:
C =cement, NS =normal fine aggregate
NG = normal coarse aggregate RCS=recycled concrete sand(fine aggregate) RCG=recycled concrete gravel(coarse aggregate)
RBS= recycled brick sand(fine aggregate
RBG=recycled brick gravel(coarse aggregate)

Table(6) compressive strength for series 1
(with crushed concrete as a partial replacement of normal gravel)

	Compressive strength (MPa)			Density(Kg/M^3) (28 days)
Mix No	7 days	28 days	90 days	2322
1	16.8	22.6	23.1	2334
2	13.2	21.8	22.1	2365
3	14.3	23.2	24	2353

4	15.5	24.2	25.2	2361
5	14.8	24.4	25.1	2372

Table (7) compressive strength for series 2
(with RCG as a partial replacement of normal sand)

	Compressive strength (MPa)			Density(Kg/M^3) (28 days)
Mix No	7 days	28 days	90 days	2322
1	16.8	22.6	23.1	2324
6	12.6	20.5	21.1	2315
7	11.4	22.3	23.2	2298
8	13.9	22.1	24.8	2290
9	14	21	23.6	2285

Table (8) compressive strength for series 3
(with {RCG +RBG} as a partial replacement of normal gravel)

	Compressive strength (MPa)			Density(Kg/M^3) (28 days)
Mix No	7 days	28 days	90 days	2322
1	16.8	22.6	23.1	2320
10	10.7	16.4	16.8	2333
11	10.8	17	17.3	2339
12	11.1	17.9	18.4	2350
13	10.5	16.8	16.9	2352

Table (9) compressive strength for series 4
(with {RCG +RBG} as a partial replacement of normal sand)

	Compressive strength (MPa)			Density(Kg/M^3) (28 days)
Mix No	7 days	28 days	90 days	2322
1	16.8	22.6	23.1	2311
14	9.9	16	16.1	2335
15	10.1	16.4	16.7	2322
16	10.5	16.9	17.1	2341
17	10.4	16.2	16.3	2333

Table (10) compressive strength for series 5
(with RCG as a partial replacement of normal gravel+sand)

	Compressive strength (MPa)			Density(Kg/M^3) (28 days)
Mix No	7 days	28 days	90 days	2322
1	16.8	22.6	23.1	2324
18	17.2	22.9	23.8	2345
19	18.7	25.9	26	2358
20	18.9	30.9	30.8	2365
21	19.2	31	31.1	2371

Table(11) compressive strength for series 6
(with {RCG+RBG}as a partial replacement of normal {sand+gravel})

	Compressive strength (MPa)			Density(Kg/M^3) (28 days)
Mix No	7 days	28 days	90 days	2322
1	16.8	22.6	23.1	2315
22	15.8	22.5	22.8	2322
23	17.5	24.3	24.4	2310
24	17.9	26.1	26.5	2298
25	18.5	27.5	27.2	2290

Table(12) splitting tensile strength for series 1
(with RCG as a partial replacement of normal gravel)

	splitting tensile strength (MPa)		
Mix No	7 days	28 days	90 days
1	0.9	1.9	2.2
2	.8	2.1	2.2
3	1.1	2.3	2.4
4	1.2	2.4	2.4
5	1.2	2.4	2.5

Table(13) splitting tensile strength for series 2
(with RCG as a partial replacement of normal sand)

	splitting tensile strength (MPa)		
Mix No	7 days	28 days	90 days
1	0.9	1.9	2.2
6	.9	2	2.1
7	1.1	2.3	2.2
8	1.3	2.2	2.2
9	1.2	2.3	2.3

Table(14) splitting tensile strength for series 3
(with {RCG +RBG} as a partial replacement of normal gravel)

	splitting tensile strength (MPa)		
Mix No	7 days	28 days	90 days
1	0.9	1.9	2.2
10	1.1	1.4	1.6
11	1.3	1.7	1.7
12	1.1	1.7	1.6
13	1.5	1.8	1.9

Table(15) splitting tensile strength for series 4
(with {RCG +RBG} as a partial replacement of normal sand)

	splitting tensile strength (MPa)		
Mix No	7 days	28 days	90 days
1	0.9	1.9	2.2
14	.7	1.6	1.5
15	.8	1.5	1.7

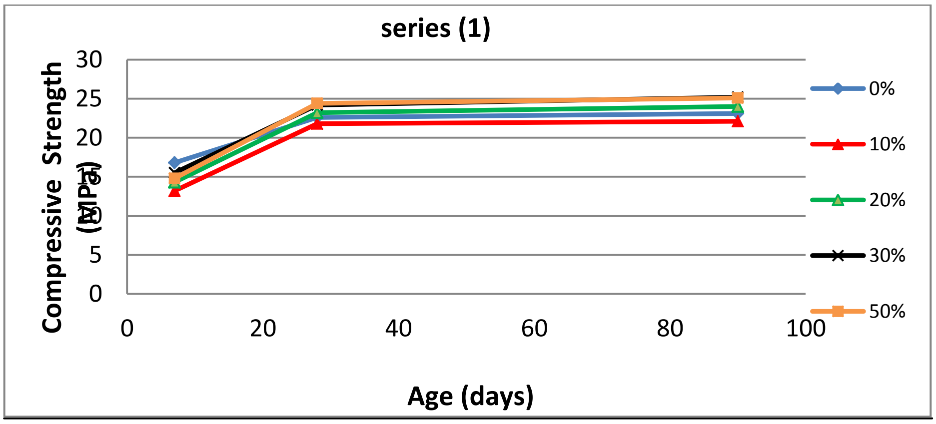
16	.8	1.7	1.7
17	.9	1.8	1.8

Table(16) splitting tensile e strength for series 5
(with RCG as a partial replacement of normal gravel+sand)

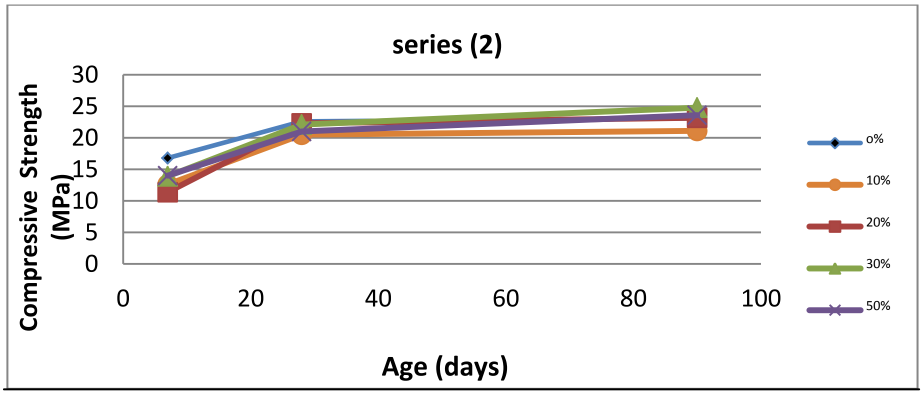
	splitting tensile strength (MPa)		
Mix No	7 days	28 days	90 days
1	0.9	1.9	2.2
18	1.1	2.2	2.5
19	1.3	2.5	2.6
20	1.8	3.1	3.2
21	1.9	3.1	3.3

Table(17) splitting tensile strength for series 6(with {RCG+RBG} as a partial replacement of normal {sand+gravel})

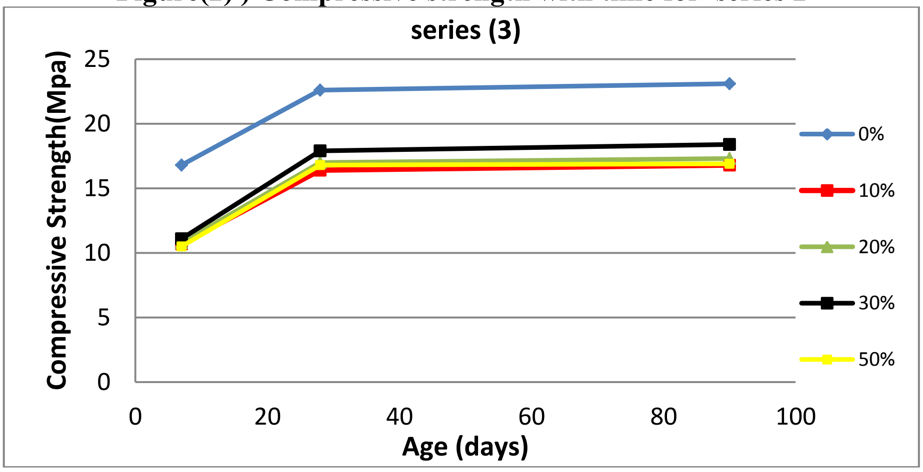
	splitting tensile strength (MPa)		
Mix No	7 days	28 days	90 days
1	0.9	1.9	2.2
22	1.1	2.2	2.2
23	1.3	2.3	2.4
24	1.2	2.3	2.5
25	1.5	2.7	2.6



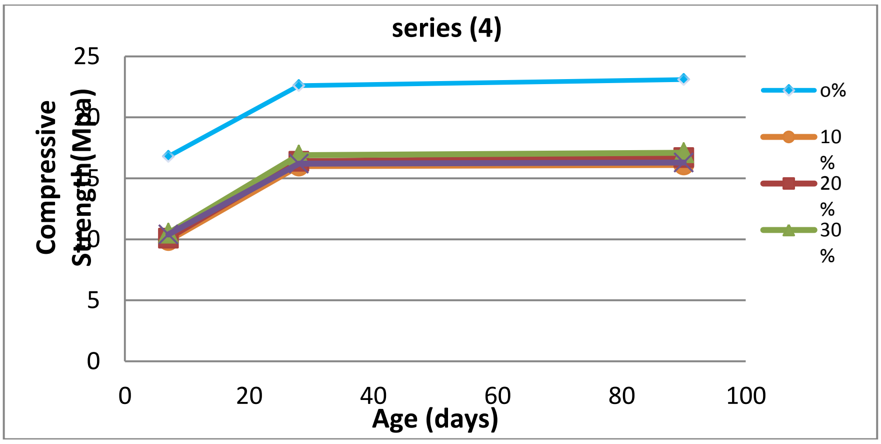
Figure(1) Compressive strength with time for series 1



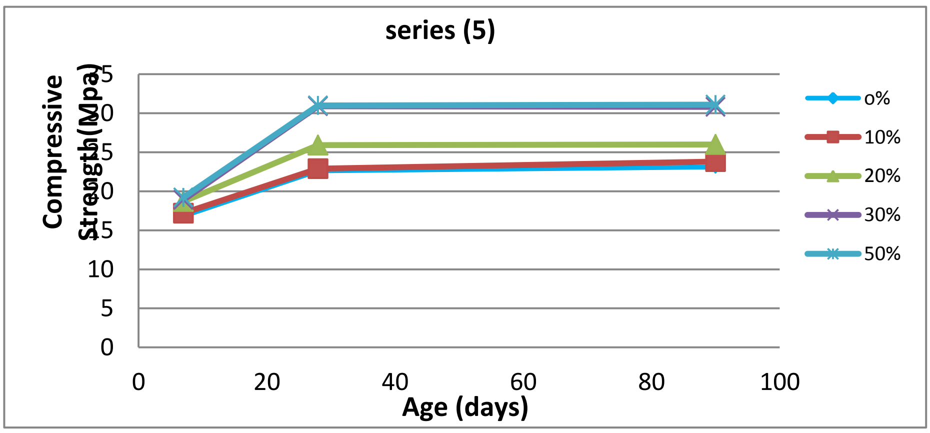
Figure(2)) Compressive strength with time for series 2



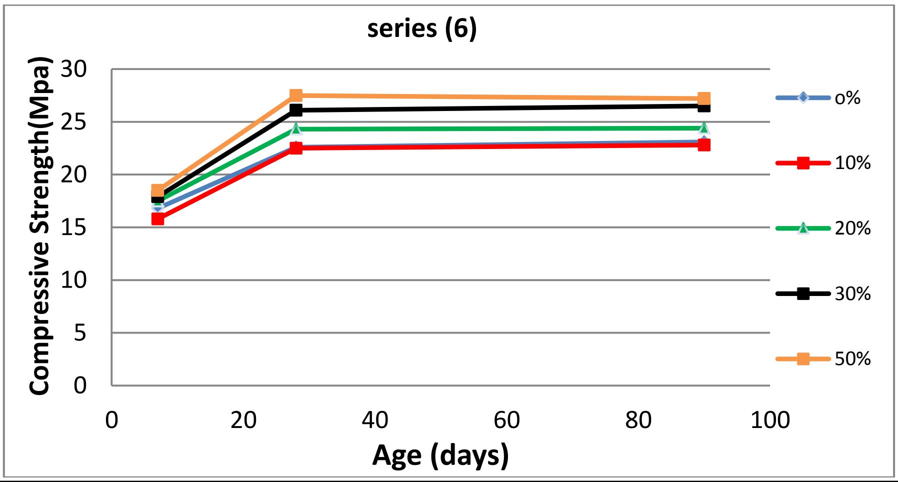
Figure(3)) Compressive strength with time for series 3



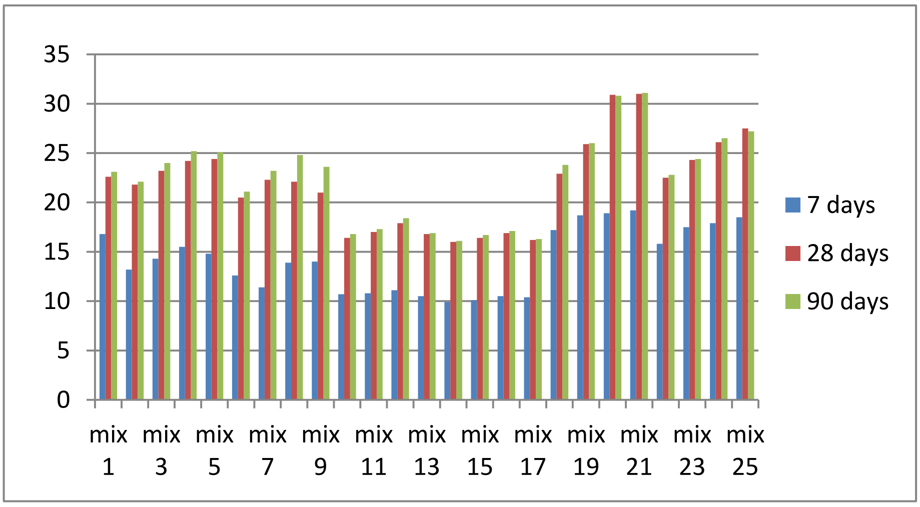
Figure(4)) Compressive strength with time for series 4



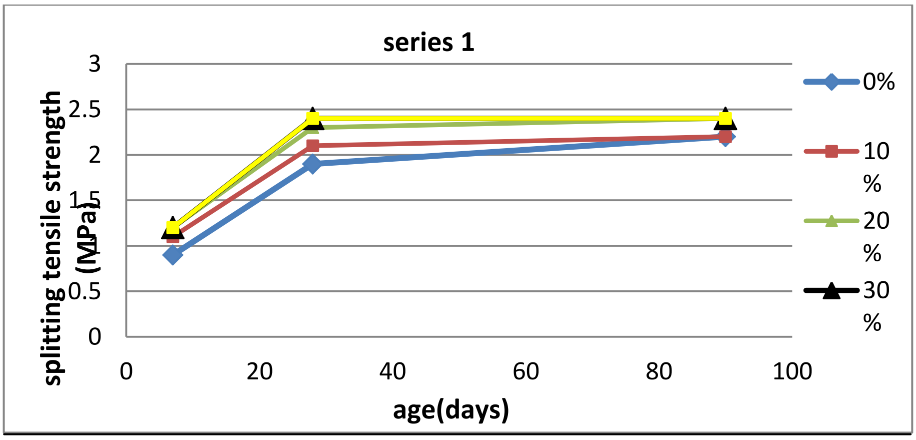
Figure(5)) Compressive strength with time for series 5



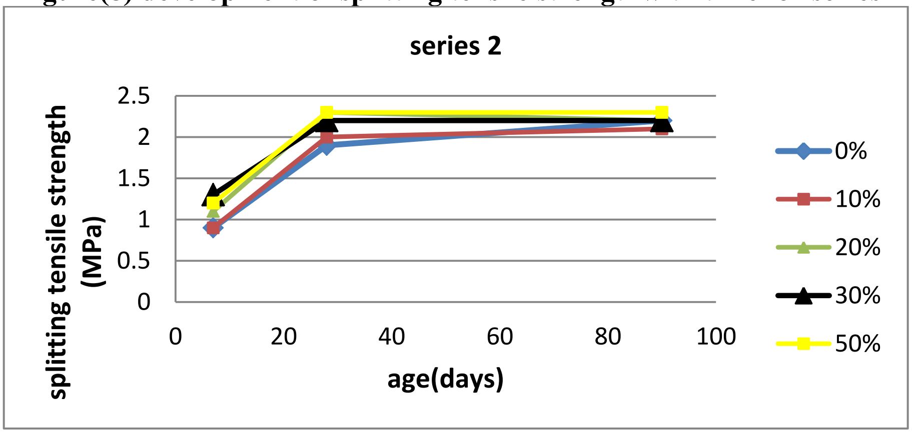
Figure(6)) Compressive strength with time for series 6



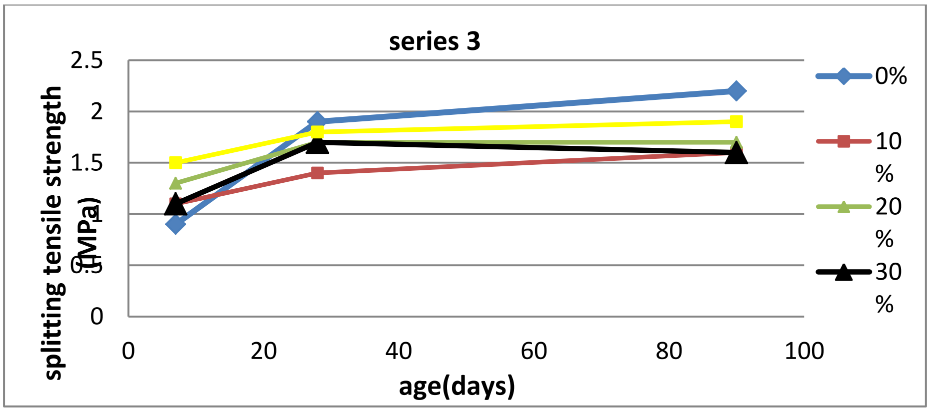
Figure(7) compressive strength with time for all mixes



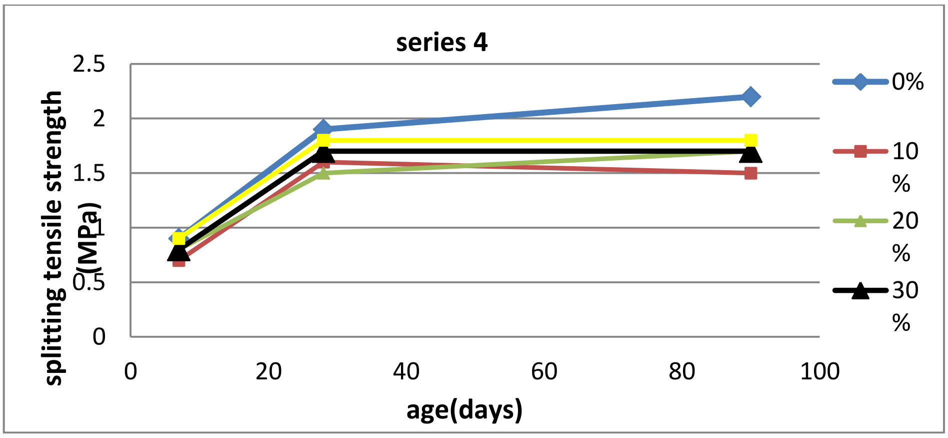
Figure(8) development of splitting tensile strengthwith time for series1



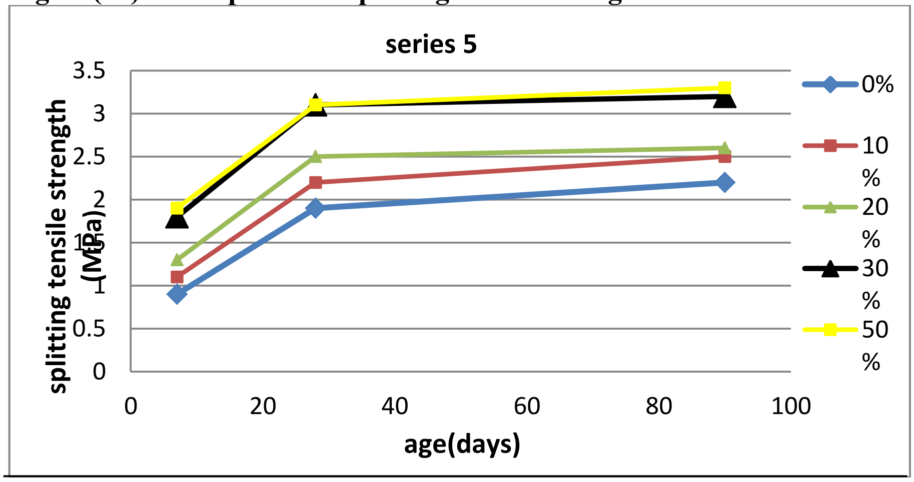
Figure(9) development of splitting tensile strength with time for series2



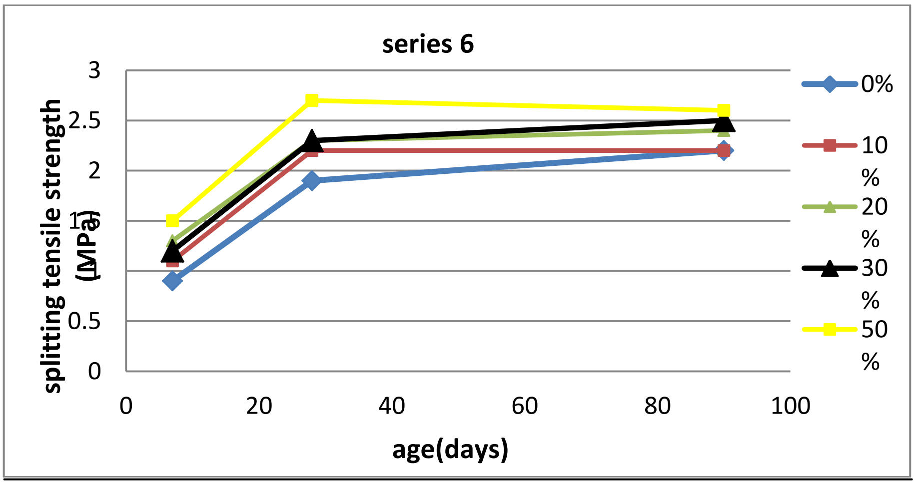
Figure(10) development of splitting tensile strength with time for series3



Figure(11) development of splitting tensile strength with time for series4



Figure(12)development of splitting tensile strength with time for series5



Figure(13) development of splitting tensile strength with time for series 6

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