Geotechnical Characterization of Recycled Aggregates (RA) Comprising of Mixed Waste from Construction & Demolition (C&D) Plants

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Abstract. India produces approximately 100 million tonnes of C&D waste per annum. Attempts are being made to separately process the C&D waste by segregating it from MSW stream. For this, C&D waste processing plants have been established in Delhi. About 1.15 million tons of C&D waste is annually processed in these plants. The bulk output from these plants are Recycled Concrete Aggregate (RCA) (10%), Recycled Aggregate (RA) (55%) and silt like fraction (below 0.075 mm) (35%). RCA and silt like fraction have reasonable demand in industry. RA comprising of mixed waste which has brickbats in highest proportion have low demand. It is coined as MRA (Mixed Recycled Aggregate) thereafter. Some areas in which gravel or sand sized fraction of the MRA can be used are filters, drains and backfill for embankments.

The geotechnical characteristics of MRA from two C&D plants C&D P1 and C&D P2 were studied in lab for the sand sized fraction. Grain size distribution, compaction, specific gravity, permeability and shear strength test was done on RAB. The results have been compared with the locally available Badarpur sand (BS). From the testing results it is observed that geotechnical properties like specific gravity, compaction, permeability and shear strength of MRA is similar to BS. This study serves as a starting point for use of MRA to be used in various geotechnical application.

Keywords: C&D waste; Recycled aggregate; brickbats; Mixed recycled aggregate.

1 Introduction

Reuse of waste materials is a topic of global concern and of great international interest. The urgent need for reuse of waste materials is driven primarily by environmental considerations attributable to the increased scarcity of natural resources and the increasing cost of landfill in most countries [1]. C&D waste generation globally exceeds 3 billion tonnes [2]. For United States, the generation of C&D waste has increased from 519 MT in 2012 to 548 MT in 2015 [3]. Globally, it is estimated that about 35% of the quantities of C&D waste produced are directed to landfills, without any further treatment, although efforts to recycle and reuse C&D waste are increasingly being made [4]. Recycling rate varies from 7% or less for various countries like Canada, Croatia, Africa etc. to more than 90% in Estonia, South Korea etc. In the countries where there is no recycling, this waste mostly ends up in a landfill. For proper recycling or reutilization of C&D waste, the focus should be on the proper collection of data. Two largest producers of C&D waste countries, China and India both have limited focus in the area of proper data collection.

In the Indian scenario, the total quantum of waste from the construction industry generated was estimated as 12 to 14.7 million tons per annum in the year 2000. According to CSE report [5], the amount of C&D waste generated in India just by buildings in one year is 530 MT. This figure is 44 times more than the official estimate of C&D waste generation in India.

Most of the data available for the assessment of C&D waste production in India is underestimated. There is an uncertainty of the quantum of C&D waste generation in India. It is estimated that the C&D waste comprises of 25-30% of total solid waste generation. India produces approximately 25-30 million tonnes of C&D waste annually, of which less than 5 per cent is processed, the remaining being sent for dumping, adding to the already overburdened dumping sites and attendant problems [6]. There is no concrete data available on the quantity of generation and reutilization of C&D waste in India. Previous researchers have shown the potential reuse of recycled C&D waste in various geotechnical applications like backfill for retaining walls, sub-base material, reclaimed soil for pipes, soft soil improvement [7].

In India so far, no study is reported which gives the systematic geotechnical characterization of waste material from C&D waste processing plants. Thus, through this paper it is an attempt to understand the feasibility of using mixed waste coming out of processing plants in Delhi in the form of Recycled Aggregate Bricks in various geotechnical applications. The results were compared with locally available sand i.e., Badarpur Sand.

2 Materials and Testing Methods

2.1 Material

C&D waste was collected from two C&D waste recycling plant C&D P1 and C&D P2 in Delhi. Both the plants do pre-sorting of waste into two streams (concrete waste and mixed waste) before processing. The concrete waste undergoes dry processing which mainly includes breaking the large chunks of concrete into a smaller size fraction and separating it out in different fractions. The mixed waste undergoes breaking off big chunks of waste material and washing it so that soil or any foreign particle sticking to the big particle can be removed. After washing it was also separated into different fractions. The processed sample coming out from concrete waste is termed as Recycled Concrete Aggregate (RCA) and from mixed stream is termed as Recycled Aggregate (RA)/Mixed Recycled Aggregate (MRA). MRA is comprising of concrete, brick bats and other waste material in mixed form. For this research Mixed Recycled Aggregate (MRA) was considered for analysis.

2.2 Sampling

The output of both C&D waste processing plant C&D P1 and C&D P2 was subdivided into different fraction range i.e., sample size ranging from 20 mm to 10 mm, 10 mm to 4.75 mm, 4.75 mm to 0.075 mm and less than 0.075 mm. For the analysis, material size passing from 4.75 mm and retained on 0.075 mm was sampled from both the processing plants C&D P1 and C&D P2. This part contributes to about around 16 to 18 % of the total waste received at the processing plant (as reported by recycling plants). In order to do various geotechnical testing, about 100 kg of sample was collected from both the recycling plant. The reference material for comparison comprising of Badarpur Sand (BS) was sampled locally.

2.3 Testing methods

Extensive geotechnical testing was carried out on MRA procured from two processing plants. The following tests were conducted:

Grain Size Distribution: This test was carried out according to ASTM D 6913. The material in the test was separated into various fractions. According to ASTM D 6913, if particle size is less than or equal to 4.75 mm, then single-set sieving is applicable.

Specific Gravity: Specific gravity of material was found adopting procedure in IS 2720: Part III using Density Bottle.

Standard Proctor Test: The test was conducted according to ASTM D698-12e2 in order to obtain Maximum Dry Density (MDD) (γd) and Optimum Moisture Content (OMC) using Standard Proctor Test.

Permeability: As the material seems to be in the range of sand, thus constant head method was employed for measuring the permeability of material. The test was conducted as per the method laid in IS: 2720 - Part 36.

Shear Strength Characteristics: For any geotechnical purpose, shear strength of material plays an important role to play. In order to find shear strength parameters of material, Direct Shear Test (DST) was carried out at dry condition on a shear box of size 60 mm X 60 mm cross section. The testing was done as per the method described in IS: 2720 - Part 13. The samples were prepared at two different densities i.e., one at dense condition (around 80% R.D.) and one at loose condition (around 30% R.D.). The test was performed at three different normal stresses i.e., 100 kPa, 200 kPa and 400 kPa for both the conditions. The strain rate employed during the test was 0.25 mm/min. The test was run till 15 % strain so that residual characteristics can also be studied.

3 Results and discussion

3.1 Grain Size Distribution

Particle size distribution and gradation characteristics are presented in Table 1 for MRA from C&D P1 and C&D P2 and reference material Badarpur sand (BS). It was not washed and no wet sieving was carried out as materials received from both the plants were already washed at the processing plant.

Table 1. Comparison of Grain Size Distribution of MRA with reference material

Properties	C&D P1	C&D P2	BS
Coarse sand size, 4.75 to 2.0 mm, %	14.3	1.16	2.6
Medium sand size, 2.0 to 0.425 mm, %	36.5	26.4	58.0
Fine Sand Size, 0.425 to 0.075 mm, %	42.0	62.9	37.9
Silt and Clay Size, less than 0.075 mm, %	7.3	9.5	1.5
D10, μm	100	77	240
D30, μm	250	160	370
D60, μm	580	294	570
Coefficient of Uniformity, Cu	5.80	3.81	2.38
Coefficient of Curvature, Cc	1.08	1.13	1.00

From the grain size distribution, it can be inferred that the C&D waste from two processing plants P1 and P2 are very much similar to that of reference material BS. Majority of material in P1 and P2 is medium to fine sand. The fraction below 0.075mm is less than 10% in both the cases.

Visually, the material in the range from 4.75 mm to 2 mm comprising mostly of bricks bats. It was not feasible to do compositional analysis for material below 4.75 mm by naked eyes. Thus, shape of the particles was studied with the help of digital microscope. The grains were angular with sharp edges.

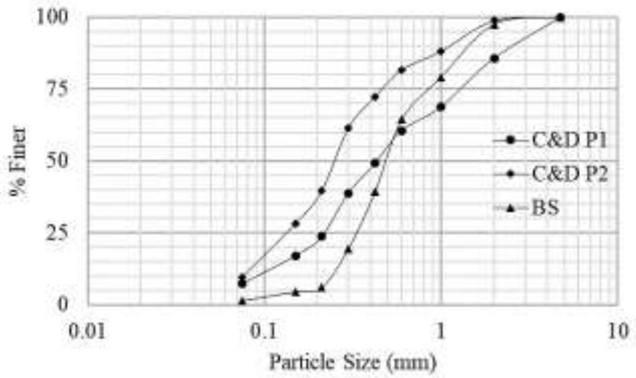


Fig. 1. Comparison of grain size distribution of MRA from two processing plant P1 and P2 with reference material

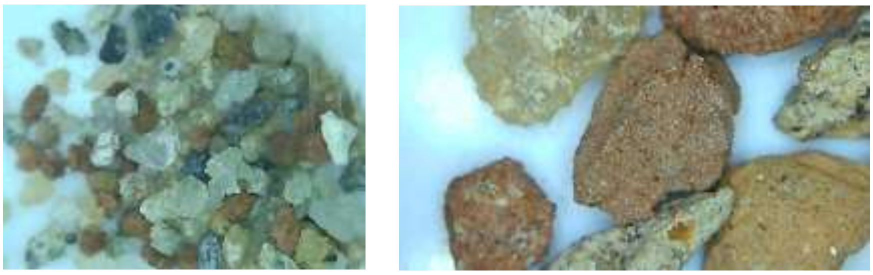


Fig. 2. Grains shape of MRA from two processing plants at 50X magnification

3.2 Specific Gravity

From Table 1 it is evident that most of the fraction of sample is in range of medium to fine sand. Thus, specific gravity of sample from C&D P1 and C&D P2 and reference material BS was found using specific gravity bottle. The specific gravity of sample from both the plants (P1 and P2) along with BS are summarized in Table 2 below:

. **Table 2.** Specific gravity of C&D waste from two processing plant

Sample	Specific Gravity
C&D P1	2.54 – 2.66
C&D P2	2.58 – 2.72
BS	2.63 – 2.69

The variation in specific gravity is more for C&D waste as compared to reference material due to heterogeneity of material.

3.3 Standard Proctor Test

The test was conducted using Standard Proctor Test. Table 3 and Fig. 3 below gives the maximum dry density and optimum moisture content for C&D P1, C&D P2 and BS.

Table 3. MDD and OMC of C&D waste from two processing plant P1 and P2 and reference material

Sample	MDD (kN/m^3)	OMC (%)
C&D P1	17.2	16.7
C&D P2	16.9	16.4
BS	17.6	16.0

The compaction curve of the waste material from both the plants P1 and P2 does not show a significant peak.

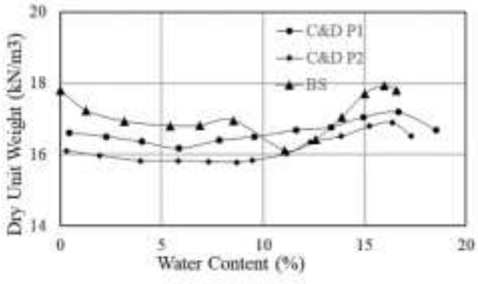


Fig. 3. Comparison of Compaction behavior of MRA from two processing plant P1 and P2 with reference material

3.4 Permeability:

The permeability of C&D waste was evaluated using constant head method. Table 4 summarizes the permeability value for C&D waste from P1 and P2 along with reference material BS.

Table 4. Permeability values of C&D waste from two processing plant

Sample	Permeability (cm/sec)
C&D P1	10^{-3} to 10^{-2}
C&D P2	10^{-3} to 10^{-2}
BS	10^{-2}

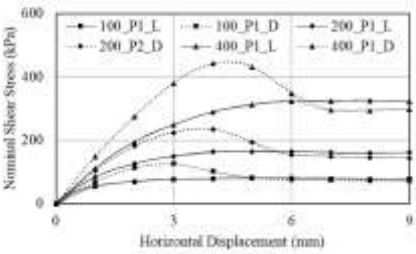
3.5 Shear Strength Characteristics:

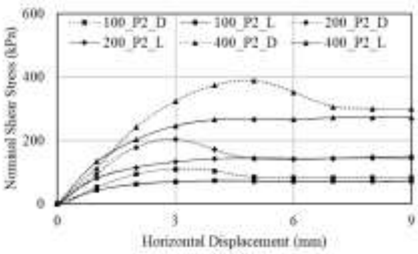
Shear test was conducted using Direct Shear Test. Table 5 shows the resulting peak and residual angle of shearing resistance (φ) at dense and loose condition. It also gives dilation angle (ψ) for both the cases i.e., at dense state and at loose state. Fig. 4 gives the shear stress behavior of the materials with the increase in horizontal displacement and volume change behavior of material with increase in horizontal displacement. Finally, Fig. 5 gives the failure envelops of material from plant P1 & P2 and BS for dense and loose condition.

Table 5. Shear Strength parameters of waste from processing plant P1 and P2 and reference material

Properties	C&D P1		C&D P2		BS	
	Dense	Loose	Dense	Loose	Dense	Loose
φ peak (°)	48.7	39.3	44.7	34.8	43.9	32.6
φ residual (°)	36.1	37.7	36.6	34.1	32.4	29.8

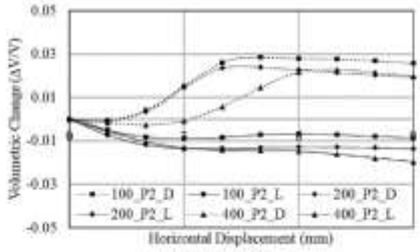
ψ (°)	12.6	1.6	8.1	0.7	11.5	2.8

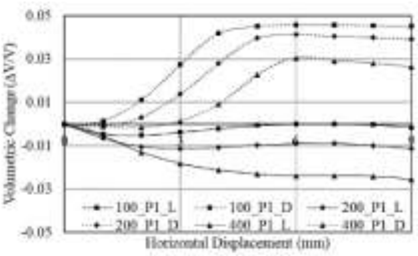


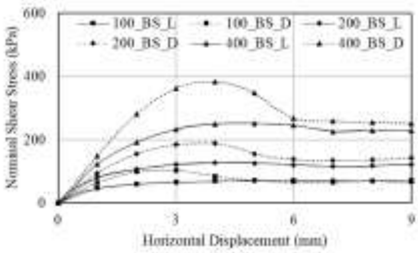


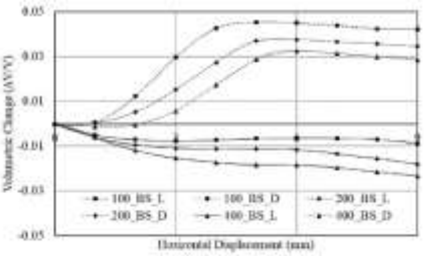
(a) C&D processing plant P1

(b) C&D processing plant P2



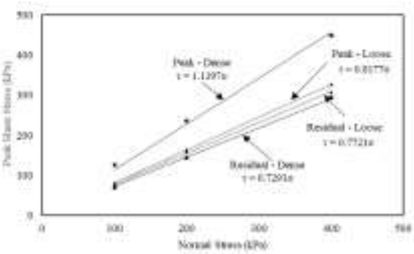




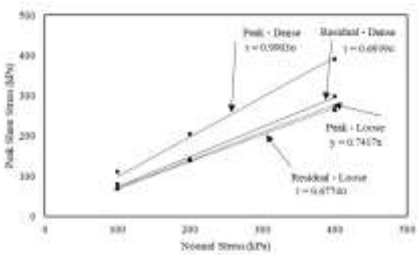


(c) Reference material BS

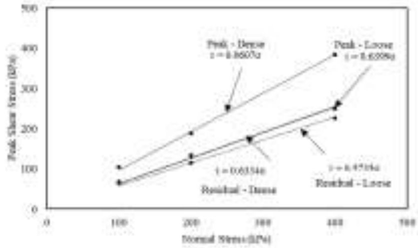
Fig. 4. Nominal Shear Stress – Horizontal Displacement and Volume change – Horizontal Displacement behavior of material from plant P1 & P2 and BS



(a) C&D processing plant P1



(b) C&D processing plant P1



(c) Reference material BS

Fig. 5. Failure Envelops of material from plant P1 & P2 and BS for dense and loose condition

From the shear strength curves, it can be concluded that the angle of shearing resistance for C&D waste from both the plants P1 and P2 are high as compared to reference material. When the sample is compacted in dense compaction state i.e., at R.D. 70%, the peak angle of shearing resistance converges to residual strength parameters with the increase in horizontal displacement. When the sample is loose compaction state i.e., at 30% R.D., the convergence of peak shear strength value to residual shear strength value was negligible with the increase in horizontal displacement. At 80% R.D., all the materials exhibited positive dilation for all the normal stresses and the dilatancy decreases with increase in normal stresses. This is the typical characteristics behavior of granular material. [8]

4 Conclusions

The material from both C&D waste processing plant P1 and P2 is comprising mainly of mixed waste and which is termed as Mixed Recycled Aggregate (MRA). From the extensive geotechnical testing carried out on sample from both the plants P1 and P2 and Badarpur Sand as reference material, following can be concluded:

1. The particle size of the MRA waste comprising predominantly of medium to fine sand.

2. The specific gravity and permeability are in the same range as that of reference material.
3. From the compaction characteristics it can be concluded that the material shows similar behavior as that of granular material.
4. The shear strength behavior of material is similar to that of reference material. The φ values obtained for the MRA is in the range of 49° to 36° for plant P1 and 45° to 34° for plant P2. The C&D waste exhibits convergence of peak shear strength to residual shear strength at dense condition, with the increase in horizontal displacement.
5. C&D waste shows positive dilation for all the normal stress in dense condition and compression in loose condition. This behavior is similar to that of granular material.

This paper gives the geotechnical characteristics of C&D waste derived from Mixed Recycled Aggregate which are similar to those of reference material i.e., Badarpur sand. The chemical characteristics which includes pH, TDS and heavy metals in the waste material have to be studied prior to use in field.

5 References

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