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DEMOLITION CONCRETE AGGREGATE: A POTENTIAL RESOURCE FOR ROAD CONSTRUCTION

Sayed Andul Mofiz[1], Md. Niamul Bari[1] and Md. Abu Bakar Siddique[1]

[1,2,3]Department of Civil Engineering, RUET

ABSTRACT

The demolished concrete is increasing in the whole world as well as in Bangladesh gradually which creates a hazard for the environment and eventually becomes a burden unless recycled. It is growing interest to innovate the scope of using demolition wastes to manage the environmental hazard by recycling. The physical properties of the concrete aggregate derived from demolition wastes were investigated aiming to use as sub-base and sub-grade materials in road construction in the present study. The demolition wastes were collected from demolition site of buildings and concrete pavement in Rajshahi City. The collected demolition waste materials were investigated for Particle Size Distribution, Flakiness Index and Elongation Index, OMC and MDD, Specific Gravity, Water Absorption, Unit Weight, Aggregate Impact Value (AIV), Los Angeles Abrasion (LAA), Soundness and California Bearing Ratio (CBR). The experimental results show that the properties of investigated demolition wastes satisfied the requirements of sub-base and base course of road pavement. The results were also compared with the fresh brick aggregate. Therefore, it is revealed that the demolition wastes materials would be a potential resource as substitute of fresh brick aggregate and utilized as coarse aggregate in sub-base and base of pavement construction.

Keywords: Demolition concrete, reuse, sub-base course, base course, pavement construction

INTRODUCTION

Aging of structure and increasing interest to build high rise building accelerated the rate of demolition of old structure worldwide. The concrete waste from demolition from public facilities is 10% and 16.7% of the generated solid waste in case of residential buildings (Sobotka, et al., 2019). Concrete waste produced in EU countries varies from 12% to 40% (Sobotka, et al., 2019). The demolition and reconstruction are the regular phenomena in both developed and developing countries. Rapid urbanization in developing countries like Bangladesh contributed a huge quantity of demolition concrete waste in total wastes stream that creates crucial situation in environmental management. Bangladesh government like other government of different countries (Singh and Kumar, 2014) has set national 3R strategy for waste management to improve the use of recycled aggregates in newly constructed building and structures for protection of environment and promotion of the principles of economical development (DoE, 2010).

The researchers are now more interested on reducing waste, reusing and recycling resources and products for sustainable waste management. The researchers are trying to develop a sustainable construction waste management practice commonly by using as coarse aggregate and fine aggregate (Tavakoli, et al., 2018; Tomas, 2015) as well as replacing cement (Collivignarelli, et al., 2020) in concrete structure. The various demolition wastes such as rubber (Tavakoli, et al., 2018), glass (Srivastava, et al., 2014), fly ash, slag, foundry sand, marble dust (Rajesh, et al., 2019), crushed concrete (Tomas, 2015) are used in concrete by different researchers. However, a few researches have been carried out on the recycled aggregate from demolition wastes for using in road construction in base layer (Zuazo, et al., 2020). On the other hand, construction of new flexible pavement is increasing every year along with the repair and reconstruct in Bangladesh that increases the demand of brick aggregates. The increasing demand of brick aggregates in road construction in addition to other construction impacts on brick production as well as environmental pollution by burning fossil fuel and green house gas emission. Therefore, the aim of this study is to investigate the different physical and mechanical properties of demolition waste aggregate to use in sub-base and base course of road construction that can reduce the demand of brick production as well as environmental pollution.

METHODOLOGY

An in-depth investigation was carried on demolition waste aggregate by collecting from different types of sources and prepared as required for the investigation as per standard procedure. The physical and mechanical properties of materials were determined and evaluated for the potential of recycling in an intended purpose. The methodology of the study is elaborately described in following section:

Collection of Demolition Concrete Wastes

The demolition wastes (concrete block) were collected from three types of sources within Rajshahi municipal area like cement concrete road pavement demolition sites (sample, S-1), seven building demolition sites (sample, S-2 to S-8), and crashed concrete cylinders made at concrete laboratory of RUET (sample, S-9). The fresh brick aggregate (sample, S-10) was also collected from local market, Rajshahi. The demolished concrete blocks were crushed into required sizes to prepare demolished concrete aggregate (DCA) manually and leveled for laboratory test.

Experimental Procedures

Various tests were performed to characterize the properties of the demolition concrete aggregate (DCA). The laboratory experiments were conducted for particle size analysis according to AASHTO T27, Flakiness Index and Elongation Index according to BS-812, Moisture/Density relationship (OMC and MDD) and Modified Proctor by using AASHTO T180, Specific gravity and water absorption properties according to ASTM C127, Unit weight and voids in aggregate using ASTM-C29, Aggregate Impact Value (AIV) using BS-812, Los Angeles abrasion (LAA) using ASTM-C131, Soundness test using AASHTO-T104 and California Bearing Ratio (CBR) test according to AASHTO T193.

RESULTS AND DISCUSSION

The physical and mechanical properties of demolition concrete aggregate obtained from laboratory investigation following the standard test methods are presented and discussed in the following sections. The acceptability of the demolition concrete aggregate as a sub base course material for pavement construction was also evaluated.

Gradation of Aggregates

Gradation or particle size distribution of aggregate is important for the use in road construction. Local Government Engineering Department (LGED), the road construction authority in Bangladesh, has their guideline for the selection of aggregate to use in sub-grade for road construction. The gradations of DCA collected from ten different sources were performed to evaluate the requirement of LGED and results are presented in Figure 1. It is observed from obtained results that the percentage passing of each size of collected DCA material is within the lower and higher value of requirement. Therefore, DCA that usually generated from demolition of old building or concrete pavement can be used in sub-grade for road construction. Moreover, the materials finer than 0.075 mm are within the 5%~15% can be used as a supplementary material of fine aggregate.

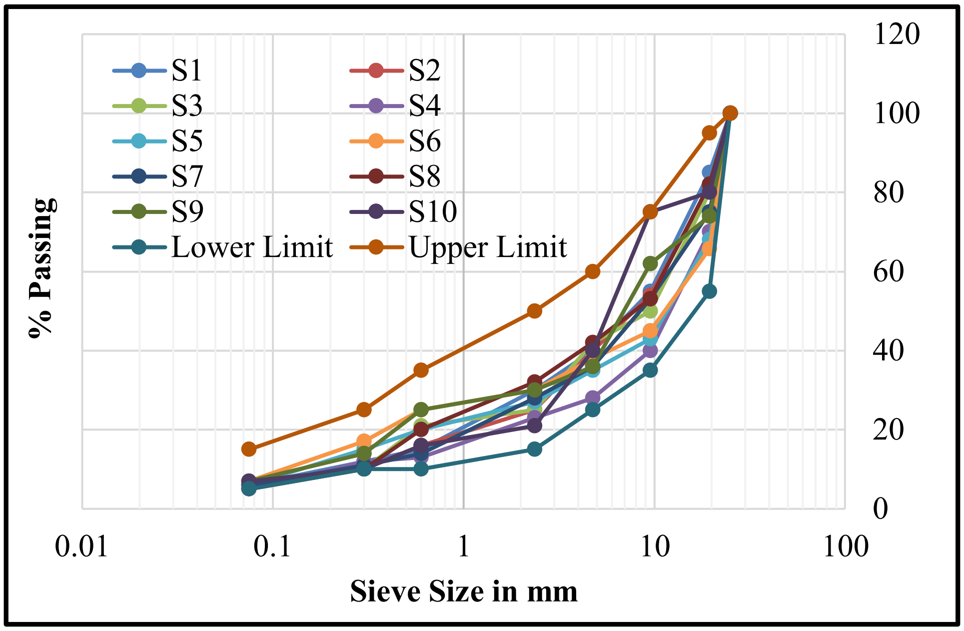

Figure 1 Gradation Curve for Selected Aggregate Type (S1~S10)

Flakiness Index and Elongation Index of DCA

The shape of aggregates is determined by the percentages of flaky and elongated particles contained in it. The presence of flaky and elongated particles is considered undesirable for construction of sub-base and base course in pavement construction as these cause inherent weakness with possibilities of breaking down under heavy loads. Flakiness Index is the percentage by weight of particles in it, whose least dimension (i.e. thickness) is less than 0.6 times of its mean dimension. Flakiness Indices of DCA are presented in the Table 1. The flakiness index greater than 30% is considered to be undesirable. The results show that the Flakiness Index of collected DCA varies from 13% to 15% which are within the limiting values of sub-base course aggregate.

Table 1 Flakiness Index of DCA and fresh brick aggregate

Aggregate Type	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Flakiness Index (%)	15	15	14	13	15	13	15	14	14	15

Furthermore, the elongation index of the tested samples varies from18% to 22% and aggregate having elongation index higher than 45% is considered as undesirable. The test results presented in the Table 2 show that the Elongation Indices are well below the limiting values for sub-base course aggregate and satisfied the requirement.

Table 2 Elongation Index of DCA and fresh brick aggregate

Aggregate Type	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Elongation Index (%)	18	19	21	18	19	19	21	22	19	19

Considering flakiness index of experimented materials reveals that the result is within the limiting value according to BS 812 and elongation index is beneath the highest allowable value of about 45%.

Moisture-Density Relationship

Modified Procter compaction test was performed to determine the optimum moisture content and maximum dry density as per AASHTO T180 for the selected aggregate types (S1~S10). The variations of dry densities with respect to moisture contents for selected 10 samples are shown in Figure 2 and the values of optimum moisture contents (OMC) to obtain the maximum dry density (MDD) obtained from the plots are presented in Table 3.

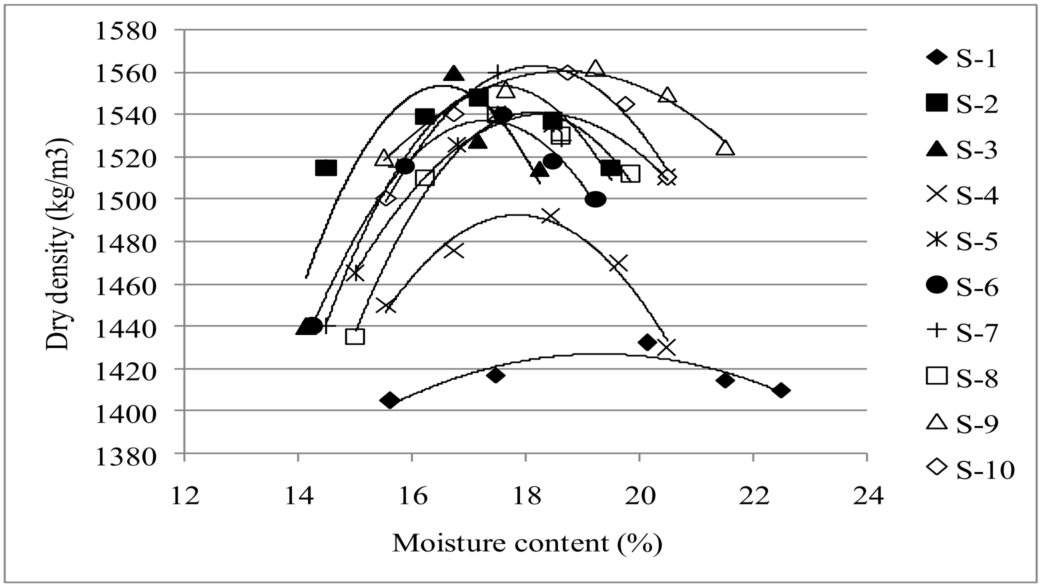

Figure 2 Relationship between OMC and MDD of DCA and Fresh brick aggregate

Table 3 The OMC and MDD values of DCA and fresh brick aggregate

Aggregate Type	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
OMC (%)	19.40	17.25	16.5	18.25	18.5	17.5	17.7	18.15	18.75	18.25
MDD (kg/m^3)	1428	1545	1555	1495	1540	1535	1555	1542	1565	1565

The results show that OMC vary from 16.50% to 19.40% and MDD vary from 1428.0 kg/m^3 to 1565 kg/m^3 for the Selected DCA (S1~S9) whereas OMC and MDD are 18.25% and 1565 kg/m^3, respectively for fresh brick aggregate. Some DCA materials show comparatively higher OMCs and lower MDDs than that of the fresh brick aggregate. The main reason for the higher water absorption is the presence of cement mortar fines. The DCA samples were prepared by two stages of crashing. Initial crushing was at the time of building demolition and second crushing was at the time of preparation of DCA samples for laboratory experiments. This causes easy breakage of the materials and adds more fines at the compaction. Therefore, lack of coarser particles and higher constituents led for lower bulk density and thus for lower MDDs in DCA materials. However, there is no significant difference between DCA materials and fresh brick aggregate in respect of moisture content and dry density. These results are encouraging for the reuse of DCA comfortably in road pavement construction.

Specific Gravity and Water Absorption

The specific gravity of solid is frequently required for computation of several qualities such as void ratio, degree of saturation, unit weight of solids in various states. Water absorption gives an idea about the strength of aggregate. The test results of specific gravity and water absorption of selected DCA (S1~S10) are shown in Table 4.

Table 4 Specific gravity and water absorption values of selected aggregates

Samples	Bulk Sp. Gr.	Bulk Sp. Gr. (SSD)	Apparent Sp. Gr.	Water absorption (%)
S1	1.82	2.07	2.42	13.4
S2	1.80	2.07	2.47	15.04
S3	1.81	1.98	2.18	9.51
S4	1.82	2.1	2.52	15.47
S5	1.84	2.15	2.6	17.19
S6	1.82	2.07	2.43	13.9
S7	1.81	2.02	2.31	12.16
S8	1.82	2.07	2.43	13.73
S9	1.83	2.05	2.37	12.5
S10	1.80	2.02	2.31	12.11

The specific gravity and water absorption of nine DCA materials vary from 1.80 to 1.84 and 9.51% to 17.19%, respectively and for fresh brick aggregate is 1.80 and 12.11%. There is no significant difference between the DCA materials and fresh brick aggregate material in respect of specific gravity. The average water absorption capacity of DCA is 13.66% while the water absorption capacity for the fresh brick aggregate is 12.11% which is near to the average value of DCA. It is observed that the results of bulk specific gravity of various DCA materials are very much consistent and that indicates the possibility of reusing DCA generated from any sources. From the obtained results, it is conspicuously understood that DCA is the same in quality to the fresh brick aggregate commonly used in sub-base course in pavement construction.

Unit weight and Voids in Aggregate

The unit weight and voids of selected aggregates (S1~S10) are presented in Table 5.

Table 5 Unit weight and voids of selected demolition concrete aggregates

Samples	Unit weight (Loose) kg/m^3	Unit weight (Dense) kg/m^3	Bulk Sp. Gr.	% Void
S1	1070	1295	1.82	28.87
S2	1120	1285	1.80	28.60
S3	1050	1210	1.81	32.93
S4	985	1205	1.82	33.53
S5	1080	1200	1.84	34.70
S6	1100	1265	1.82	30.54
S7	1050	1255	1.81	30.68
S8	1080	1260	1.82	30.80
S9	1050	1235	1.83	32.24
S10	1005	1155	1.80	36.19

The value of unit weight (Dense) vary from 1200 kg/m^3 to 1295.00 kg/m^3, with an average of 1270 kg/m^3 and the same for the fresh brick aggregate is 1155 kg/m^3. The percentage voids in aggregate of DCA materials vary from 28.60% to 34.70%, with an average of 31.43% while for the fresh brick aggregate is 36.19%. From the results it is observed that unit weight of DCA materials is somewhat higher than fresh brick aggregate and the corresponding voids in aggregate is lower than fresh brick aggregate. The higher unit weight and lower percentage voids in DCA compared to the fresh brick aggregate are might be due to presence of sand that reduced the voids and increased the unit weight. Another possible reason is the adhered cement mortar attached to the surface of recycled aggregate that might increase unit weight and decrease voids in the DCA samples. Furthermore, the initial quality of aggregate as well as concrete present in DCA plays the vital role to the unit weight of the demolition concrete aggregate. It is understood that DCA exhibits better or similar properties as fresh brick aggregate commonly used in sub-base course in pavement construction.

Aggregate Impact Value

The aggregate impact value is the measure of material having sufficient toughness to resist their disintegration due to impact. It represents the resistance to sudden impact or shock of aggregate, which may differ from its resistance to gradually applied compressive load. The impact test is very important to estimate toughness characteristics of the road aggregate (Das, et al., 2021). The values of AIV vary from 16% to 24%, with an average of 20% for DCA while for the fresh brick aggregate is 23% (Table 6). The cement mortar coating over the aggregates reduces the impact value. The limiting impact value is not more than 30% in sub-base course aggregate and base course aggregate in pavement construction as per the specification of LGED. Therefore, the DCA has satisfied the requirement for using in sub-base course in pavement construction.

Table 6 Aggregate Impact Value of Selected Aggregates

Aggregate Types	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
AIV (%)	24	23	18	22	16	23	20	22	16	23

Los Angeles Abrasion and Impact Value

Los Angeles Abrasion (LAA) test is commonly used to evaluate the hardness of aggregates as well as an indicator of the relative quality or competence of various sources of aggregates having similar mineral composition. The test results of LAA of selected DCA and fresh brick aggregate (S1~S10) are shown in Table 7.

Table 7 Los Angeles Abrasion (LAA) values of selected aggregates

Aggregate Types	S1	S2	S3	S4	S5	S6	S7	S8	S9	S1 0
LAA (%)	48	42	35	41	40	41	38	40	29	37

The LAA values for DCA vary from 29% to 48% with an average of 39% and for the fresh brick aggregate is 37%. The adhered mortar portion increases the LAA value of the recycled concrete aggregate irrespective of fresh brick aggregates. As per the specification of the road pavement design manual of LGED the LAA value for coarse aggregates shall not be more than 40%. It is observed from the experiment that the LAA values of DCA materials are within or slightly higher than the limit. Therefore, it can be noted that recycled concrete aggregate may be used as a replacement of fresh brick aggregate in pavement construction.

Soundness of DCA

This test was performed to study the resistance of aggregate to weathering action for use in road pavements. The test results of soundness values of selected aggregate (S1~S10) are presented in Table 48. The value of soundness varies from 7.35% to 8.95%, with an average of 6.95% and the same for the fresh brick aggregate is 9.25%. Soundness of DCA materials is slightly lower than fresh brick aggregate due to adhered cement mortar attached to the surface of the DCA materials. The limiting value is 12% for the usage of aggregates in pavement construction. So, it is noted that RCA materials can be used as supplement of fresh brick aggregate in pavement construction.

Table 8 Soundness of selected DCA materials

Aggregate Types	S1	S2	S3	S4	S5	S6	S7	S8	S9	S1 0
Soundness (%)	7.4 4	8.2 0	8.4 5	8.3 5	7.3 5	8.8 5	8.9 5	8.6 5	8.2 5	9.2 5

California Bearing Ratio (CBR)

The CBR test is one of the most commonly used methods to evaluate the strength of a sub-grade soil, sub-base and base course material for the design of thickness for highways and airfield pavement. Table 9 shows the results of OMC, MDD and CBR values of selected aggregate (S1~S10).

Table 9 CBR Values with MDD and OMC of Selected Aggregates

Aggregate Types	MDD (kg/m^3)	OMC (%)	Compaction (98%)	CBR (%)
S1	1428	19.40	98	40
S2	1545	17.25	98	48
S3	1555	16.50	98	52
S4	1495	18.25	98	44
S5	1540	18.50	98	46
S6	1535	17.50	98	50
S7	1555	17.70	98	48
S8	1542	18.15	98	41
S9	1565	18.75	98	54
S10	1565	18.25	98	86

The results show that the values of CBR vary from 40% to 54% with an average of 47% and the same for the fresh brick aggregate is 86%. According to the Road Pavement Design Manual of LGED the optimum moisture content for fresh brick aggregate is accepted from 16% to 18% for CBR value of 30% for sub-Base. The test results show that OMC vary from 16.50% to 19.40% and MDD vary from 1428 kg/m^3 to 1565 kg/m^3 for the selected Aggregates (S1~S9) whereas for fresh brick aggregate obtained OMC and MDD are 18.25% and 1565 kg/m^3. So it is observed no significant difference between DCA materials and fresh brick aggregate in respect of moisture and dry density. In case of pavement design the designed CBR for base course and sub-base course should not be less than 80% and 30%, respectively. CBR is very much important property of pavement for the evaluation of the strength of sub-base and base course materials. As sub-base course need 30% CBR and we obtained CBR value of DCA materials from 40% ~ 54% that is higher than required value of sub-base and lower than base course. So RCA can be used in sub-base course of pavement construction.

CONCLUSIONS

It could be concluded from results obtained from the study that the demolition concrete aggregate could be used as a sub-base material for the flexible pavement construction. Considering physical properties like particle size and gradation, specific gravity and voids, unit weight, flakiness index and elongation index it can be concluded that DCA materials may be used as like as fresh brick aggregate in pavement construction. However, further study may be needed to determine the effect of having different proportions mixing the demolition concrete aggregate with sand and to meet the limiting value of CBR of sub base of the pavement construction.

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