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An Experimental Study on the Valorization of Crushed Concrete in Pavement Base and Sub-base Applications

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Abstract. Due to booming in construction industries mostly in developing countries, the following problems immerging in solid waste handling like:- reduction of landfill space, increasing disposal costs etc. So, it becomes essential to identify the applications that involve the utilization of large volumes of Construction and Demolition (C&D) waste. This identification is also helpful in conservation of natural resources. Use of C&D waste in high-volume construction projects, besides alleviating the growing disposal problems, offers a promising way to help preserve dwindling naturally available building materials. One of the major components of C&D waste is Crushed Concrete (CC). This paper presents a laboratory experimental study of CC on its Geotechnical aspects and its application in pavement base and sub-base applications. CC is collected from a site nearby EHCC hospital, Jaipur City which was dumped as waste material. The material has been processed and graded according to size requirement of base and subbase materials as per 'MORTH Specifications for Road and Bridge Works, 5th revision'. A laboratory evaluation program is undertaken to determine the physical and engineering properties of CC. It is found that Crushed Concrete (CC) has a great potential to be used as pavement material based on the results of the experimental study. The present study that includes waste characterization and compaction studies will also open way to other research possibilities using C&D waste.

Keywords: Construction and Demolition Waste; Crushed Concrete; Recycled Materials; Experimental Modeling.

1 Introduction

The minimization of land filled waste volumes have been the aim of environmental policies for sustainability development. The construction and demolition (C&D) wastes are the major part of this landfilled waste volume. One of the solutions of this waste landfilled volume minimization problem is its reuse. Various studies are already there regarding utilization of C&D waste material in civil engineering applications. The crushed concrete (CC) is the major component of the C&D waste volume. CC is a granular material and there is large scope utilization of this granular material in various geotechnical applications like:- retaining walls, embankments, road bases etc.

This study investigates the application of CC as a base and sub-base material for road pavements. The CC material has been processed and graded as per 'MORTH Specifications for Road and Bridge Works, 5th revision' according to size requirement of the pavement base and sub-base materials. A systematic experimental program is performed to determine the various physical and engineering properties of CC material. This experimental program includes:- water content, specific gravity, relative density, water absorption, abrasion value, standard proctor test, CBR test (soaked & un-soaked), crushing strength, constant head permeability test. The test results of this study are compared with the relevant standards.

2 Literature Review

There are lots of studies in the field of reuse of C&D waste material in Civil Engineering applications. Some of them are related to the Geotechnical applications of C&D waste like:- crushed brick (CB), recycled concrete aggregate (RCA), waste rock (CR), recycled asphalt pavement (RAP), fine recycled glass (FRG) etc.

Bennert et al. (2000) performed laboratory tests on RCA, dense graded aggregate base coarse (DGABC) and RAP blended materials. The test results presented in this study indicated that the above mentioned blended material provided the higher values of resilient modulus than the currently used DGABC in roadway base applications in New Jersey. Sivakumar et al. (2004) investigated the reuse of construction waste under the repeated loading. This research concluded that the C&D waste materials used in this research were susceptible to particle crushing due vertical pressure and cyclic loading, which leads to the decrease in peak internal friction angle (Φ). Arulrajah et al. (2011), the geotechnical properties of the recycled crushed brick material were tested in this study for pavement applications. This study reported that the CB material provided the satisfactory performance as a pavement sub-base material only up to 65% moisture content. Leite et al. (2011) evaluated the physical and engineering properties of the typical Brazilian construction and demolition waste. The experimental test results of this study concluded that C&D waste aggregates may be used as base and sub-base layers of low volume roads.

Disfani et al. (2011) investigated the reuse of recycled crushed glass waste in road work applications. This study reported that the fine and medium crushed waste glass provided the satisfactory geotechnical and geo-environmental properties required for pavement sub-base application. Arulrajah et al. (2012a) performed a laboratory testing program on excavated waste rock (WR) to determine the geotechnical properties. This research concluded that crushed basaltic WR satisfied the criteria for use as a pavement sub-base material. Arulrajah et al. (2012b) evaluated the geotechnical properties of the recycled crushed brick blends. This study concluded that up to 25% of

CB blended with RCA and WR, provided the satisfactory results as a pavement sub-base material. Arulrajah et al. (2013a) performed the geotechnical and geo-environmental characterization of recycled construction and demolition (C&D) waste. RCA and WR were found to have good performance, whereas RAP, CB and FRG required some durable aggregate mix ton enhance their properties as pavement base and sub-base material.

Arulrajah et al. (2013b) investigated the performance of waste rock and recycled glass blends in footpath construction. This study concluded that up to 30% recycled crushed glass blended with crushed waste rock, provided the satisfactory performance in footpath bases. Arulrajah et al. (2013c) tested the resilience moduli response of recycled C&D waste in pavement sub-base application. This research concluded that most of the recycled C&D waste materials provided the high resilient modulus and low permanent deformation at 98% MDD and 65-90% OMC. Mohammadinia et al. (2015) explored the use of cement treated C&D waste material in pavement base and sub-base application. This study indicated that the cement treated C&D wastes provided the good performance as a pavement base and sub-base material. Rahman et al. (2015) performed the geotechnical and hydraulic characterization C&D waste material to determine its application in permeable pavements systems. This study reported that C&D waste materials provided the satisfactory geotechnical and hydraulic characteristics in permeable pavements as compared to typical natural granular material.
On the basis of above mentioned literature studies, a comparison between natural aggregates and recycled C&D waste aggregates is presented in Table 1.

Table 1. Comparison of physical properties of C&D waste aggregates and natural aggregates.

Properties	Comparison
Shape & Texture	Depends on crushing process but natural aggregates are more homogenous than the C&D waste aggregates
Size	Depends on crushing process but higher breakage problem occurs in C&D waste aggregates
Porosity & Density	Higher density and lower porosity occurs in natural aggregates
Stiffness	Generally C&D waste aggregates provided the lesser stiffness but RCA stiffness is not significantly away from natural aggregates
Crushing Strength	C&D waste aggregates provided the lesser crushing strength than the natural aggregates due to lack of homogeneity and particle density
Toughness & Soundness	C&D waste aggregates are less tough and sound as compare to the natural aggregates due to presence of high amount of cracks and porosity
Water absorption	C&D waste aggregates shows the higher water absorption due to presence of adhered cement paste

Based on the studies presented above, out of all the C&D waste materials, crushed concrete (CC) has the better application in geotechnical applications like:- backfill material, geosynthetics reinforced structures, base and sub-base material of pavements etc.

3 Material and Experimental Tests

3.1 Material

The C&D waste material tested in this study was collected from a site nearby EHCC hospital, Jawahar circle, Jaipur. The waste was consisted of large irregular shape concrete blocks. The material was processed and graded according to size requirement of base and sub-base materials as per 'MORTH Specifications for Road and Bridge Works, 5th revision'. The images of CC material before and after processing are presented in Fig. 1 and Fig. 2 respectively. The CC material was processed and graded in four ranges of size which were < 4.75 mm, 4.75-9.5 mm, 9.5-26.5 mm and 26.5-50 mm (Table 2).

Fig. 1. CC material in raw condition.

Fig. 2. CC material after processing.

Table 2. Gradation of processed CC as sub-base and base material.

Sieve size (mm)	Sub-base Course (%)	Base Course (%)
26.5 – 50	40	10
9.5 – 26.5	30	40
4.75 – 9.5	20	30
< 4.75	10	20

3.2 Laboratory experimental works

After the processing and gradation of CC material, a systematic experimental program was performed to evaluate various physical and engineering properties of the waste. This experimental testing includes:- specific gravity, relative density, water absorption, abrasion value, standard proctor test, CBR test (soaked & un-soaked), crushing strength, constant head permeability. The tests were performed on three samples of processed CC material to maintain the consistency. The laboratory test results are presented in Table 3.

Table 3. Laboratory test results of crushed concrete (CC) waste.

Properties	Test standards	Value
Specific gravity	IS: 2720 – Part (IV)	2.61
Fineness modulus	IS: 2386 – Part (I)	4.5
Water absorption – coarse (%)	IS: 2386 – Part (III)	5.77
Water absorption – fine (%)	IS: 2386 – Part (III)	5.95
Aggregate impact value (AIV) (%)	IS: 2720 – Part (IV)	37.66
Los Angeles abrasion value (%)	IS: 2386 – Part (IV)	42.4
Aggregate crushing value (ACV) (%)	IS: 2720 – Part (IV)	24.13
Maximum dry density – (Modified Proctor Test) (gm/cm^3)	IS: 2720 – Part (VIII)	1.87
Optimum moisture content – (Modified Proctor Test) (%)	IS: 2720 – Part (VIII)	10
Minimum void ratio (Relative density test) (e_{min})	IS: 2720 – Part (XIV)	0.35
Maximum void ratio (Relative density test) (e_{max})	IS: 2720 – Part (XIV)	0.43
Hydraulic conductivity (mm/sec)	IS: 2720 – Part (XVII)	13.57

Some laboratory tests were also conducted on soil samples, collected from the site nearby MNIT, Jaipur as a subgrade material for pavement. The test results on sub-grade soil like CBR values are useful in designing the thickness of upper layers of the pavement. The test results on soil sub-grade are presented in Table 4.

Table 4. Laboratory test results of sub-grade soil.

Geotechnical properties	Test standards	Value
Specific gravity	IS: 2720 – Part (IV)	2.6
Fineness modulus	IS: 2386 – Part (I)	2.6
Maximum dry density – (Standard Proctor Test) (gm/cm^3)	IS: 2720 – Part (VII)	1.83
Optimum moisture content – (Standard Proctor Test) (%)	IS: 2720 – Part (VII)	13
CBR value (Soaked) (%)	IS: 2720 – Part (XVI)	4.62
CBR value (Un-soaked) (%)	IS: 2720 – Part (XVI)	21.17

4 Results and Discussion

The experimental test results of this study on CC material are compared with standards of "MORTH Specifications for Road and Bridge Works, 5th revision". This comparison between CC material and natural granular material as pavement base and sub-base material is presented in Table 5.

Table 5. Experimental results comparison between CC and natural granular material.

Sr. No.	Properties	Natural granular material (Recommended value)	CC material (Experimental Value)
1	Specific gravity	2.68	2.61
2	Fineness modulus	Field value	4.5
3	Aggregate impact value (AIV) (%)	< 45% for CC base course	37.66
4	Los Angeles abrasion value (%)	< 40% for WBM course	42.4
5	Aggregate crushing value (ACV) (%)	< 45% for base and sub-base course	24.13
6	Maximum dry density (Modified proctor test) (gm/cm^3)	Field value	1.87
7	Optimum moisture content (Modified proctor test) (%)	Field value	10
8	Hydraulic conductivity (mm/sec)	10-18	13.57
9	Water absorption (%)	< 2%	5.77

The above mentioned comparison indicated that the variations of the most of the properties of CC material and natural granular material are not very significant. On the basis of CBR values of CC material and natural granular material, the total thickness of flexible pavement were designed as per standards of IRC-37-2018 for 10 msa. The designed total thickness results for flexible pavement are presented in Table 6.

Table 6. Comparison of pavement thickness.

Sr. No.	Natural granular aggregates	Crushed concrete aggregates
CBR %	4	4.62
Designed total pavement thickness (mm)	660	680

The variation of designed pavement thickness based on CBR value of CC from natural granular aggregates is not much significant (Table 6).

5 Conclusions

On the basis of the various test results and their comparison with relative standards, this study reaches to the following conclusions:-

1. The reuse of CC material as pavement base and sub-base material is a good solution for C&D waste sustainability development.
2. The engineering properties of CC material were not significantly varied from the natural granular material.
3. The subgrade-soil CBR value in this study is 15.5% more than the natural subgrade soil.
4. The results indicated that the total thickness of flexible pavement in case of crushed concrete aggregate is increased by only 3.03% as compared to the natural granular aggregates.
5. The difference of pavement thickness is negligible for CC material and natural granular material as pavement base and sub-base material.
6. The replacement of CC as pavement base material in-place-of natural granular material is economical, also sometimes for large quantity and small transportation distance.
7. Reuse of C&D waste as pavement granular base material, also reduces the over consumption of natural resources.
8. The strength of the structure made by CC material is slightly inferior in comparison to natural aggregate structures. So, the utility of CC material in pavement construction is more effective under the light traffic loading.
9. The abrasion test results indicated that the CC material is more abrasive in nature compared to the natural aggregates so utility of this waste material in top surface layer of pavements is limited.

10. The drainage properties of the CC material are almost similar to the natural aggregates as permeability test results indicate.
11. As water absorption of the CC material is slightly above than the permissible limit, it indicates that the CC material is not durable as pavement base material in the damp areas.

So, this research concluded that CC material provides good and effective results as pavement base material. The replacement of natural aggregates by CC aggregates may be economical and safe solution.

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