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Research Note

Exploring the opportunities for reuse of municipal Construction and Demolition (C&D) wastes in concrete

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Abstract. The sustainable practices in the built environment are based on conservation of resources, such as minimum use of material, energy and water. Disposal of construction waste poses major challenge to the municipal administration of the developing countries. The fast urbanization and rapid construction in these countries has generated substantial volume of construction wastes. There are many options for the disposal of construction wastes. One of such options is to utilize these wastes as aggregates for concrete. The reuse of such aggregates in the concrete would reduce the disposal costs of construction wastes on one hand and burden on natural resources in terms of resource harvesting on the other hand. In this research work, the construction wastes collected from the municipal sources have been segregated, graded and utilized as aggregates in cement concrete. Considering different percentages of recycled aggregates, various concrete mixtures were prepared and tested to determine their compressive strengths for evalauating suitability of the concrete mixtures for construction purposes. The test results indiacte that the recycled aggregates can be used for producing plain concrete mixtures for mass concreting and construction of pavements and walkways.

1. Introduction

Almost 40% of the global solid wastes originate from Construction and Demolition Wastes (CDW). Construction and Demolition Wastes (CDW) constitute a major part of the municipal wastes in the developing countries of Asian continent. According to US Environmental Protection Agency (EPA) definition, CDW are waste materials produced in the process of construction, renovation and demolition of structures. The structures include residential, non residential buildings, roads & bridges of all types. The typical components of C&D wastes are concrete, bricks, asphalt, gypsum wall boards, metal and woods.

According to Gulf Today, the Gulf Cooperation Countries (GCC) produces 120 million tons of solid waste every year in which about 15% is construction wastes [1]. In Dubai municipality alone C&D wastes accounts for 75% of the daily solid wastes of 10,000 tons. Kartam et al. (2004) discussed the current status of construction and demolition waste disposal system in Kuwait and identified the potential problems to the environment, people and economy [2]. They investigated alternative solutions to manage and control this waste in an economical, efficient and safe way. The need for green buildings in Bahrain was

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investigated by AlNaser and Flanagan (2007). They reported that implementation of sustainable construction practices are limited in the country due to the lack of public awareness about sustainable technologies, lack of markets importing sustainable technologies, and client concerns about the profitability and pay-back period [3]. Kayali et al. (2008) reviewed the available industrial waste products that can be used in making sustainable concrete and their relevance to the Middle East, with particular attention to the GCC [4].

In research by Galbraith (2008) on structural sustainability, the role of structural design in sustainable buildings and its implication within the Gulf region were highlighted. Lately, Bahrain took the initiative to hold a Green Building Forum in 2010 at Manama. The forum's objective was to discuss the challenges faced by the construction industry, with consideration of the environmental concerns, including sustainable building materials, smart buildings, and other topics related to sustainable construction [5]. Sirin et al. (2013) reported that around 20 million tones of construction wastes are being annually generated at Qatar due to construction boom. They used the Reclaimed Asphalt Pavement (RAP) in the construction of road bases and sub bases. Different combinations were prepared and tested. The values were compared to Qatar's Construction Specification (QCS). However the results showed poor performance of the RAP as compared to the QCS [6].

In Hong Kong, the annual C&D wastes to the tune of 14 million tons are produced every year and the goverment of Hong Kong has formulated two sets of specification for use of recycled aggregates [7].

Similarly about 200 million tons of rubble is annually produced from the construction industry and building demolition in the European Union (EU). Approximately 40 million tons C&D wastes are generated annually in Spain, the equivalent of 2 kg per inhabitant per day; a figure higher than that for domestic waste. The pioneering countries in the areas of reusing and recycling of C&D include Holland, where 95% of construction residues are recycled, England with 45%, and Belgium with 87%, 17% of which is used in concrete production. In Spain only 5% of the aggregates are recycled and used as road base course. In 2007, 450 million tones of aggregates were extracted from quarries and 65% of it was used in concrete.

Awareness about CDW is increasing in the South Asian and Asia Pacific regions including countries like Hong Kong, Malaysia, Thailand, India and Sri Lank. There is an increased commitment from advanced countries like UK, Switzerland, Austria Netherland etc. to utilize non renewable material to avoid the construction wastes as these countries are faced with the space shortage for land filling [8].

UNEP- IETC (2006) initiated Sustainable Building and Construction Initiatives (SBCI) to support the sustainable environment friendly solutions for design and construction of built environment to ultimately reduce the CDW and resources utilization.

Some of the commonly used recycled aggregates include the following types:

- Recycled Concrete Aggregate (RCA);
- Recycled Concrete and Masonry (RCM);
- Reclaimed Aggregate (RA);
- Reclaimed Asphalt Pavement (RAP);
- Reclaimed Asphalt Aggregate (RAA);
- Glass cullet;
- Scrap tires;
- Used foundry sand.

American Concrete Institute (ACI) has focused on reuse of hardened concrete. The Recycled Concrete Aggregates (RCA) contain crushed sound and clean concrete by 95% of the total weight of concrete and contamination of 1% or less. The brick contents in RCA have to be limited to 0.5% of the total weight of concrete. The use of RCA has been mainly recommended for footpaths, kerbs, sideways, gutter etc. To limited extent RCA are used for structural members but here the RCA must be impervious and sound. RCA are commercially available in many developed countries. The Recycled Concrete and Masonry aggregates (RCM) must have not more than 30% of the crushed bricks. RCM are used in road sub bases and base courses. In some parts of the world, RCM are commercially available. The Reclaimed Aggregates (RA) are separated from cement slurry of the refused concrete from batching plants etc. and can be used effectively for developing the structural and non structural concrete provided that the aggregates are separated carefully. Reclaimed Asphalt Pavements (RAP) are obtained from old pavements and are widely used in the new asphalt concrete pavements. Sometimes RCA and PAP are blended to make aggregates for flexible pavements.

The use of recycled aggregates from CDW is becoming a popular option in many developing countries of Asia, mainly due to the initiatives of the respective Governments. Rafi et al. (2011) used the Recycled Aggregates (RA) from construction and demolition wastes in the Hot Mixed Asphalt (HMA) mixture. They used 50% recycled aggregates with the natural aggregates in the asphalt mix prepared in accordance to the requirements for wearing course as per National Highway Authority Pakistan specification. They conducted various tests and reported good performance of the HMA [9].

In Kuwait, Al-Mutairi and Haque (2010) used old demolished concrete to replace 50 and 100% of the coarse aggregate and seawater to replace 25, 50 and 100% of the tap water in a standard concrete mix having moderate target strength. The recycled concrete was cured in seawater for a period of 28 days. The results indicated that even with 100% usage of recycled concrete aggregate, design strength of 35 MPa was attainable. Highest concrete strength was obtained when the mixing water consisted of a blend of 25% seawater and 75% tap water [10]. Al-Harthy et al. (2007) conducted laboratory tests to examine the strength and durability of recycled aggregate concrete. The results showed that concrete strength is enhanced with the replacement of normal aggregates by recycled aggregate content of up to 30%, thereafter the strength decreases with further increase in recycled aggregate [11]. Fong et al. (2010) applied steam curing techniques to concrete made with recycled aggregates, and preliminary results indicated that compared with concretes cured under normal water temperature, steam curing increased the early strengths but reduced the long-term strengths for all normal and recycled aggregate concretes [12]. Chen et al. (2003) used the construction rubbles including bricks and tiles as replacement to aggregates in various proportions from 0% to 67%. They also proposed a flowchart for the preparation and processing of recycled aggregates [13]. Rakshvir et al. (2006) used various proportions of recycled aggregates and studied different mechanical and rheological properties of concrete. They showed that the water requirements have been increased with the use of recycled aggregates [14].

The use of industrial and quarry wastes have also been investigated by Binici et al. (2012). They used ground granulated blast furnace slag and basaltic pumice in equal proportions as fine aggregates in various proportions as substituent to the natural fine aggregates as 5%, 10% and 15% by weight. It was observed that at 5% substitution level of both the alternate fine aggregates led to the highest compressive strength as compared to the reference concrete without these additives [15].

Construction industry in India produces about 10-20 million tones of construction wastes annually, however it is mostly used as landfill material. Dabhade et al. (2012) studied various properties of concrete produced with recycled concrete from construction wastes such as workability test, compressive test, split tensile test and bulk density, water absorption, impact value test, crushing value test, and fineness modulus. They used various levels of recycled aggregates as substitutes of natural aggregates and found that up to 20% level of substitution, the compressive strength of concrete was relatively good, as compared to the reference concrete [16].

Kumar and Dhinikaran (2012) used four series of mixes of fresh aggregates concrete and recycled aggregates concrete with three different combinations of fly ash and super plasticizers. The various mechanical properties of concrete in fresh and hardened form were studied. On comparison of the results of the two types of concrete, it was reported that the results with recycled aggregates are encouraging [17].

The literature review illustrates that there is an increased awareness amongst the researcher and concrete technologists to explore and indentify alternate raw material as substitutes for natural material particularly aggregates in construction. However due to lack of standardization of collection, sorting, crushing and testing procedures for the construction wastes, these opportunities are not harnessed to the greater extent. Furthermore at local level, the limited research work has also impeded the use of waste material in construction.

2. Materials and methods

2.1. Material

The MSW collected from the Islamabad, Pakistan, and construction sites of Allama Iqbal Open University (AIOU) was used for the research work. The demolished material collected from the construction site was crushed with the help of jaw crusher to the desired sizes. The gradation of the done as per ASTM methods and the results of the sieve analysis are given in Table 1 and the corresponding gradation curve is given in Figure 1.

For fine aggregates, sand collected from local source of Lawrencepur River was used. The sieve analysis of the fine aggregates is shown in Table 2 and gradation curve is shown in Figure 2. Here, the fineness modulus is defined as:

$$\text{Finess modulus} = \frac{\sum \text{cumulative \% retained}}{100}, \qquad (1)$$

which has been numerically found to be 2.22.

To check the resistance to degradation, Los Angeles abrasion test for the coarse aggregates was carried

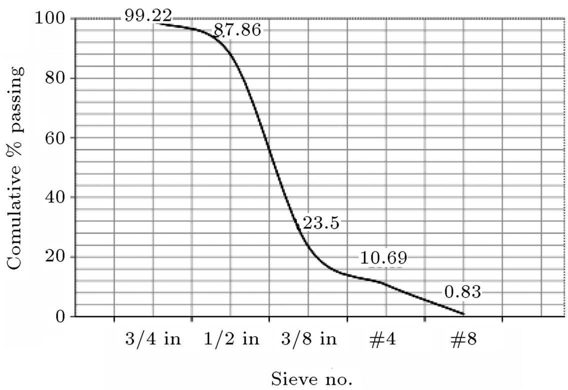

Figure 1. Gradation curve of crushed recycled aggregates collected from construction wastes.

Table 1. Gradation and sieve analysis of crushed reused aggregates.

Sieve size/#	Mass retained (gm)	Retained %	Cumulative % passing	Cumulative % retained
1 in	78	0.78	99.22	0.78
3/4 in	1136	11.36	87.86	12.14
1/2 in	6436	64.36	23.5	76.5
3/8 in	1281	12.81	10.69	89.31
# 4	9860	9.86	0.83	99.17
Pan	83	0.83	0	-

Table 2. Gradation and sieve analysis of fines aggregates used in tests.

Sieve size/#	Mass retained (gm)	Retained %	Cumulative % passing	Cumulative % retained
# 4	0	0	100	0
# 8	0	0	100	0
# 16	11	0.40	99.60	0.40
# 30	1243	49.83	49.76	50.24
# 50	663	26.58	23.17	76.82
# 100	462	18.52	4.64	95.35
# 200	97	3.88	1.05	98.94
Pan	18	0.72	0.32	99

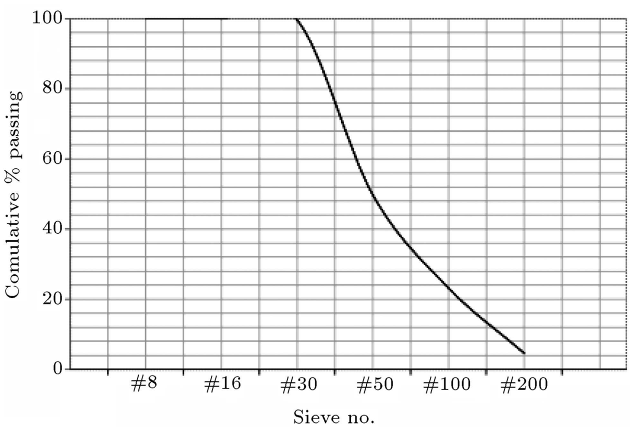

Figure 2. Gradation of fine aggregates used in the tests.

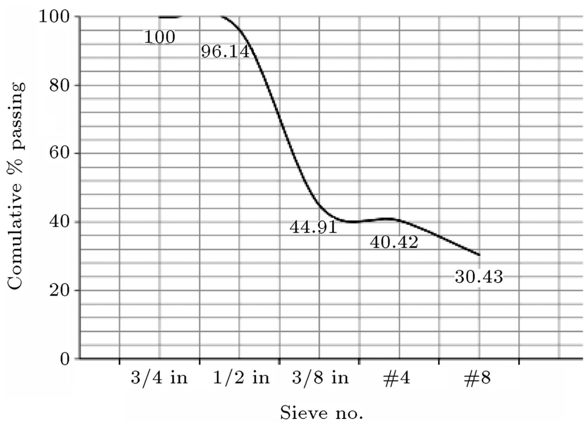

Figure 3. Gradation of recycled aggregates after abrasion test.

out as per ASTM C535-09 methods. The data of test results after abrasion test is given in Table 3 and respective gradation curve is given in Figure 3.

To calculate the loss on abrasion, the following procedure was followed:

Sample taken = 1000 gm (10 Kg),

Weight of sample taken = w_1 = 10 kg

Weight of aggregates greater than #10 sieve = w_2 =7.442 kg

Loss = $w_1 - w_2$ =10 - 7.441 = 2.528

Abrasion loss % =(2.528/10) $\times$ 100 = 25.28%.

The value is reasonable for the use in concrete. Ordinary Portland Cement (OPC) type-1 was used conforming to ASTM C150-97.

Mix design of concrete. For concrete mix design, the nominal ratio of 1:1.8:3.6 was used by weight. In controlled mix, natural aggregates were used. The proportion of the ingredients was kept the same for both the Natural Aggregates Concrete (NAC) and Recycled Aggregates Concrete (RCA). The standard cylinder of 150 mm diameter and 300 mm depth was used as per ACI-318 standards. The slump of concrete was fixed at about 50 mm and clean potable water was used. The water cement ratio was adjusted to achieve the desired concrete slump. The substitution of natural aggregates was done with recycled aggregates in 25%, 50%, 75% and 100%. These concretes have been labeled as RAC-25, RAC-50, RAC-75 and RAC-

Table 3. The sieve analysis of the coarse aggregates after abrasion test.

Sieve size/#	Mass retained (gm)	Retained %	Cumulative % passing	Cumulative % retained
1 in	0	0	100	0
3/4 in	378	3.86	96.14	3.86
1/2 in	5013	51.23	44.91	55.09
3/8 in	440	4.49	40.42	59.58
# 4	978	9.99	30.43	69.57
Pan	2976	30.43	-	

Figure 4. Concrete compressive crushing strength machine.

100. The concrete with natural aggregate was labeled as NCA. Three concrete cylinders were cast from each types of concrete, i.e. NAC, RAC-25, RAC-50, RAC-75 and RAC-100 and a total of 15 cylinders were cast at the specified mix design as already explained. The slump of the concrete was measured with slump cone.

Testing of concrete cylinders. To check the compressive strength of the cylinders, concrete crushing machine was used as shown in Figure 4. The cylinders were tested under compression testing machine and the loads were gradually applied with the hydraulic load system. The cracking pattern of the cylinders and crushing strength was noted for each sample.

3. Results and discussions

The results of the compressive strength of RCA based concrete and other properties are given in Table 4 and Figure 5.

Water content of the recycled aggregates concrete. The water requirement of the RAC has been

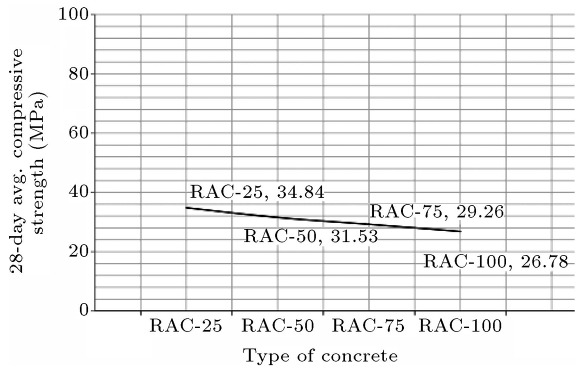

Figure 5. Compressive strength (28 days) of various concretes.

increased with the increase in the proportion of recycled aggregates in the concrete. This is mainly due to the fact the recycled aggregates contain a large part of the mortar sticking with the aggregates and cannot be removed even with crushing of the used concrete blocks. The mortar is relatively porous as compared to natural aggregates. This increase in water requirements has also contributed to the partly decrease of compressive strength of RAC. In cases where RAC is used on large scale, it is advisable to moist the aggregates to reduce the water requirements.

Compressive strength of concrete. Compressive strength of RAC decreased with the increase of the proportion of the recycled aggregates as compared to the controlled concrete of NAC. However with 100% replacement of natural aggregates with the recycled aggregates, the strength of concrete observed is reasonably good for its use as ordinary plain concrete. The use of RAC for structural components needs to be explored further.

Failure mechanism of Recycled Aggregates Concrete (RAC). There is a marked difference in the failure mechanism of NAC and RAC. In NAC, the failure normally occurs at the boundary of aggregates and the micro cracks passes through the cement mortar at the periphery of natural aggregates. The irregular shape of aggregates provides an interlocking property

Table 4. The 28-day compressive strength, water cement ratio slump and other details of Recycled Aggregates Concrete (RAC).

Concrete type	Sample no.	Aggregates mix (%)		Nominal mix ratio by weight	w/c ratio	Slump (mm)	28-day compressive strength (MPa)
		Natural	Recycled				
NAC	NAC-01	100	0	1:2.8:3.6	55%	52	35.86
	NAC-02	100	0	1:2.8:3.6	57%	54	34.52
	NAC-03	100	0	1:2.8:3.6	60%	55	34.14
RAC-25	RAC-25-01	75	25	1:2.8:3.6	62%	48	32.42
	RAC-25-02	75	25	1:2.8:3.6	63%	50	31.17
	RAC-25-03	75	25	1:2.8:3.6	61%	51	31.01
RAC-50	RAC-50-01	50	50	1:2.8:3.6	65%	54	29.65
	RAC-50-02	50	50	1:2.8:3.6	64%	53	29.12
	RAC-50-03	50	50	1:2.8:3.6	62%	56	29.01
RAC-75	RAC-75-01	25	75	1:2.8:3.6	66%	59	26.89
	RAC-75-02	25	75	1:2.8:3.6	68%	53	27.14
	RAC-75-03	25	75	1:2.8:3.6	69%	54	26.32
RAC-100	RAC-100-01	0	100	1:2.8:3.6	70%	51	22.06
	RAC-100-02	0	100	1:2.8:3.6	74%	54	21.98
	RAC-100-03	0	100	1:2.8:3.6	72%	56	21.32

Figure 6. Failure plains of old mortars in RAC.

for concrete, which contributes to the increase in crushing strength in general and shear strength of concrete in particular. For high strength concrete, this aggregates interlocking is however reduced as due to high strength of the concrete mix, the aggregates are broken instead, before reaching at the level of aggregates interlocking. This is one of the major causes for the reduction of shear strength of high strength concrete. In RAC, the weak part of the concrete is the old mortar, as the strength of the previous mortar cannot be ascertained for new concrete. The cracks normally develop in the old concrete mortar as shown in Figure 6.

4. Conclusions

The aggregates form CDW can be used for the mass concrete, pavements and walkways on the basis of the strength of concrete achieved. The existing batching plants in the region needs separate facilities to crush, sort and grade the used aggregates for its potential use in the concrete. The mechanical properties of RAC for its use in structural concrete require extensive research in the region.

There is certainly an additional cost associated with transportation, sorting and crushing of the construction wastes before its use as aggregates. This makes the reuse of construction waste least attractive for the contractors and Engineers. However the environmental cost of using virgin aggregates is also playing havoc with the natural resources in the world. However Governments in the developing countries would require offering incentives and tax subsidies for use of recycled aggregates to promote the culture of reuse of old building material. This is an essential component of LEED (Leadership in Energy and Environmental

Design) and related certification but unfortunately, this kind of certification has not been applied in most of the developing countries.

There is a need to develop specification and testing procedure for recycled aggregates in the region.

It is recommended that the countries of South East and South Asia may work collaboratively to explore opportunities for reusing and recycling of old concrete for aggregates.

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