Reusing of Construction Debris in Plain Concrete Elements

A. Abdelrahman Abuserriya^{1,*}, B. Bashir H. Osman¹ and C. Salma Y. Mahmoud²

¹ Civil Engineering Department, faculty of engineering, Sinnar University, Sinnar, Sudan

² Civil Engineering Department, faculty of engineering, Science and Technology University, Khartoum, Sudan

* Corresponding author: A. Abdelrahman Abuserriya (e-mail: engabedsoliman@hotmail.com).

Article history: Received 27 August 2020, Received in revised form 4 November 2020, Accepted 11 November 2020

مُستخلص: البناء هو مشكلة بيئية خطيرة و تحدي للذين يهتمون بالاستدامة في مجال البناء والدراسات السابقة برهنت على وجود نتائج إيجابية لاستخدام الركام الخرساني المعاد تدويره في مجال البناء و توضح هذه الدراسة نتائج استخدام مخلفات البناء في صب أنواع مختلفة من الكتل الخرسانية. استخدام الركام الخرساني المعاد تدويره بنسب مختلفة (0% ، 50% ، 100%) لاستبدال الركام الطبيعي لاختبار عدة قيم من قوة الكسر (B250, B300, B350, B400) و تم استخدام نوعين من المياه (مياه نقية ومياه البحر) لمعالجة الكتل. بالإضافة إلى ذلك ، تم صب بلوك البناء وبلوك الرصف بنسب مختلفة من الركام الخرساني المعاد تدويره (0% ، 20% ، 45% و 100%) وأيضاً تم معالجته بنوعين مختلفين من المياه. أظهرت النتائج انخفاضاً في قوة الكسر مع زيادة محتوى الركام المعاد تدويره. كما لوحظ أن نسبة امتصاص العنصر للمياه تزداد مع زيادة محتوى الركام المعاد تدويره.

الكلمات المفتاحية: الركام الخرساني المعاد تدويره، قوة الكسر، بلوك الرصف، بلوك خرساني، بلوك الرصف

ABSTRACT Construction is a serious environmental problem and a challenge for people who concerned with sustainability in the construction field. Previous studies showed positive results for the use of recycled aggregates in the concrete production. This study portrays the results for utilizing construction debris for casting different types of concrete blocks. The recycled concrete debris was used in different ratios (0%, 50%, and 100%) in replacement for natural coarse aggregates for different targeted compressive strength (B250, B300, B350 and B400). Two types of water (pure and sea water) were used for curing the blocks. In addition, hollow block and paving block were casted with different ratios of recycled aggregate (0%, 20%, 45% and 100%) and cured with two types of water. The results showed a decrease in compressive strength with the increase recycled aggregate content. It was also noticed that the absorption capacity increases with high recycled aggregate content.

Keywords: Recycled aggregate, compressive strength, paving block, concrete block, paving block

1. INTRODUCTION

The disposal of construction and demolition wastes is one of the challenging problems due to the scarcity of open lands and the limited size of municipal dumping sites to accommodate large quantities of debris and unprocessed construction wastes. Aggregate produced from recycled concrete are needed due to the scarcity of natural aggregate and due to the large volume of demolition debris in many places around the world. Normally, random and uncontrolled disposal of construction and demolition wastes creates several environmental impacts. So, any potential for reusing the construction waste will resulted in a reduction in local environment

problems and minimizes the pressure on natural resource of aggregates. Therefore, the potential of recycled aggregate has been investigated as a replacement of concrete natural aggregates or combined with natural aggregate to produce concrete mixes in structural elements.

Many research papers have been published in recent years dealing with recycled debris around the world. Tam et al. [1] explained that the porosity of cement mortar attached to recycled aggregate can directly influence the properties of the aggregate such as lower strength, higher water absorption and lower density. Therefore, removing the cement mortar remains around the recycled aggregate is the best method in improving the quality of recycled aggregate and

making it as competitive as the virgin aggregate. Fong et al. [2] reported that for lower grade applications, concrete with 100% recycled coarse aggregate is allowed. Recycled fines are not allowed to be used in concrete. The target strength was at 20 MPa and the concrete can be used in benches, stools, planter walls, concrete mass walls and other minor concrete structures.

Khalaf and DeVenny [3] used clay brick and granite brick as coarse aggregate. They used uniaxial compressive strength, relative density, impact value, water absorption and density. They designed three mixes of concrete using each type of brick for three different mixes. The results showed that clay brick preformed similar or even better than granite concrete as coarse aggregate after the exposure of the specimen to a high temperature.

Ngo and Chai [4] used different ratios (0%, 20%, 40%, 60%, 80% and 100%) of recycled aggregate replacement with natural aggregate in concrete mixes. The concrete mixes designed with w/c of 0.45 and cement aggregate ratio of 1:4. The slump test results were between 78 and 90 mm and the compressive strength at 28 day between 35. MPa to 50. MPa. When ratio of recycled aggregate is increased, the compressive strength is decreases.

Poon et al. [5] explained that replacement of coarse and fine natural aggregates by recycled aggregates at the level of less than 50% had small effect on the compressive strength of concrete specimens. The compressive strength at higher levels of replacement is reduced. The transverse strength is increased as percent of replacement of recycled aggregate is increased. The density of paving block at 50% replacement was 2281 kg/m³ and at 100% replacement was 2258 kg/m³. On the other hand, the compressive strength at 50% replacement was 62. MPa and at 100% replacement was 51. MPa.

Zuhud [6] reported that the density of concrete made with recycled aggregate is lower than that of natural aggregate by 5.5%, due to a higher adsorption capacity of recycled aggregate and bad compaction because of its texture. The workability of recycled concrete is reduced because the mortar from the original concrete makes the recycled aggregate more porous and absorptive than its natural counterpart; the absorption capacity of recycled aggregate is more

than twice of natural aggregates. The additional absorption requires more water to be added to the recycled aggregate stockpile to reach saturation before it can be added to the concrete mix. Concrete with recycled aggregate can provide strength almost equivalent to the corresponding concrete with natural aggregates for the same quantity of cement. The use of recycled aggregate does not seriously affect the compressive strength of the concrete when only coarse natural aggregates replaced by coarse fragments of demolition debris. When 60% of recycled coarse aggregate used in concrete mixes, it decreases the compressive strength by about 25 %. He also reported that concrete with 60% recycled aggregate has bonding strength of 1.45 times concrete of natural aggregate.

Abed [7] used different ratios of recycled aggregate (0%, 30%, 60% and 100%) as replacement of natural aggregate and different water cement ratios (0.35, 0.42, and 0.50) to find optimum ratio that have practical properties. He concluded that concrete blocks can be produced using 100% recycled aggregate for practical application.

2. MATERIALS USED

This research focuses on the potential of using demolition waste in concrete mixes and concrete hollow and paving block. Portland cement type 1 52.5N and super-plasticizer TP 101 were used. Figure 1 shows the gradation for the recycled and natural aggregate of different mixes A1, A2 and A3, paving and hollow block. Also, crushed fine aggregate were used for all mixes A1, A2, A3 hollow block and paving block. Properties of fine and coarse recycled and natural aggregate for all mixes are tabulated in Table 1. Table 2 shows the chemical analysis for the natural and recycled aggregates as well as the water used in the mix. It is clear that the recycled aggregate has a higher value of TDS and EC values by more than 60 % compare to the natural aggregates.

3. MIX DESIGN

Four mixes (B250, B300, B350 and B400) were designed for a slump of 80-100 mm, air content of 0.015 by volume and w/c 0.69, 0.61, 0.53 and 0.47 respectively. Each mix has three groups A1, A2 and A3. Group A1 has 100% RCA, group A2 has

50% RCA and group A3 has 0% RCA and ratio of 0.4 between NFA to CFA for each mix. Table 3 shows mix design for mix A1, A2 and A3 for different compressive strength.

All mixes have w/c ratio of 0.42, 470 kg of sand, 238 kg of cement and 1634 kg of RCA and NA. The mixes differ in recycled aggregate ratio only. Table 4 shows Mix proportions per unit volume for concrete hollow block mixes.

Also, four mixes (P1, P2, P3, and P4) were prepared for hollow block. Mix P1 has 0% RCA, Mix P2 has 20% RCA, Mix P3 has 45% RCA and Mix P4 has 100% RCA. All mixes have w/c ratio of 0.36, 417 kg of sand, 575 kg of cement and 1276 kg of RCA and NA. The mixes differ in recycled aggregate ratio only. Table 5 shows Mix proportions per unit volume for paving block mixes.

Figure 1: Gradation of recycled and natural aggregate for mixes A1, A2 and A3, paving, hollow block, and minimum and maximum gradation of coarse and fine aggregate.

TABLE 1: PROPERTIES OF RECYCLED AND NATURAL AGGREGATE.

Physical properties	Specific gravity	Water absorption (%)	Unit weight (kg/m ³)	Moisture content (%)
Natural coarse aggregate	2.7	2.2	1493	1.2
Recycled coarse aggregate	2.45	5	1369	1.5
Natural fine aggregate	2.65	1.1	1672	0.24
Recycled fine aggregate	2.62	2.3	1610	0.1

TABLE 2: CHEMICAL ANALYSIS FOR RECYCLE AND NATURAL AGGREGATE.

TEST	TDS (ppm)	EC (Micro-seam/cm)	PH	CL (Mg/l)
Natural coarse aggregate	208	405	6.99	50.4
Recycled coarse aggregate	372	650	8.36	62
Water	109	218	6.1	37

TABLE 3: WEIGHT OF MATERIALS IN DIFFERENT MIXES (A1, A2 AND A3) FOR DIFFERENT DESIGN COMPRESSIVE STRENGTH (KG/M³). IN ADDITION, FOUR MIXES (H1, H2, H3, AND H4) WERE PREPARED FOR HOLLOW BLOCK. MIX H1 HAS 0% RCA, MIX H2 HAS 20% RCA, MIX H3 HAS 45% RCA AND MIX H4 HAS 100% RCA.

Material	Design of compressive strength			
	B250	B300	B350	B400
Cement	320	361	415	464
Coarse aggregate	934	934	934	934
CFA	558	537	508	482
NFA	222	216	202	188
w/c	0.69	0.61	0.53	0.47

TABLE 4: MIX PROPORTIONS PER UNIT VOLUME FOR CONCRETE HOLLOW BLOCK MIXES.

Mix name	RCA (%)	w/c	Cement (Kg/m ³)	Natural coarse aggregate (Kg/m ³)	RCA (Kg/m ³)	Sand (Kg/m ³)
H1	0%	0.42	238.1	1634	0	470
H2	20%	0.42	238.1	1307	327	470
H3	45%	0.42	238.1	899	735	470
H4	100%	0.42	238.1	0	1634	470

TABLE 5: MIX PROPORTIONS PER UNIT VOLUME FOR PAVING BLOCK MIXES.

Mix name	RCA (%)	w/c	Cement (Kg/m ³)	Natural coarse aggregate (Kg/m ³)	RCA (Kg/m ³)	Sand (Kg/m ³)	Water (Kg/m ³)
P1	0%	0.36	575	1276	0	417	207
P2	20%	0.36	575	1021	255	417	207
P3	45%	0.36	575	702	574	417	207
P4	100%	0.36	575	0	1276	417	207

4. TESTS PROGRAMS

Three mixes of scenarios were chosen in this study for each compressive strength of B250, B300, B350 and B400. Eight samples for every mix group also were prepared to be tested for compressive strength at 7 and 28 days. Four samples were cured in pure water and four samples were cured in sea water for each target group.

A total of eight samples were presented and tested. used for compressive strength test at 14 and 28 days for every percentage of hollow block and paving block and cured with pure water and sea water. Absorption test, unit weight for both hollow block and paving block and abrasion test for paving block were conducted. Figure 2 shows failure of B250 block in compressive strength test.

5. ANALYSIS AND DISCUSSION

Actual compressive strength of different Mixes (A1, A2 and A3) for different design compressive strength B250, B300, B350 and B400 cured with pure water for 7 and 28 days is shown in Figure 3. Actual compressive strength was decreased, when recycled aggregate ratio was increased for 7 and 28 days at different design compressive strength as shown in Figure 3. The actual compressive strength of A1 decreased about 21% and actual compressive strength of A2 is decreased about 7% from actual compressive strength of A3 at 7 days for different design compressive strength. While the actual

Figure 2: Failure of B250 block in compressive strength test.

compressive strength of mix A1 is decreased about 11% and actual compressive strength of mix A2 is decreased about 7% from actual compressive strength of mix A3 at 28 days for different design compressive strength.

Figure 4 shows actual compressive strength for different Mixes (A1, A2 and A3) for different design compressive strength B250, B300, B350 and

B400 cured with sea water. As shown in Figure 4, actual compressive strength was decreased, when recycled aggregate ratio was increased for 7 and 28 days at different design compressive strength. The actual compressive strength of mix A1 is decreased about 21% and actual compressive strength of mix A2 is decreased about 7% from actual compressive strength of mix A3 at 7 days for different design compressive strength. While the actual compressive strength of mix A1 is decreased about 11% and actual compressive strength of mix A2 is decreased about 7% from compressive strength of mix A3 at 28 days for different design compressive strength.

The actual compressive strength for same mix cured with pure or sea water there is no difference, it stills in same range. Table 6 shows density at 28 day for mix A1, A2 and A3 for different design compressive strength cured with pure water.

Density was increased, when recycled aggregate ratio was increased as shown in Table 6. But, increasing in density still small comparing with increased in compressive strength.

Results of tests for hollow block shows in Table

7. It is clear that increased in RCA ratio from 0 to 100% decreased in compressive strength at 14 day about 36% in water cured and about 40% in sea water cured and there is decreased about 0.2 to 0.3

Figure 3: Actual compressive strength of different Mixes (A1, A2 and A3) for different design compressive strength cured with pure water at 7 and 28 days.

Figure 4: Actual compressive strength of different Mixes (A1, A2 and A3) for different design compressive strength cured with sea water at 7 and 28 days.

Kg/cm² for samples cured with sea water to pure water. It is noted that increased in RCA ratio lead to decrease in compressive strength at 28 day around 32% - 35% for all type of cured and there is decreased about 0.2 to 0.3 Kg/cm² for samples cured with sea water to pure water. The increasing in RCA ratio from 0 to 100% decreased in unit weight about 19 %. and increased in Absorption capacity about 116%.

Table 8 shows results of tests for paving block. It is clear the compressive strength at 14 day decreased around 20 % when increased in RCA ratio from 0 to 100%. And there is almost no change for samples cured with sea water to pure water in compressive strength.

It is clear that increased in RCA ratio from 0 to

100% lead to decreased in compressive strength at 28 day about 16 % and there is almost no change for samples cured with sea water to pure water in compressive strength. It is noted that increased in RCA ratio, unit weight decreased around 10 % and increasing in Absorption capacity about 85 % and around 14% increasing in Abrasion test.

6. CONCLUSION:

A series of tests were conducted for block with different recycled aggregate ratios (0%, 50% and 100%). The actual compressive strength is decreased from 7 % to 21% when recycled coarse ratio increase from 50% to 100% at 7 days and decreased from 7 to 11% when recycled coarse ratio increase from 50% to 100% at 28 days and actual compressive strength of A2 is decreased about 7% from actual compressive strength of A3 at 7 days for different design compressive strength. While the actual compressive strength of mix A1 is decreased about 11% and actual compressive strength of mix A2 is decreased about 7% and it is slightly difference between blocks cured with pure water and sea water because of recycled coarse aggregate.

For hollow blocks, it is clear that increased in RCA ratio lead to decrease in compressive strength at 28 day around 35% for all type of cured. The increasing in RCA ratio from 0 to 100% decreased in unit weight about 19%. An increase in absorption capacity about 116% and the influence of recycled aggregate ratio on absorption capacity is so high and danger.

For paving blocks, increasing in RCA ratio from 0 to 100% leads to decreased in compressive strength at 28 day about 16% and decreased 10% of unit weight and increased in Absorption capacity about 85% and around 14% increasing in Abrasion test. The effect of RCA on abrasion test is so good but still not enough according to compressive strength and absorption.

TABLE 6: DENSITY (KG/M3) OF MIX A1, A2 AND A3 FOR DIFFERENT DESIGN COMPRESSIVE STRENGTH CURED WITH PURE WATER.

Compressive strength	B250	B300	B350	B400
Mix A1	2252	2284	2295	2305
Mix A2	2305	2317	2330	2342
Mix A3	2398	2413	2426	2433

TABLE 7: RESULTS OF TESTS FOR HOLLOW BLOCK.

Mix name	H1	H2	H3	H4
Recycled aggregate ratio (%)	0	20	45	100
Compressive strength at 14 day cured with water (MPa)	5.20	4.80	4.10	3.30
Compressive strength at 14 day cured with sea water (MPa)	4.90	4.60	3.80	2.90
Compressive strength at 28 day cured with water (MPa)	6.07	5.66	5.16	4.11
Compressive strength at 28 day cured with sea water (MPa)	5.89	5.43	4.88	3.80
Unit weight (kg/m ³)	1257	1189	1119	1020
Absorption capacity (%)	4.06	5.46	6.89	8.79

TABLE 8: RESULTS OF TESTS FOR PAVING BLOCK.

Mix name	P1	P2	P3	P4
Recycled aggregate ratio	0	0.2	0.45	1
Compressive strength at 14 day cured with water (MPa)	45	41	38	35
Compressive strength at 14 day cured with sea water (MPa)	44	40	36	35
Compressive strength at 28 day cured with water (MPa)	55	51	49	46
Compressive strength at 28 day cured with sea water (MPa)	54	50	48	45
Unit weight (kg/m ³)	2459	2392	2318	2195
Absorption capacity (%)	4.21	5.37	6.52	7.8
Abrasion test (mm)	4.19	4.33	4.5	4.8

NOTATIONS

W/C: Water cement ratio, TDS: Total dissolved solids, EC: Electrical conductivity

RCA: Recycled coarse aggregate, NFA: Natural fine aggregate, CFA: Crushed recycled fine aggregate, NA: Natural coarse aggregate

REFERENCES

- [1] Tam, V. W., Tam, C. M., & Le, K. N. (2007). Removal of cement mortar remains from recycled aggregate using pre-soaking approaches. *Resources, Conservation and Recycling*, 50(1), 82-101.
- [2] Fong, W. F., Yeung, J. S., & Poon, C. S. (2004, May). Hong Kong experience of using recycled aggregates from construction and demolition materials in ready mix concrete. In *Proceedings of the International Workshop on Sustainable Development and Concrete Technology* (pp. 267-275).
- [3] Khalaf, F. M., & DeVenny, A. S. (2004). Performance of brick aggregate concrete at high temperatures. *Journal of Materials in Civil Engineering*, 16(6), 556-565.
- [4] Ngo, N., & Chai, S. (2004). High-strength structural concrete with recycled aggregates (Bachelor thesis). University of Southern Queensland
- [5] Poon, C., Kou, S., & Lam, L. (2002). Use of recycled aggregates in molded concrete bricks and blocks. *Construction and Building Materials*, 16(5), 281-289.
- [6] Zuhud, A. (2008). "Performance of recycled aggregate concrete". M.Sc. thesis, Islamic University of Gaza.
- [7] Abed, F. (2009). Using of recycled aggregate in producing concrete elements". M. Sc. thesis, Islamic University of Gaza.

Abdelrahman Abuserriya has bachelor degree of civil engineering from Islamic University of Gaza. Now, he is a master student of geotechnical engineering in Sinnar University in Sudan. His research interest is soil lab tests, concrete lab tests, retaining wall, soil stress, data analysis, data envelope analysis, and goal programming.

Bashir H. Osman has bachelor degree of civil engineering from Sinnar University, Master of structural engineering from Khartoum university and doctoral degree (PhD) in Structural Engineering from Hohai University. Now, he is Head Department of Civil Engineerin in Sinnar University and visitor teacher in Hohai University. His research interest is structural

analysis and design, material, numerical analysis, Finite element and beam strength.

Salma Y. Mahmoud was born in Sudan, on 15th November 1972. In 2005 earned a PhD in Construction Management from the University of Newcastle Upon Tyne, UK and an MSc in 1999 in the field of Construction Management from Sudan University of Science and Technology, Khartoum, Sudan and a BSc in 1996 in Construction Engineering from the American University in Cairo, Egypt.

She initially worked as a Quantity Surveyor and an AutoCAD Instructor before joining the Civil Engineering Department, Faculty of Engineering, Sudan University of Science and Technology (1999) as a full-time staff member assuming several posts there. She started as a Teaching Assistant then a Lecturer and later an Assistant Professor of Construction Engineering and Management. Along with that she was appointed Head of the Construction Engineering Unit then the Faculty Coordinator for the assessment and accreditation

program then the Postgraduate Programs Coordinator before heading the Civil Engineering Department. In 2009, she moved to the University of Science and Technology (UST), Omdurman, Sudan to develop the department and instigate the Civil Engineering program. She is currently an associate professor of Construction Engineering and Management and the acting Head of the department. She has participated in many scientific conferences in Sudan and abroad and has several publications related to construction management and building materials. Few examples include: Development & use of Key Performance Indicators in the UK Construction Industry' Association of Researchers in Construction Management (ARCOM), 18th. Annual Conference, Newcastle; 'Scheduling Problem under Constrained Resources: A Historical Review of Solution Methods and Computer Application', Journal of Science and Technology, 13 (2); Preliminary Investigation on the causes of variation orders in building projects in Sudan, Red Sea University Journal, 2017). Current research interests are geared towards sustainability as related to construction materials and legal issues in construction with specific focus on claims and variation orders.