Concrete hollow blocks made with recycled coarse aggregate and recycled water "Green blocks"

E. Elgaali[1,a], M. Elchalakani[2,b]

[1] Faculty, Department of Civil Engineering, The Higher Colleges of Technology, Dubai, Men's Campus, UAE, P.O. Box 15825.
[2]Faculty, Department of Civil Engineering, The Higher Colleges of Technology, Dubai, Men's Campus, UAE, P.O. Box 15825.
[1] eelgaali@hct.ac.ae, [b] melchalakani@hct.ac.ae.

ABSTRACT

Numerous research studies have examined the effect of using recycled aggregate in manufacturing concrete building blocks whereas little research investigated the influence of recycled water. Worldwide, fresh water scarcely has become an increasing environmental threat particularly in the Middle East. In this paper, the suitability of using recycled aggregate and recycled water to produce blocks of comparable physical and mechanical properties as the commercial blocks was investigated. The combined effects of using recycled aggregate and recycled water on strength and durability of the blocks are presented and discussed. The test program involves the preparation of moderate strength concrete mix out of recycled water and recycled aggregate obtained from concrete waste. Twenty four specimens (hollow blocks) were prepared; six commercial and twenty four made of recycled materials (green blocks). In all the green block specimens the fresh aggregate and water were replaced by 100% recycled aggregate and 100% recycled water. The effect of recycled aggregate and water on axial strength was found to be moderate where the strength dropped by about 20% at 7 days curing. To enhance the durability and lower the carbon footprint of the recycled concrete mix, the Ordinary Portland Cement (OPC) was replaced by micro-silica. It was found that the axial strength of the blocks was further reduced by about 32% and 52% for 60% and 70% replacements at 7 days curing.

KEYWORDS: concrete, sustainability, recycled, wastewater.

1. INTRODUCTION

Concrete blocks are widely used in construction. Different types are used for different purposes. In comparison to conventional bricks, hollow blocks have been found to have better uniform quality, longer durability, faster speed of construction, and lower labor requirements. In view of these advantages, hollow blocks are increasingly used in different construction activities. These activities include, but not limited to, load bearing walls, interior walls, panel walls, retaining walls and compound walls.

The annual demand for the hollow concrete blocks, in Dubai – UAE, is estimated to be several millions (DM, 2013). The value of the hollow concrete blocks may be taken to be about 8 to 10% of the total cost of the construction assuming that about 20% of the construction activities would use hollow blocks.

The hollow block has a standard size of 390 x 190 x 190 mm, with 25% to 50% of this size is voids. In the manufacturing process, each typical hollow block is estimated to consume 2.0 kg of cement, 9.0 kg of sand, 11.0 kg of aggregate, and 0.80 kg of water. Thus the manufacturing industry of concrete blocks was found, annually, to consume millions of metric tons of aggregate and fresh water around the world. Recycled materials (aggregate/water) have been anticipated to provide a good alternative to the huge amount of these fresh materials.

Statistics show that, globally, large amounts of materials are wasted annually. The Gulf Cooperation Council (GCC) countries rank in the top 10 of the world waste producers with 120 million tons of waste per year, and the figures are expected to reach 350 million tons by 2014 (Dubai Municipality 2010). Around 75% of this amount is construction and demolition wastes. The city of Dubai, in the UAE, alone turns out more than 76,000 tons of waste every single day with the highest per capita worldwide (Table 1). Unfortunately, most of this amount goes to landfills posing hazards to the local and regional environment. Therefore, sustainability of the natural resources and mitigation of the waste's environmental impact have been long standing objectives of governments worldwide.

Table 1. Waste production (Fisher and Werge 2009, EPA 2008, Dubai Municipality 2010)

Region	**EU-28**	**USA**	**GCC**
Population in 2010 (million)	501	310	40
Total Waste (million ton/year)	2742	380	120
C&D Waste (million ton/year)	850	130	90
C&D Waste (ton/capita/year)	1.70	0.42	2.25
C&D Waste / Total Waste (%)	31%	35%	75%

The use of recycled materials (aggregate/water) in the construction industry has been an alternative under investigation for a while (Fisher and Werge 2009, EPA 2008, Dubai Municipality 2013). Numerous research studies have examined only the effect of using recycled aggregate in manufacturing concrete building blocks (e.g. Soutsos etal., 2011). In this paper, the suitability of using recycled aggregate and recycled water to produce blocks of the same physical and mechanical properties as the commercial blocks was investigated. The combined effects of using recycled aggregate and recycled water on strength and durability of the blocks are presented and discussed.

2. TEST PROGRAM

2.1 Recycled Aggregate Materials

The recycled aggregate (RA) was obtained from a recycling plant (Fig. 1) for demolition waste in the UAE, where the waste concrete is segregated into different categories and crushed into different sizes. Following Dubai municipality specifications, the aggregate used in this research has particle size of 10 mm. The average measured density and water absorption of the recycled aggregate were 2.51 t/m^3 and 5.2%, respectively. Thus it may be classified as Low quality (L) according to Japanese Standards (Tsujino *etal* 2007). But in general the aggregate used has less dust and slime contamination, is better separated, better classified and particularly free from organic matters (Jungmann and Quindt 1999). This expected to make the results more consistent with less irregularity and scatter.

(a) Input material from landfill (b) Output material

Figure 1. Recycling of demolition waste in Dubai, UAE

After it was obtained from the plant, no further treatment was performed on the RA (e.g. the surface modification treatment as in Tsujino *etal* 2007); only further cleaning was performed. Finally, the recycled aggregate was checked to be not saturated with water prior to the mixing operation.

2.2 MBR Recycled Water

The amount of the Recycled Water (RW) used to make the concrete mixes was obtained from a compacted wastewater treatment plant recently constructed in Dubai. The water is treated using the Membrane Bioreactor (MBR) technique which recycles the sewage into water with a relatively high quality makes it reusable (Table 2). The MBR technique is a process that combines a membrane filtration process and an activated sludge process (Judd 2011; Hi Star Water Solution 2010). The MBR process is used in place of the secondary sedimentation tank where a sand filter is often used for tertiary treatment in the conventional activated sludge process. By adopting simple and high-performance flat sheet type membrane of 0.1μm pore size, the MBR system effectively provides space-saving and easy maintenance and operation. In addition to that, the removal of nitrogen and phosphorus can be achieved by anoxic/oxic advanced treatment. The measured chlorides and sulfates contents in the effluent of the MBR process were 92 and 46 ppm, respectively. These values are significantly lower than the allowable limits in EN 1008 (2002) for mixing water used in reinforced concrete, which are 1000 and 2000 ppm, respectively (Table 2). The chlorides and sulfates in the tap water were measured to be 71 and 19 ppm, respectively.

Table 2. Chemical analysis of mixing water

Parameter	**Tap Water**	**MBR Water**	**EN 1008 (2002)**	**ASTM C94 (1994)**
Chloride ion, ppm	71	92	< 1,000	< 1,000
Sulfate ion, ppm	19	46	< 2,000	< 3,000
PH	6.5	7.09	> 4	-
Total Suspended Solids (TSS), ppm	5	5	< 100	< 50,000
Total Dissolved Solids (TDS), ppm	234	328	< 2,000*	
Biochemical Oxygen Demand (BOD), ppm	10	2	-	-
Chemical Oxygen Demand (COD), ppm	40	16	-	-
Ammonia Nitrogen NH_3-N, ppm	1.2	0.11	-	-
Total hardness, (CaCO3), ppm	-	102	< 1,000	-
Oil and Grease, ppm	-	5	-	-

2.3 Specimens

The test program involved preparation of a moderate strength concrete (nominal strength about 6 N/mm^2) mixes made out of recycled water and recycled aggregate to produce blocks of the same physical and mechanical properties as the commercial blocks. A total of 30 standard hollow blocks (390mmx190mmx190mm) were prepared according to Dubai Municipality Specifications. Figure 2 shows the recycled hollow blocks without any micro-silica additives.

In the first mix (N00), six control specimens with fresh water and fresh aggregates were prepared and free of any additives (i.e., no micro-silica). In the second mix (M00), six hollow blocks were made using 100% recycled water (RW) and 100% recycled aggregate (RA). In the third mix (M60), to enhance the durability and to lower the carbon footprint of the recycled concrete mix, the Ordinary Portland Cement (OPC) was replaced by 60% micro-silica in addition to 100% RW and 100% RA. In the fourth mix (M70), the OPC was replaced by 70% micro-silica, in addition to 100% RW and 100% RA. The control (normal) concrete mix was composed of OPC, tap water, crushed RAK Rock (10 mm), and washed Wadi sand and it was cured for 7 days in a fresh water tank.

Figure 2. Recycled hollow block 390x190x190

3. TEST RESULTS

Table 3 shows the results of testing of all the three concrete mixes (M00, M60, M70). Six specimens (blocks) from each mix were crushed and the crushing strength of each one was recorded. The result of each mix was compared to the result of testing of the control (commercial) specimens (N00). The result presented in Table 3 shows that the recycled block with no micro-silica (G00) meet the criteria set by Dubai Municipality (2013) with crushing strength not less than 6 N/mm^2. In general, the results show that the crushing strength reduces with the increase in the amount of the recycled material. Micro-silica was added to enhance strength/durability and lower carbon footprint, but the high replacement ratios (60% and 70%) of OPC led to a decrease in strength. Therefore, further research is required to examine lower replacement ratios of OPC.

Table 3. Testing Results

N00		M00		M60		M70	
	N/mm^2		N/mm^2		N/mm^2		N/mm^2
1	8.1	1	5.8	1	6.1	1	3.9
2	7.6	2	6.3	2	5.7	2	4.1
3	8.4	3	6.6	3	5.5	3	3.2
4	8.2	4	6.8	4	4.4	4	4.5
5	7.9	5	6.0	5	5.6	5	3.5
6	8.0	6	7.5	6	5.7	6	4.1
Average	**8.03**		**6.50**		**5.50**		**3.88**

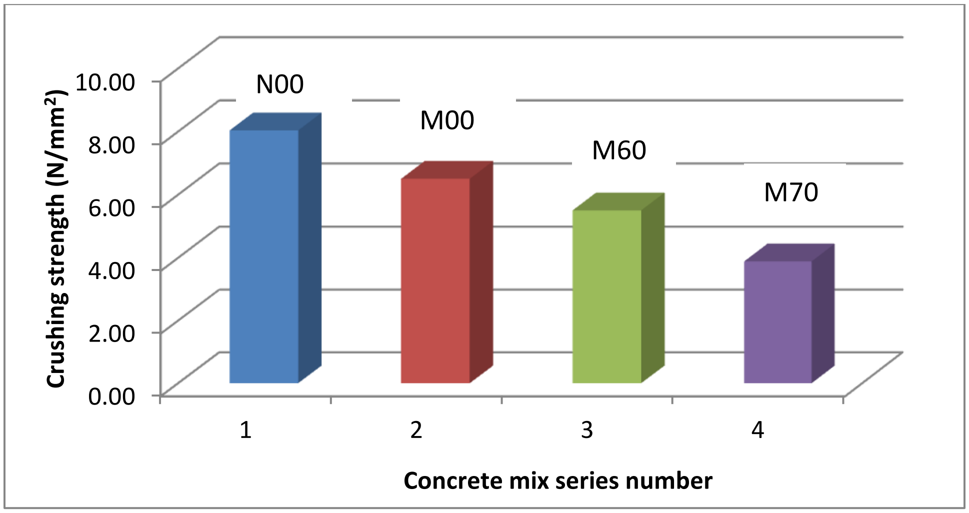


Figure 3. Summary of hollow blocks average strength tests results at 7 days

Figure 3 shows the variation in the average crushing strengths of each concrete mix at 7 days curing. Compared to the commercial blocks the crushing strength of the blocks, made of recycled materials with no additives (G00) dropped to 6.5 N/mm^2. In comparison, a significant drop continues to 5.5 and 3.88 N/mm^2 at 60% and 70% micro-silica replacements. Figure 4 shows the percent variation in the average crushing strength. As it is shown in the figure the blocks, made of the recycled materials G00 (no micro-silica), experienced an average reduction in strength of 19.1% at 7 days curing and the bocks made with 60% (M60) and 70% (M70) replacement of micro-silica experienced reductions in strength of 31.5% and 51.7% respectively at 7 days curing.

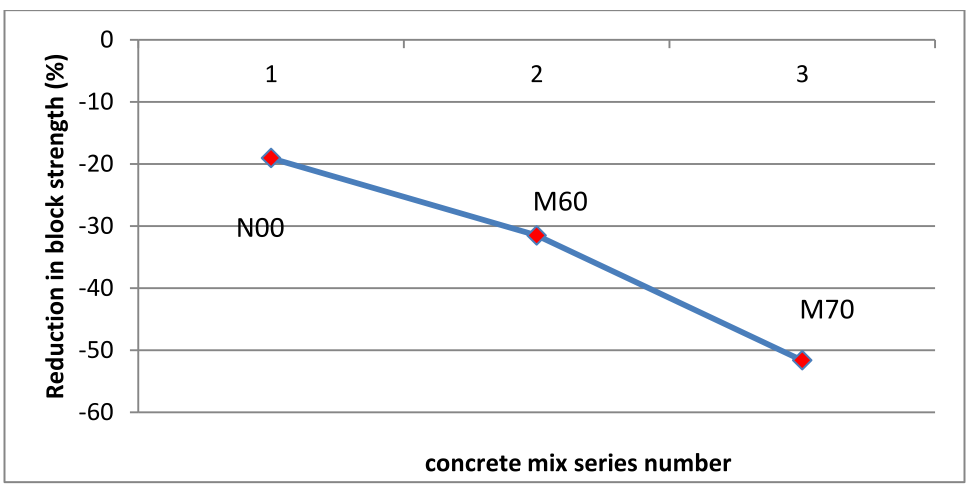
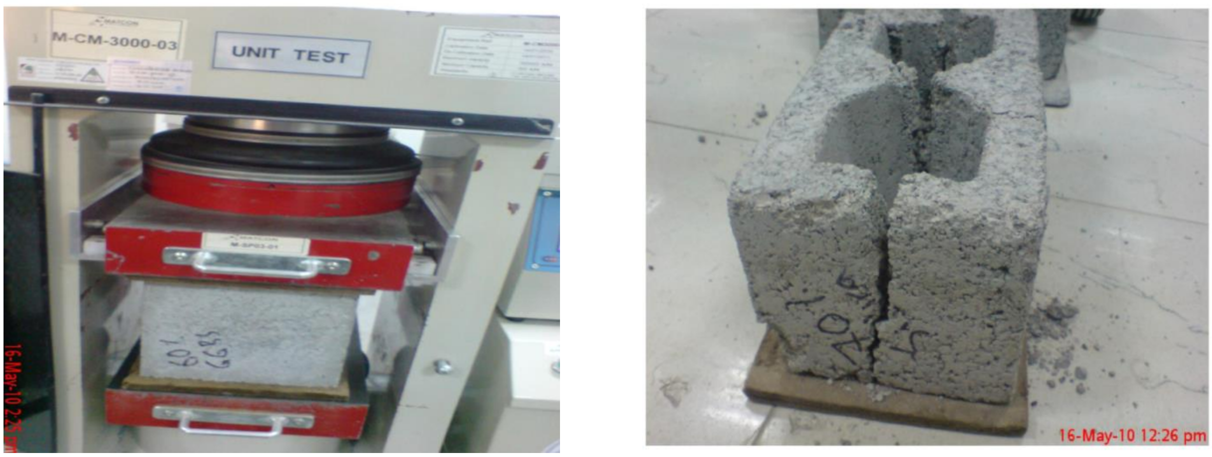


Figure 4. Effect of % of micro-silica on blocks strength at 7 days

The reduction in strength is significantly affected by the amount of the recycled materials added. Previous research showed that the axial compressive strength of the concrete reduces with the increase in the amount of RA (Li 2008, Park *etal* 2009). They showed that when the RA is less than 20% its influence is negligible; however when it reaches 100% the reduction in strength is in the range of 12% to 25%. They gave the following reasons for such reduction: (i) the RA has a relatively higher water absorption hence absorbs the water required for hydration of the cement, and (ii) the RA is covered by the old cement paste which acts as a barrier between the RA and the new cement paste; (iii) effect of curing time. To enhance the properties of the recycled materials the aggregate is suggested to have further treatment such as mechanical scrubbing to remove the cement paste and the water can be treated further using the reverse osmosis process (Tsujino etal. 2007, Judd 2011). EN 1008 (2002) specifies that when using qualified recycled water the maximum reduction in the crushing strength shall not be more than 10% at 7 days curing. Table 2 shows that the measured mineral contents of the MBR treated water are generally less than those specified in EN 1008 (2002). Thus the MBR treated water is qualified according to EN 1008 (2002). However, it may be concluded that the strength of the blocks, made of recycled materials, moderately drops; increasing the amount of the micro-silica in the concrete mix, made of recycled aggregate concluded that increasing the amount of the GGBS in the concrete mix made of recycled materials has beneficial effects on the durability. Figure 5 shows the typical failure mode of the hollow blocks.



(b) Blocks during test (b) failure mode of blocks

Figure 5. Selected photos from the project

4. CONCLUSIONS

The results show that using recycled materials produces concrete blocks have lower axial compressive strength than those made of fresh materials. Adding micro-silica has further reduced the strength of the blocks. It was found that the MBR recycled water is qualified to EN 1008 (2002) and ASTM C 94 (1994) based on chemical and strength tests at 7 days. The effect of recycled aggregate and water on axial strength was found to be moderate where the strength dropped by about 19.1%. To enhance the durability and lower the carbon footprint of the recycled concrete mix, the Ordinary Portland Cement (OPC) was replaced by micro-silica. It was found that the axial strength of the blocks was further reduced by about 31.5% and 51.7% at 60% and 70% replacements. The results showed that the recycled block with no micro-silica (G00) meet the criteria set by Dubai Municipality (2013) with crushing strength not less than 6 N/mm^2. Further research is required to examine lower replacement ratios of OPC using micro-silica. However, the results show the feasibility of using recycled materials especially recycled water to produce blocks of comparable physical and mechanical properties as the commercial blocks at a lower cost. The use of recycled water in concrete mixing was not widely adopted and poorly documented but the chemical analysis and the results presented here showed that the type of water used here (MBR) is of accepted quality to produce concrete mix of reasonable quality at a lower cost. By reusing the large amount of recycled water and materials contained in the construction and demolition waste the sustainability of the natural resources and the mitigation of the wastes impact on the environment is a long standing objective achieved. In general, the study shows the suitability of reusing the large amount of wastewater and materials contained in the construction waste in making a sustainable concrete with a good performance in the long term and friendly to the environment.

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