On the Durability of Recycled Aggregates Concrete

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***Abstract*—As increasing durability of materials is considered an important tool to improve sustainability, the durability of concrete produced using recycled aggregates was investigated. Physical and chemical properties of crushed concrete aggregates were assessed and compared to those of fresh aggregates. Concrete samples were produced using different water to cement ratios and were tested for absorption, density, compressive strength, tensile strength and flexural strength. Cubes were cast and subjected to different exposure conditions up to one year, before being tested. The considered exposure conditions include fresh water, open air, sea water and burying samples underground. Samples were tested for compressive strength, absorption and specific gravity. Although aggregates from demolished concrete were found to be inferior to new aggregates in terms of absorption, abrasion resistance and impact resistance, the durability of concrete produced using recycled concrete as aggregates was found to be comparable to this of concrete produced using fresh aggregates.**

***Index Terms*—durability, aggregates, recycled concrete, seawater**

I. Introduction

Recycling of structural wastes represents an essential step and a pillar to approach and satisfy the requirements of sustainable, green and environmentally responsible construction industry. Recycling is inevitable to the "economics of resources" which represents one of the main principles of sustainability.

The construction and operation of buildings consume the majority of the world's natural resources and energy, and contribute the bulk of landfill waste. Thus, the way we design, construct and maintain buildings has a tremendous impact on our environment and natural resources. Buildings use one-third of all the energy consumed in the US and two-thirds of all electricity. Buildings, in the US, accounts for 49% of sulfur dioxide and 25% of nitrous oxide emissions, that damage urban air. They also produce 35% of the carbon dioxide, blamed for the climate change.

The challenge of the sustainable, or green, buildings is to design, construct and maintain them in such a way to use a minimum of renewable energy, produce a minimum of pollution and cost a minimum, while increasing the comfort, health and safety of the people who live and work in them. In general, the utilization of the sustainable building concept is to consider the interrelationships between a building, its components, its surroundings, and its occupants.

Life cycle design is an important integrated part of the sustainable building concept. It is sometimes referred to as "from cradle to grave design" or better yet "from cradle to grave to cradle again design", as recyclability is another important component of the sustainable building design concept.

The criteria for selecting sustainable building materials, or what is known as the "Green Features" of a building materials, may be divided to the following three phases:

- Pre-building phase or the manufacture phase which include waste reduction, pollution prevention, recycled content, embodied energy and use of natural materials.
- Building phase or the use phase and this include reduction in construction waste, energy efficiency, water treatment/conservation, use of non-toxic or less toxic materials, renewable energy systems and longer life or durability of the material.
- Post-building phase or the disposal phase which include reusability, recyclability and biodegradability. The utilization of recycled materials in the structural industry is, therefore, of great importance as it will contribute to all the three criteria of selecting sustainable building materials

Many studied were conducted on the use of recycled concrete in concrete production [1]-[3].

Due to the harsh environment in the Gulf area, concrete usually experience some type of premature deterioration. The study of the durability and behavior of concrete under expected exposures is, therefore, of great importance. The environment in Kuwait is describes as hot marine environment. A marine environment is the place where concrete becomes wet with seawater. This could happen to concrete submerged under water, in a tidal zone, in a splash zone or at any place inland where wind could carry the salt water spray. The marine

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environment in Kuwait is characterized by high ambient temperature during summer, which accelerates the deterioration of concrete. Some work was conducted on the effect of temperature on the mechanical behavior of polymer concrete [4], in which compressive, tensile and flexure strength of polymer concrete along with the stress -strain relations were evaluated. An extensive research was also conducted on the behavior and durability of conventional concrete elements repaired using different types of polymers and subjected to sea water, elevated temperatures and tidal zone in Kuwait [5], [6]. The behavior of epoxy coated bars in marine environment was also investigated [7].

In this paper the durability of concrete, produces using recycled concrete as aggregates, under different exposures, is investigated.

TABLE I. COMPARISON BETWEEN RECYCLED AND NEW AGGREGATES

Property	New	Recycled	Difference
Water absorption 3/4	0.73	4.79	556.2
Water absorption 1/2	0.98	5.24	434.7
Water absorption 3/8	1.30	6.76	420
Density	2.70	2.48	8.1
Impact Value	6.3	13	106.7
LA abrasion	15.01	32.54	116.8
10% fines	373.3	163.98	56.1
Sulphate content	0.17	0.7	311.8
Chloride content	0.003	0.055	1733

II. PROCEDURE AND RESULTS

Crushed concrete was collected from the recycling plant in Kuwait. The crushed concrete was tested for their properties as aggregates [8]. Table I, includes some of the properties of these aggregates. Aggregates were collected from different batches at different times and a statistical analysis of properties was performed [8]. Concrete mixes were prepared using the two types of coarse aggregates (virgin and recycled). A typical rich concrete mix consists of 420 kg of ordinary Portland cement, 560 kg of 12.7 mm (half inch) coarse aggregates, 570 kg of 9.5 mm (3/8 inch) coarse aggregates, 640 kg of sand and 3 liters of superpalsticizers per cubic meter of concrete was used. Two water cement ratios of 0.44 and 0.6 were used. Four mixes were prepared using the two types of aggregates and the two w/c ratios. Cubes, cylinders and beams were prepared, cured for 28 days under water before being tested. Table II shows the compressive, split tensile and flexural strengths of the prepared concrete after 28 days. In addition to the control mixes, designated with a letter C, where virgin aggregates were used and the recycled mixes, designate with a letter R, where recycled aggregates were brought from the recycling aggregates factory, recycled from control mixes, designated as RC, were used. In these samples concrete samples prepared in laboratory were crushed and reused as aggregates. The use of recycled aggregates has reduced the compressive by 18.8 % for w/c of 0.44 and 32.5 % for 0.6. The reduction, however, was only 7.8% for w/c of 0.44, when recycled aggregates from the controlled mixes were used.

TABLE II. 28 DAY COMPRESSIVE, SPLIT AND FLEXURAL STRENGTH

% W/C	0.44			0.6		
	RC 0.44	R 0.44	C 0.44	RC 0.6	R 0.6	C 0.6
compressive strength (Mpa)	45.31	39.91	49.15	23.93	26.21	38.85
spilt tensile strength (Kpa)	3183.1	2746.9	4353.1	2133.9	2192.3	2853.4
flexural strength (Mpa)	4.82	3.9	5.69	3.66	3.69	4.73

The reductions due to the use of recycled aggregates in tensile and flexural strengths are 36.9% and 31.4%, respectively, for mixes with a water/cement of 0.44; while the reductions were 25.4% and 22%, in order, for the 0.6 water/cement mixes. Very little differences were noticed due to the replacement of the factory recycled aggregates with recycled from control aggregates for the weak mixes with w/c of 0.6. The changes, however, for the mixes with w/c ratio of 0.4 are 13.5%, 15.9% and 23.6% for the compressive, tensile and flexural strengths, respectively.

To study the effect of aging under different exposure conditions, some samples were kept in laboratory while others were left in open air (Fig. 1), some buried (Figure 2) and some were subjected to sea water in tidal zone (Fig. 3).

Compressive strength was evaluated after 0, 90, 180, 270 and 360 days of exposure. Time elapsed after 28 days of casting. The relations between the compressive strength and the exposure duration for w/c of 0.44 are shown in Fig. 4-Fig. 6, and for w/c of 0.6 in Figures 7 through 9.

Figure 1. Samples in open air

Figure 2. Buried samples

Figure 3. Samples in tidal zone

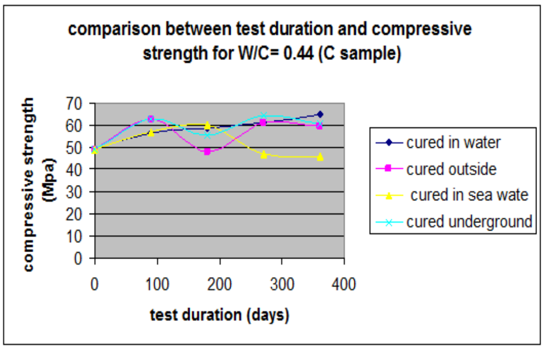

Figure 4. Compressive strength for different exposures, w/c of 0.44 (C samples)

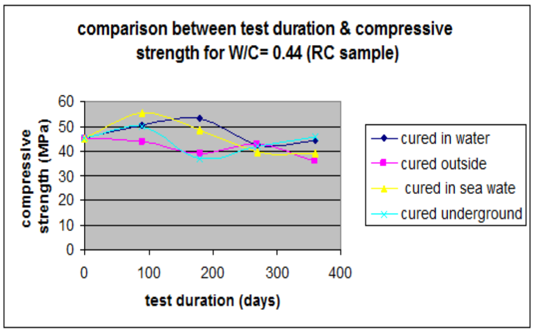

Figure 5. Compressive strength for different exposures, w/c of 0.44 (RC samples)

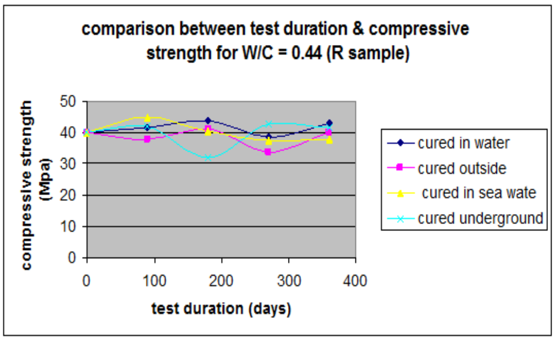

Figure 6. Compressive strength for different exposures, w/c of 0.44 (R samples)

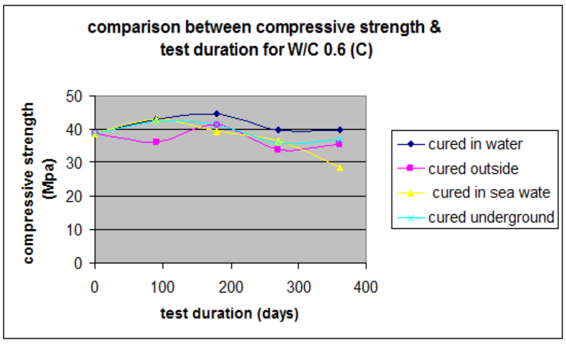

Figure 7. Compressive strength for different exposures, w/c of 0.6 (C samples)

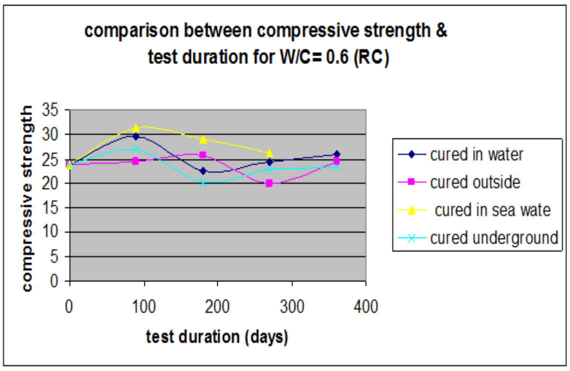

Figure 8. Compressive strength for different exposures, w/c of 0.6 (RC samples)

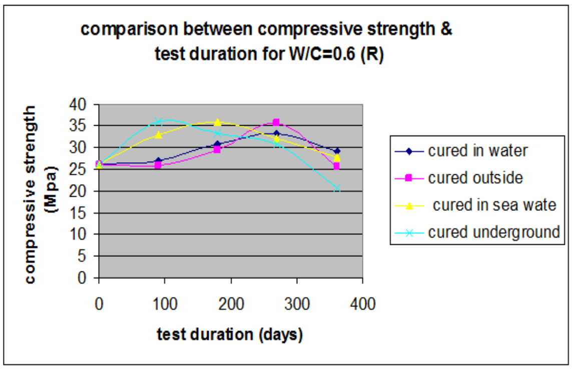

Figure 9. Compressive strength for different exposures, w/c of 0.6 (R samples)

In all cases the lower w/c resulted in a higher compressive strength and a reduction in strength due to sea water exposure was noticed; the reduction is higher for the samples where recycled aggregates were used.

As can be seen no noticeable reduction was noticed before 180 days after which some reduction in strength was noticed for both recycled and controlled recycled samples. The reduction is more for the samples buried underground and those left in air.

Specific gravity and water absorption were also evaluated for some samples exposed to different types of exposures and tested after different time durations. No apparent differences were noticed for specific gravity as the lowest value recorded was 2.21 and the largest was 2.38 with average values of 2.36, 2.29 and 2.23 for the C, RC and R samples with w/c of 0.44, respectively; while the values were 2.37, 2.25 and 2.24 for the samples with w/c of 0.6, in the same order.

The evaluated average water absorption for the mixes with w/c of 0.44 were found to be 3.92, 4.2 and 4.73 for the C, RC and R mixes, respectively, with an overall average of 4.28. For the mixes with w/c of 0.6, however, the absorption values were 4.17, 5.59 and 5.94 for the C, RC and R mixes, in order, with an average value of 5.23. Lower values were noticed for samples cured in sea water with an average of 3.83 for the samples with w/c of 0.44 after 360 days exposure with a reduction of 10.5 %. For average water absorption for the mixes with w/c of 0.6 after 360 days exposure in sea water was found to be 3.36 with a reduction of 35.8 % compared to those obtained in other exposure conditions. These reductions are attributed to salt crystallization in the pore system, which is a common phenomenon in the gulf and was reported by the author in previous work [6].

III. Conclusions

The following are the main conclusions:

- Old concrete may be crushed and used as aggregates in the production of new concrete. The resulting aggregates have higher sulphate and chloride contents. Their properties were inferior to new aggregates in terms of absorption, abrasion resistance and impact resistance. Their density was almost the same as the new aggregates.
- Compressive strength of the resulting concrete was of the same order as that of conventional one. The rate of strength gain was higher for the recycled concrete.
- Additional superplasticizers should be used with recycled aggregates to get the same slump as that of conventional concrete.
- Variation in the properties of the recycled aggregates between different batches was found to be tolerable. However it should be kept in mind that a limited number of batches were considered for the statistical investigation.
- The durability of different types of recycled aggregates concrete was found to be analogous to that of control concrete. The effect of exposure to sea water, soil conditions and open air for durations up to one year was in general the same for both recycled and new concretes.

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