Kufa Journal of Engineering
Vol. 8, No. 3, October 2017, P.P. 128-141
Received 5 February 2017, accepted 14 March 2017

ULTRA-HIGH PERFORMANCE REINFORCED BY POLYPROPYLENE FIBER CONCRETE MADE WITH RECYCLED COARSE AGGREGATE

Laith A. Ahmed[1], Shatha S. Hassan[2] and Osama A. Al-Ameer[3]

[1] **Building Materials Engineering Branch, Department of Building and Construction Engineering, University of Technology. Email: laith_almaki@yahoo.com**

[2] **Asst. Prof., Department of Building and Construction Engineering, University of Technology.**

[3] **lecturer, Department of Building and Construction Engineering, University of Technology.**

ABSTRACT

Preserve natural environmental resources and losing of land used as a graveyard for demolition waste concrete buildings, recycling concrete aggregate is one of the green sustainability practices and keep the land and reduce material losses. Investigation on mechanical properties of high performance concrete with polypropylene fiber reinforced. Coarse recycled concrete aggregate was replaced by natural coarse aggregate in three percent 25%, 50%, and 75%. Mechanical properties of high performance concrete are made from replacing natural coarse aggregate by 25% of recycled coarse aggregate, is considered the best among the other replacement ratios compared with the mixture of reference with slight reduction in compression strength by 8%, splitting tensile strength 8%, flexural strength by 9%, with increased total absorption by 4%, and no water under pressure permeable to the concrete specimen. In this study found that it can produce ultra-high performance fiber reinforced concrete using recycled concrete aggregate with high workability and low cement/water.

KEYWORDS: coarse normal aggregate, fine normal aggregate, ultra-high performance concrete, compressive strength, coarse recycled aggregate.

الخرسانة فائقة الأداء المسلحة بألياف البوليبروبلين المنتجة من ركام الخرسانة الخشن المعاد تدويرها

ليث عبد القادر احمد **شذى حسن** **اسامة الامير**

قسم هندسة البناء والانشاءات، الجامعة التكنلوجية

الخلاصة

للحفاظ على الموارد البيئية الطبيعية وعدم ضياع المزيد من الأراضي نتيجة أستخدامها كمدافن لنفايات هدم الأبنية الخرسانية, فأن احد ممارسات الأستدامة الخضراء ولتقليل الخسائر المادية, هي أعادة أستخدام هذه النفايات الخرسانية كركام لأنتاج خرسانة جديدة. في هذا التحقيق تم العمل على دراسة الخواص الميكانيكية للخرسانة فائقة الأداء والمسلحة بالياف البوليبروبلين من خلال أستبدال الركام الخشن الطبيعي بركام خرسانة خشن معاد تدويرها وبثلاث نسب 25%، 50%، و 75%. الخواص الميكانيكية للخرسانة فائقة الأداء المنتجة من أستبدال الركام الخشن الطبيعي بركام خشن معاد تدويره وبنسبة 25%,أظهرت نتائج أفضل النتائج من نسب الأستبدال الأخرى وبأنخفاض طفيف مقارنة مع الخلطة المرجعية, حيث أن قوة الأنضغاط أنخفضت بنسبة 8%، قوة الشد بنسبة 8%، وقوة معامل التمزق بنسبة 9%، مع زيادة الأمتصاص الكلي بنسبة 4%، والخرسانة عديمة النفاذية للماء المسلط تحت الضغط. في هذه الدراسة تم التوصل الى أنتاج خرسانة مسلحة بالألياف فائقة الأداء وبأستخدام ركام خرسانة معاد تدرويرها مع قابلية تشغيل عالية وبنسبة ماء\سمنت منخفضة.

1. INTRODUCTION

The newly world draws attention to the environment and the trend towards sustainable development, the need for concrete recycling and waste from demolitions to accomplish this goal, which will reduce the cost of producing concrete and other goals, like landfill cost reducing, and the cost of transporting the materials. And as a result of increased world research recycling and use of crushed concrete and demolished, as reviewed by Hansen (1986), and followed by several international conferences such as Denmark and London Conference that led to the use of recycled concrete in several projects in different countries (Newman & Choo, 2003). Recycling concrete is to balance the consumption of natural resources to ensure the sustainability of the industry, and also to improve and develop products and additives that make recycled material more acceptable and a desire among consumers (Chisholm, 2011). The need to develop specifications for recycled materials to be used for total concrete is an important step forward in enhancing confidence for products manufactured from these materials, with continued reliance on natural sources of construction materials as an important part of strengthening demand for these materials (Bickley, 2001).

2. EXPERIMENTAL WORK

2.1. Materials

For all specimens, the mixes constituents were cement, water, PP fibers, natural fine, and coarse aggregate. Water it will be used potable water of Baghdad in mixing and curing samples. A high-range water reducing admixture (HRWRA). Sika Viscocrete-5930 produced by sika Company, satisfying the (ASTM C494/494M, 2004). For mineral Admixture, silica fume (SF) used through this study was MS610 which produced by BASF's company. High performance monofilament polypropylene fibers made by sika company were used in this investigation.

2.1.1. Cement

Ordinary Portland cement (Type I) manufactured by United Cement Company commercially known (KARASTA) was used. The test result showed that this cement conforms to the Iraqi Specification (Iraqi standard 5, 1984).

2.1.2. Natural aggregate

Al- Ukaider natural sand of 4.75 mm max. size (zone 2) was used as a fine aggregate. The sand grading, Fig. 1, and the sulfate content are within the requirements of the Iraqi Specification No.45/1984. Crushed gravel of nominal maximum sizes 10 mm was used as a coarse aggregate.

It was brought from *Al- Nebai quarry* region. The used coarse aggregate conforms the grading (Fig. 1) and requirements of Iraqi Specification, Table 1 (Iraqi standard 45, 1984).

2.1.3. Recycled concrete aggregate

It has been used recycled aggregate crushed from various 20-year-old demolition conventional concrete removed building, is crushed and processed into various size fractions according to Iraqi standards for aggregate. Reinforcing steel and other embedded items, if any, has been removed and care must be taken to prevent contamination by dirt or other waste building materials such as plaster or gypsum. To product high-performance concrete throughout the study in this research. Records of the history of the demolition concrete (strength, mix designs etc.) would seldom be available, but if available these will be useful in determining the potential of the recycled aggregate concrete. The recycled concrete aggregates stored at or slightly above SSD moisture state for at least 24 hours before using in mixture.

Table 1. Properties of natural and recycled aggregate.

Properties	CNA	CRA	FNA
Sulphate content	0.080%	0.09%	0.103
Dry specific gravity(OD)	2.66	2.60	2.52
Relative specific gravity(SSD)	2.68	2.62	2.60
Apparent specific gravity	2.71	2.67	2.73
Absorption%	0.71%	1.11%	3.1%

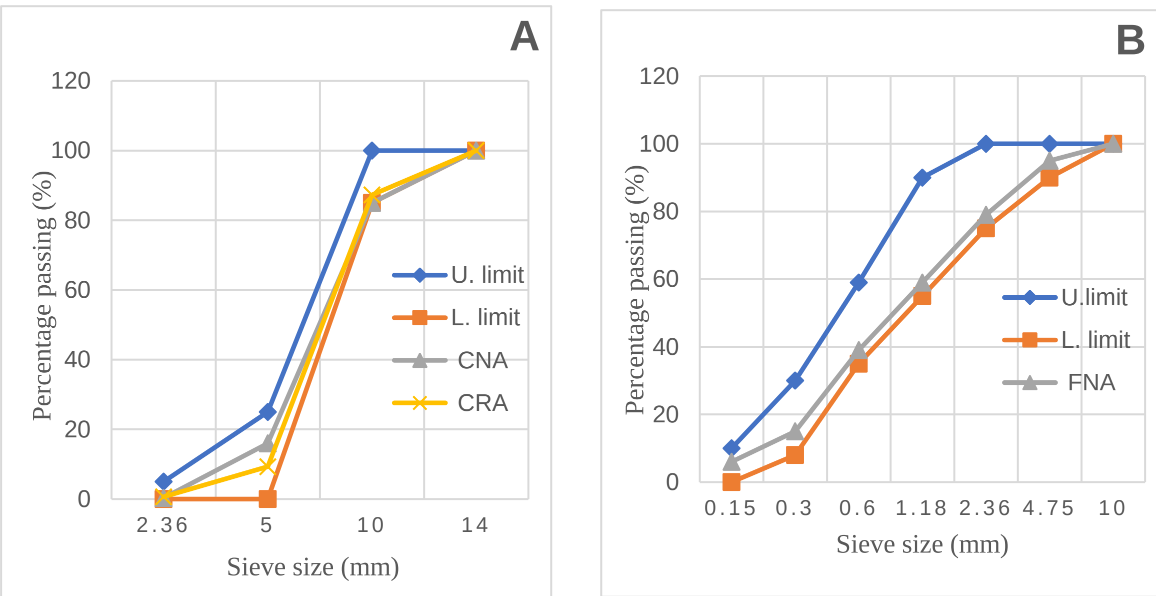

Fig. 1. Sieve analyses (A) for coarse aggregate, (B) for fine aggregate.

2.2. Mix proportion

For all concrete mixes, proportion for material content are constant. The only variable in all mixtures was the content of recycled aggregate replacement, as it shown in Table 2.

Table 2. Mix proportion for all mixes.

Mixes symbol	Cement, kg	NFA, kg	NCA, kg	CRA, kg	SP, %	SF, %	PPF, %	Slump, mm	Water content, L	w/c
reference	528	640	960	---	1.3	15	0.9	190	137.3	0.26
Mca1	528	640	720	240	1.3	15	0.9	185	137.3	0.26
Mca2	528	640	480	480	1.3	15	0.9	180	137.3	0.26
Mca3	528	640	240	720	1.3	15	0.9	170	137.3	0.26

2.3. Curing

After initial 24 hours curing period, from the end of the casting process, the samples are demolded and transferred into basin containing lime-saturated water. And keep the molds in this basin until the specified testing date at 7, 14, 28, 56, 90 days.

2.4. Tests

All tests were determined according to the methods as shown in Table 3.

Table 3. Tests methods in this study.

Test	Test method
Slump test	ASTM C-143/C143M-03
Fresh density	ASTM C 138M-01
Compressive Strength test	BS 1881: part 116, 1989
Splitting Tensile Strength test	ASTM C 496/C 496M – 04
Flexural Strength test	ASTM C78-03
Total Absorption Test	ASTM C642-03
Depth of Permeability of Water under Pressure Test	British Standard EN12390-8:2009

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Workability

The workability will have affected by replacing natural aggregate concrete (NAC) with recycled concrete aggregate (RCA). The physical and mechanical properties for recycled concrete aggregate (RCA) have significant role on concrete workability, due to adhered mortar on aggregate partials.

The results in Table 2, shows that the workability for mixes (Mca1, Mca2 and Mca3) that contained (0.25%, 0.50%, and 0.75%) replacement percent respectively of coarse recycled aggregate (CRA) by weight of coarse normal aggregate (CNA) is slightly affected compared with reference fiber high performance concrete (FHPC) (reference). Also, the results show that Mca1 had 3% reduction in slump value, while Mca2 and Mca3 had 5% and 11% reduction in slump value respectively.

The addition of coarse recycled aggregate (CRA) as a replacement of coarse normal aggregate (CNA) in mixture will reduced the workability due the physical and mechanical properties of the recycled concrete aggregate (RCA). The adhered mortar increased the porosity of the RCA, and reducing workability by increasing demand on water. Farther more, the surface texture for RCA more angularity and this will reduce the workability (ACI 555, 2001) and (Gomez-Soberon , 2002). The reduction in workability in this study had little variation in value due to low w/c ratio and in acceptable limit (less than 25 mm).

3.2. Specific gravity

Recycled concrete aggregate (RCA) always contain an adhered mortar, and the amount of the adhered mortar depending on the crushing method, nominal size of aggregate required, etc. and the adhered mortar affected on the specific gravity of the aggregate and reducing the density of aggregate (Mokhtarzadeh, 2000) and (Duggal, 2008). The bulk specific gravity reduced for coarse recycled aggregate (CRA) comparable with coarse normal aggregate (CNA) was 2%. The reduction in specific gravity in CRA due to the absorption ability for water. The ability absorption for CRA to the water was 56% higher than CAN, as shown in Table 1.

3.3. Density of fresh and hardened RAC concrete

Recycled aggregate concrete (RCA) containing adhered mortar with any amount, must be more porosity than normal aggregate. For same nominal size, present adhered mortar in recycled concrete aggregate (RCA) will reduced bulk specific gravity and will reduced density of unit weight comparable with natural aggregate (NA). Fresh unit weight and hardened unit weight will have lowered proportionally with increasing the proportion of RCA. Increasing recycled concrete aggregate volume in mixture will reduced fresh unit weight and bulk density as approved by others (Buyle-Bodin & Hadjieva-Zaharieva, 2002).

The concrete made by coarse recycled aggregate (CRA) as 25%, 50%, and 75% replacement by weight of coarse normal aggregate (CNA) in mixes Mca1, Mca2, and Mca3 respectively, had same reduction in fresh density about 1% comparable to reference mix except mix Mca1 had no reduction in fresh density. But in hardened concrete the density for these three mixes had a reduction equal to 1% comparable to reference mix as shown in Table 4.

Table 4. Densities for mixes.

Mix symbol	Fresh density, kg/m^3	Hardened density @28d, kg/m^3
Reference	2468	2453
Mca1	2466	2434
Mca2	2441	2434
Mca3	2440	2431
Mfa1	2391	2380

3.4. Compressive strength

There is a reduction in compressive strength when coarse recycled aggregate (CRA) replaced instead of coarse natural aggregate (CNA) compared with reference mix. Because CRA had large surface area due to adhered mortar more than CNA, also more pores, more absorb ability, and more microcracks in old adhered mortar as a recycled aggregate. These reasons will weekend the new interfacial transition zone (ITZ) (Shetty, 2005) and (Hansen & Narud , 1986). Small actual nominal size of aggregate had more demand for water, and more absorbed water on particles surface for CRA. Thus, made CRA more demand for water and this ability lead to lowering ITZ density, and more reduction in compressive strength (Hansen & Narud , 1986). High strength in three mixes indicate to causality between presence of pores in adhered mortar and quality of RCA, interface zone between old aggregate and new paste illustrates high bonding, (Vaishali & Ghorpade, 2013) and (Poon, et al., 2004). As its shown in Fig. 2.

The proportion of reduction increased with increasing replacement percent in mix proportion. Therefore, mix Mca1 with replacement of coarse recycled aggregate (CRA) proportion (25%) had less reduction in strength with average percent 12%. And Mca2 which contained (50%)

CRA replacement had average reduction about 23%. While mix Mca3 with 75% CRA replacement proportion had highest average reduction in compressive strength about 27%.

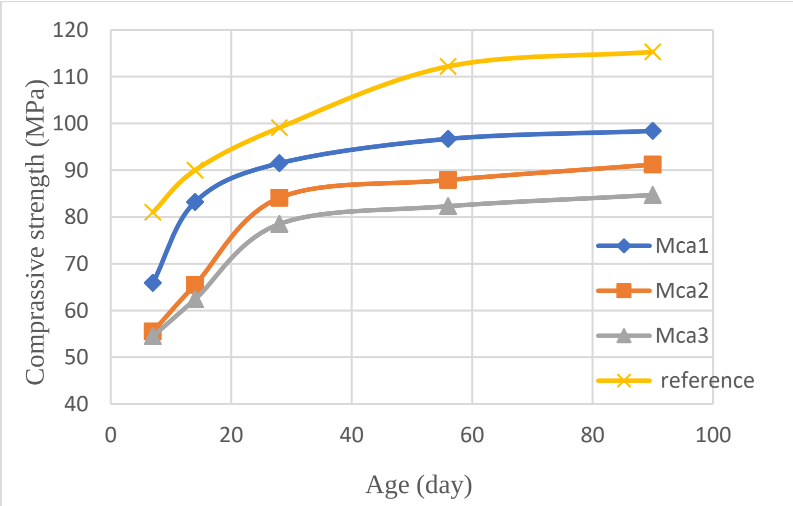

Fig. 2. Compressive strength for all mixes with age.

Table 5. Compressive strength and slump value.

Mix symbol	Compressive strength, MPa					Slump, mm
	7 d	14 d	28 d	56 d	90 d	
reference	81	90	99.1	112.2	115.3	---
Mca1	65.9	83.2	91.5	96.7	98.4	-5%
Mca2	55.5	65.5	84.1	87.9	91.2	-11%
Mca3	54.5	62.4	78.5	82.3	84.7	-13%

3.5. Splitting strength

Replacing 25% coarse aggregate recycled concrete aggregate mixture (Mca1) showed highest splitting strength comparable with other replacement mixes, due to low replacement percent for Coarse recycled aggregate (CRA) with coarse normal aggregate (CNA) in mixture. Thus, Fig. 3, indicated to reduction in splitting strength of replacement CRA mixtures in this study compared with reference mix.

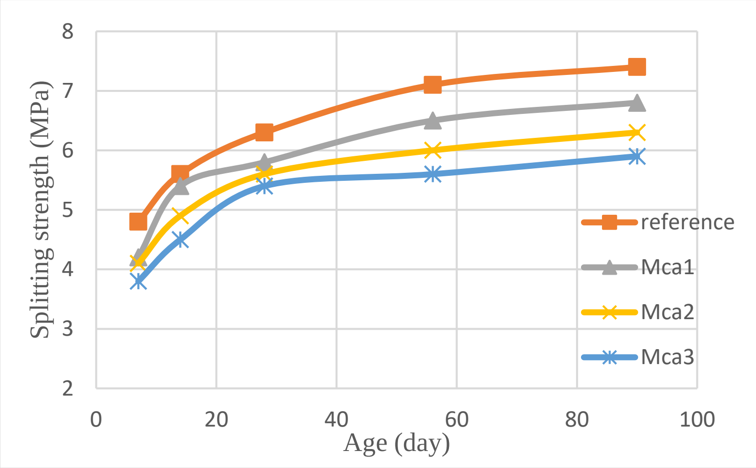

Fig. 3. Splitting strength with age for reference mix and CRA mixtures replacement.

The results illustrate with increasing coarse recycled aggregate (CRA) replacement percent causes lowering tension strength comparable with their reference. Splitting strength at 7-day have a reduction 13%, 4% at 14-days, 8% for 28-day, 8% at 56-day, 8% at 90-days compared to the reference FHPC specimens. Adding polypropylene fiber (PPF) in mixture, and lowering water/ cement ratio will be increased splitting strength for fiber high performance concrete (FHPC). Replacing 25% coarse aggregate recycled concrete aggregate mixture (Mca1) showed highest splitting strength comparable with other replacement mixes, due to low replacement percent for Coarse recycled aggregate (CRA) with coarse normal aggregate (CNA) in mixture.

Table 6. Splitting tensile strength value

Mix symbol	Splitting strength, MPa				
	7 d	14 d	28 d	56 d	90 d
reference	4.8	5.6	6.3	7.1	7.4
Mca1	4.2	5.4	5.8	6.5	6.8
Mca2	4.1	4.9	5.6	6	6.3
Mca3	3.8	4.5	5.4	5.6	5.9

3.6. Flexural strength

In CRA mixture, flexural strength (modulus of rupture) had increased with time but still had reduction in flexural strength compared with reference mixture. Flexural strength for mix Mca1 had a reduction about 17.4% for 7 days, 7.3% for 14-day, 9.3% for 28-days, and 13.8% for 56-day respectively and it shows a slight reduction in modulus of rupture compared with their reference. The slight lowering behavior in flexural strength due to physical and mechanical properties for CRA. Several factors affect the strength or weakness of interface zone between the cement paste and the aggregates, the most important of these factors is the ratio of water/cement. When water is added to the concrete mixture the water will form a water film around the particles of aggregates, cement/water ratio in this area more than twice the rate in cement paste, this increase water amount lead to increase the pores and therefore the interface zone will be weakest and increase its tendency to crack.

Fig. 4 shows that Mca1 had high flexural strength, due to the size and quantity of pores in recycled aggregate and therefore its strength significantly depends on the amount of adhered mortar. So, the use of recycled coarse aggregate lead to produce weaker concrete comparable with reference concrete (Topcu, 1995).

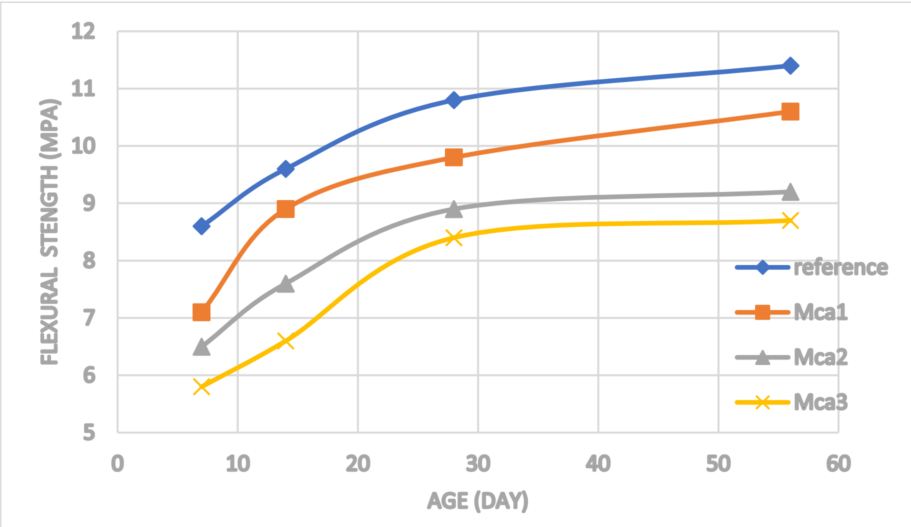

Fig. 4. Modules of rapture with age for all mixes.

3.7. Total absorption

Table 6, shows the percentages of increasing the water absorption at test ages 28 day was (16.4%) for mix Mca1 compared with reference mix. While, the water absorption at test ages 56 day are (37.3%) for mix Mca1 compared with reference mix. Since pore size and pore connectivity decreased with decreasing the w/c ratio, decrease of water absorption was observed with reducing of w/c ratio. In other words, low w/c ratio concretes will be reduced capillary pore volume with disconnected pores which results in low water absorption, Fig. 5 (Vaishali & Ghorpade, 2013) and (Shahroodi , 2010).

Table 7. Total water absorption.

Mix symbol	Oven dry weight, (gm)	Saturated surface dry weight, (gm)	Total Absorption, (%)	Oven dry weight, (gm)	Saturated surface dry weight, (gm)	Total Absorption, (%)
	28 day			56 day		
Reference	2423	2515.6	3.8	2464.5	2487.6	0.9
Mca1	2370	2475.4	4.4	2409.5	2440.5	1.3
Mca2	2362	2470	4.6	2390	2435	1.9
Mca3	2338	2456	5.0	2375	2430	2.3

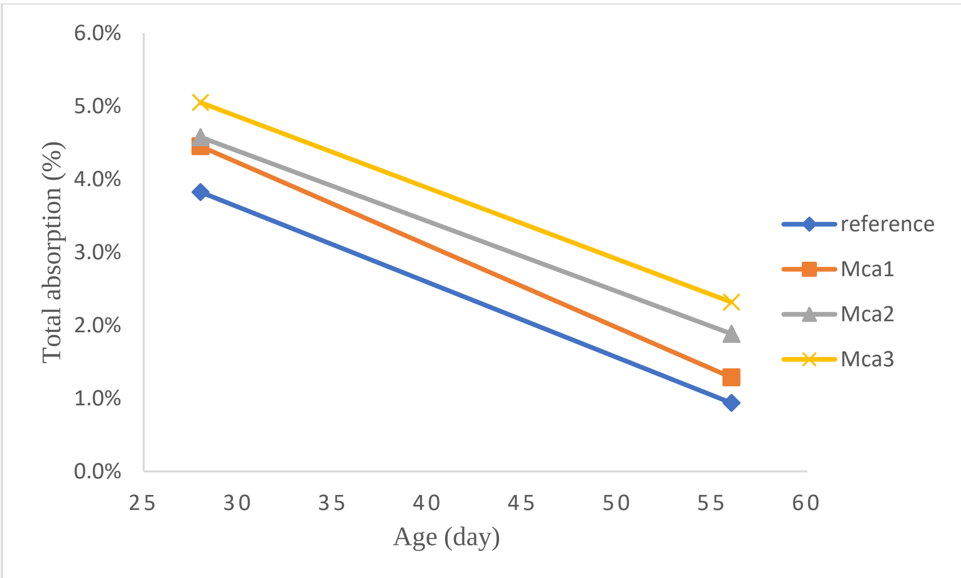

Fig. 5. Relationship between total water absorption and age.

3.8. Depth of water permeability under pressure

This test was performed according to the British Standard (BS. EN. 12390-8, 2009), water permeability depth (WPD) at the ages of 28-days of both reference and optimum mixture with coarse recycled aggregate (CRA) replacement mix (Mca1). Water was applied to one face of concrete specimen under water pressure of (500 ± 50) KPa for (72 ± 2) hour. Mix (Mca1) specimens value under this test is equal to 2mm, Fig. 6. This may be due to fact the filler affects pozzolanic reaction and heterogeneous nucleation particles, and disconnected pores chain which have substantially reduced the permeability of the concrete (Zain, et al., 2000). It must not be overlooked that cure conditions and mineral additives used in the mix have a significant impact in determining permeability in concrete produced (Tavakoli & Soroushian, 1996) and (Topcu, 1997).

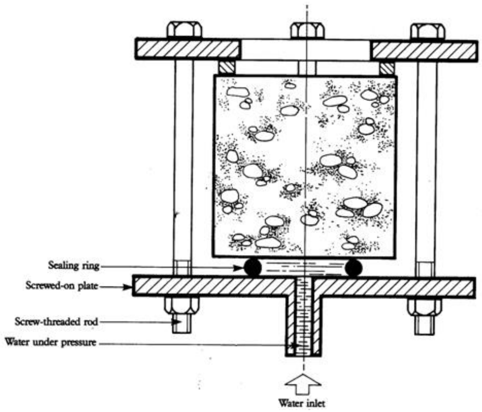

Fig. 6. Test arrangement device.

4. CONCLUSIONS

1. Using recycled concrete aggregate as a coarse recycled concrete aggregate alternative partial replacement with coarse natural aggregate had slightly effect on workability for FHPC.
2. The replacement of the portion of recycled aggregate by the total natural aggregate had slightly negative impact on compressive strength of the reference concrete mixture. And the best combination with the nearest compressive strength value (at 28 days' age at test) to the reference mix strength, and decreased by 8%, was percent 25% replacement ratio of coarse recycled aggregate concrete.
3. Recycled aggregate bulk density was less than the bulk density of natural aggregates, this is because the adhered cement slurry on recycled aggregates granules.
4. The fresh and hardened density had decreases in FHPC when produced with recycled concrete aggregate, and the reduction increased with increasing the amount of recycled concrete aggregate. Fiber high-performance concrete produced from coarse recycled concrete aggregate had reduction 1% for both densities in optimum mix.
5. Fiber high performance concrete (FHPC) specimens containing Coarse recycled aggregate (CRA) by weight of coarse normal aggregate (CNA) had a reduction in splitting tensile strength. For three replacement of CRA the proportion 25% was the highest splitting tensile strength value with reduction about 8% at age 28 day compared with their reference.

6. Flexural strength had increased with time for all replacement mixture like conventional mixture, but all replacement mixes had reduction in flexural strength compared with their reference mixture. For optimum CRA replacement (with 25% proportion) had a reduction about 9% for 28-day age.
7. The total absorption of various types of concrete mixes had reduced in the total absorption values with progressive curing in water at 28, and 56-day age. Generally, the absorption will be reduced with progressive curing for all mixes, but the variation between CRA concrete mix will be had increased comparing with reference mix.
8. The results obtained from water permeability depth (WPD) test at the ages of 28-days of both reference and optimum mixture with coarse recycled aggregate (CRA) replacement mix, that the mixture had no water permeability under pressure. Thus, the RCA replacement had no negative effect on water permeability under pressure.

5. REFERENCES

Buyle-Bodin, F. & Hadjieva-Zaharieva, R., 2002. Influence of industrially produced recycled aggregates on flow properties of concrete. *Materials and Structures,* Volume 35, pp. 503-509.

Gomez-Soberon , J. V., 2002. Porosity of recycled concrete with substitution of recycled concrete aggregate. *Cement and Concrete research,* Volume 32, pp. 1301-1311.

ACI 555, 2001. *Removal and reuse of hardened concrete,* s.l.: committee 555.

ASTM C494/494M, 2004. *Standard Specification for Chemical Admixtures for Concrete.* s.l., American Society for Testing and Materials.

Bickley, J. A. a. F. R., 2001. *Optimizing the Economics of High-Performance Concrete.* Ottawa, Ontario: Cement Associatio of Canada.

BS. EN. 12390-8, 2009. *Depth of Penetration of Water Under Pressure,* s.l.: British Standard, European Standard.

Chisholm, D., 2011. *Best Prastice Guid for the use of Recycled Aggregate in New Concrete,* New Zealand: Cement & Concrete Association of New Zealand (CCANZ).

Duggal, S. K., 2008. *Building Materials.* s.l.:New Age International (P) Ltd..

Hansen , C. T. & Narud , H., 1986. Strength of recycled concrete made from crushed concrete coarse aggregate. *Materials and structure,* 1(No.111).

Iraqi standared 45, 1984. *aggregate of natural resources use in concrete and construction.* s.l., Central Organization for Standardization and Quality Control.

Iraqi standared 5, 1984. *Portland cement.* s.l., Central Organization for Standardization and Quality Control.

Mokhtarzadeh, A. &. F. C., 2000. Mechanical properties of high strength concrete with consideration for precast applications. *Materials Journal,* 97(2), pp. 136-148.

Newman, J. & Choo, B. S., 2003. *advancced concrete technology processes.* London: Elsevier Ltd.

Poon, C. S., Shi, Z. H. & Lam, L., 2004. *Effect of Microstructure of ITZ on compressive strength of concrete prepared with recycled aggregate,* s.l.: Construction and Building Materials.

Shahroodi , A., 2010. *Development of Test Methods for Assessment of Concrete Durability for Use in Performance-Based Specifications.* [Online] Available at: https://tspace.library.utoronto.ca/handle [Accessed 11 Jan 2011].

Shetty, M. S., 2005. *Concrete Technology Theory and Practice.* s.l.:Chand and Company Ltd..

Tavakoli, M. & Soroushian, P., 1996. Strength of recycled aggregate concrete made using fielddemolished concrete as aggregate. *ACI Materials Journal,* pp. 182-190.

Topcu, I. B., 1997. Physical and mechanical properties of concretes produced with waste concrete. *Cement and concrete research,* 27(No.12), pp. 1815-1824.

Topcu, L., 1995. Using waste concrete as aggregate. *Cement and concrete research* , 25(7), pp. 1384-1396.

Vaishali, G. & Ghorpade, 2013. Effect of recycled coarse aggregate on workability and shear strength of fiber reinforced high strength concrete. *International Journal of Innovative Research in Science,* 2 (8).

Zain, M. M., Safiuddin , M. D. & Mahmud, H., 2000. Development of High Performance Concrete Using Silica Fume at Relatively High Water-Binder Ratios. *Cement and Concrete Research,* 30(9), pp. 1501-1505.