International Journal on Advanced Science Engineering Information Technology

Vol.8 (2018) No. 3
ISSN: 2088-5334

Preliminary Investigations for Policy Framework to Regulate the Utilisation of Residual Strength of Demolition Waste Aggregate in Cement Concrete Mix

M. R. Raja Shekhara[#1], Reshma.E.K[#2]

Department of Civil Engineering Dayananda Sagar College of Engineering, Bengaluru, 560078, India
E-mail: [1]mrrs1957@gmail.com; [2]reshu.ek@gmail.com

***Abstract*— Millions of tonnes of demolition waste of different types is generated from various sources in the construction industry. Improper disposal of such waste results in loss of valuable land in cities and also such deposits may breach into reservoirs, water bodies, canals, etc. leading to blocking the path for the free flow of rainwater. Dissolution of harmful compounds that may be present results in contamination of water bodies. Hence it is necessary to frame guidelines and rules for regulating the various Demolition activities. This facilitates the granting of permission, actual demolition, segregating different materials and making the best use of the derived aggregates for various activities. Using derived aggregates in partial /full replacement is possible in concrete mixes of different grades. An attempt is made to collect demolition waste from three different locations. Requisite tests were conducted. An attempt is made to design a pavement quality concrete (PQC) of M40 grade to satisfy compressive and flexural strength requirements. A policy framework is needed at the national level for utilizing demolition waste aggregate in civil engineering works of both structural and nonstructural applications. Proper regulation of CD waste management is essential to channelize the entire process to convert it into useful construction material.**

***Keywords*— demolition waste; policy framework; blending; residual life; sustainability; acceptance criteria**

I. Introduction

Construction and Demolition waste is the material available at construction sites in the form of leftover material, may be of low quality available at the site not suitable for good quality construction. Demolition waste is generated due to changes incorporated during construction of buildings, due to razing of old buildings, changes incorporated for the use of building for a different purpose, etc. Demolition waste is available more in metropolitan cities rather than in towns, small cities, and megacities. The Construction and demolition (CD) waste have some residual life which could be effectively used in various civil engineering applications.CD waste may contain aggregates much stronger or weaker in strength than the original aggregates due to adherence of mortar on the surface with sufficient bonding.

Usually, Demolition waste is dumped as landfilling in identified sites on the outskirts of cities. This results in loss of valuable space in the urban area and further aggravates the space constraint. Dumping of waste for filling in the low lying area may result in the flow of materials during heavy rains and may contaminate the downstream water bodies and underground water table to some extent. The above problem may be solved by recycling or reuse of such CD waste in place of new aggregates which could be partially or fully replaced depending on the type of work.

In view of large quantity of CD waste generated and available for disposal in metropolitan cities and having its wide alternate applications in construction industry, an attempt has been made in this research paper to suggest a methodology for identification, procurement and processing of demolition waste followed by collection of samples, testing and processing of demolition waste for its further use. A policy by urban, local and municipal bodies is essential to be framed and implemented for a better CD waste management for its continuing use. CD waste is not a waste material but a beneficial material in the construction industry for its extended life in cement concrete and other engineering applications.

II. Material and Method

A. Problems Associated with CD Waste in Cities

A large number of buildings are demolished in the cities for various reasons like change in the ownership and the property opting for other type of land use, declaration of a particular road as commercial zones by Metropolitan bodies, Municipal and local bodies prompting the building owners for different type of construction, change in the floor area ratio from time to time by local bodies due to various reasons. Sometimes alterations of buildings to make it more suitable for the present requirements may result in the demolition of a part of the building that generates CD waste. Old buildings are normally demolished due to obsolescence in the design.

All the above types of activities in a building generate a large number of waste materials like masonry debris, concrete fragments, brickbats, etc. The material if not usable at another site is considered as waste or debris and dumped merely in pre-identified dumping site. Usually, old wooden door or window frames have very high resale value and could be reused after demolition process. The quantity of such items varies from site to site hence; there is no guarantee of quantity and quality of recoverable material from a demolished building. Hence it is a difficult and challenging task to make the whole event to come under one roof. Hence it is imperative to bring in the proper regulatory framework for the entire process of C&D waste management.

B. The necessity for Requisite Guidelines for Acceptance of Demolition Waste as Blending Material and Test Values for Design Mixes

The guideline for C D waste usage in construction is dealt in BIS: 4562 2000 and IRC: 383- 2016, but they do not permit the use of aggregates other than natural sources confining to BIS. Given the development of this field regarding policy, guidelines, regulations, specifications, and testing of C D waste across the other developed countries, it is imperative to adopt similar steps as far as for the use of CD waste in various construction sectors in general and road construction in particular. However, before doing this, the provisional specification for collection and processing or segregation, testing, acceptance of test values based on prescribed test procedure has to be done need of the day. Following basic steps and points are recommended in view to use of C D waste and management in the country.

- Declaration by the building owner regarding property identification number, the age of the building, approximate quantity of categorized material recovery after demolition.
- Creation of common facility or agency for demolition, collection, and segregation of CD waste and testing of recovered material as per the prescribed BIS specifications.
- Basic tests like physical and mechanical test are to be conducted on CD materials like concrete to know the suitability for recycling or use in construction.
- Testing may also be done based on the categorization as follows

1) Category 1: Material which satisfies the requirements of BIS 383: 2016;

2) Category 2: Not meeting the actual requirements *with the* content of unbound stone if more significant 85%, a dry density greater than 2.5 g/cc, water absorption less than 3 %;

3) Category 3: crushed concrete portions greater than 70 % and brick masonry should not exceed 30 %.

Based on the above criteria the CD waste may be used as follows:

- Category 1: Unrestricted use in all construction;
- Category 2: Coarse and fine aggregate replacement to the extent of 30 % for M 50 and grades up to 100 % for an M25 grade of concrete;
- Category 3: Use in nonstructural concrete (M20) up to 100 % replacement of natural aggregate.

C. International Scenario in Recycling of CD waste

European countries and in USA utilization of CD waste is in the most advanced stage and is well organized from planning for demolition, segregation, testing and its reuse. Following are some of the highlights of the mechanism involved in CD waste management in some selected countries.

- In Germany, closed-loop recycling system is accepted to recycle about 86 % of waste generated due to demolition activity of old buildings.
- In Japan, they can recycle 95 % of materials based on the classification of waste in three categories like light, medium and heavy by adopting three stage crushing process; mechanical scrubbing heated scrubbing and adopting chemical and physical treatment
- In the USA, by adopting series of successive crushing and screening, they can use maximum CD waste for reconstruction.
- Singapore has adopted the microwave technology of high-frequency heating technique for the recycling process.

From this, it implies that in advanced countries, technology is effectively used for C D waste for its effective reuse.

D. Problems Associated with Test-values due to Variation of Sources

One crucial factor that likely affects the variation in test results of demolition waste is the age of the building or structure demolished. Demolished buildings may not have proof regarding construction year and also it is difficult to get the details in the present context. This is also due to the building records being maintained in all cities manually. Usually, buildings construction having low-quality material may result in inferior derived CD waste compared to recently built buildings with right quality materials.

Some old buildings may fetch right quality doors and window frames with shutters and have higher resale value after its recovery. It is essential to establish a relationship between the age of the building and quality of recovered materials with regards to CD waste to decide its suitability for use in concrete. Concrete used for plinth, lintel and roof slab may have varying mix proportions of materials. Separating each type of concrete for recycling is a difficult task and not practically impossible as it is a very costly process.

On the other hand age of the building is not very important in deciding the quality and quantity of CD waste. This may be omitted from the process, as it may not be a critical factor in deciding its use in various applications. For convenience sake it is better to categories CD waste into 3 or 4 groups, to analyze the characteristics. The analysis may be carried out to take the age of the building as a parameter and study the effect of age on all aspects of mix design process if the age is known from a different source.

If the results are found to be dependent on age, in that case, age may be used as a factor for blending CD waste with natural aggregate for optimum results and economy. Demolition waste is one such material which may counter the good quality of conventional concrete, and hence it is essential that some qualifying tests should be prescribed like fineness modulus, specific gravity and water absorption, mechanical properties, shape tests or any other tests for aggregates. It may be the fact that CD waste may not satisfy all the tests requirements prescribed by the respective codes and in that case, some acceptance criteria for CD waste as a replacement for coarse aggregate is essential.

Some preliminary nominal concrete mixes for trials like compression test may be suggested for qualifying the C D waste as reconstruction material. This would prevent further steps in using C D waste for concrete mixes and thus save money, labor and time to some extent. Due to a poor rating of the CD waste, it may not pass all the tests or may end up with variable test values than recommended values.

To overcome this problem, for CD waste it may be required to increase the permissible limits for acceptance to a higher value, as CD waste alone is not used in any structural concrete. This would enhance the percentage of CD waste that could be used in designing concrete mixes. A series of qualifying tests have to be identified to determine the suitability of CD waste for use in concrete mixes.

E. Need for an Advanced Statistical Testing Methods for Design of Blended Concrete Mixes for Minimum Sample Size.

It is known that cement concrete strength and its variation, performance under different loading conditions depends on the quality of the materials. Coarse aggregates which form bulk of the volume in as much as 70 % contribute more to the concrete mixes. Apart from this, made of concrete, the degree of quality control exercised during the making, Water cement ratio, curing duration and condition and rate of loading are the reasons for the variations in test values. Good quality control would result in better concrete mixes. The strength of concrete mix and its deviation from mean value and the standard deviation is essential to be considered. To achieve this, a minimum number of samples to be tested to get a required range of strength values in getting reliable concrete strength.

Quality of CD waste, control of concrete making process, the optimum blending of aggregates and CD waste is essential in attaining a mix of reliable strength of concrete. Advanced statistical methods may be the more reliable approach in deciding the quality of the mix based on mean and variance of the obtained values to study the mix performance. The statistical method is more scientific and extensively used in many engineering applications. Also, advanced statistical packages are available in the market for easy data handling

Statistical methods are more useful in the study of variations of test results during an intermediate stage of the process of testing. At any given point in time, while establishing the credibility of the mix to achieve a minimum strength of concrete, the above steps are recommended.

F. Literature review

A brief review of the literature on the management of CD waste is presented here to understand the research done by different people in this field across many countries.

The perceptions of the Hong Kong construction participants toward the construction waste disposal plan after three years of implementation [2]. A survey with follow-up interviews with experienced professionals in the field revealed that waste reduction is less than 5% after the implementation of the plan. Some waste generation was unavoidable, and necessary changes are payable for waste disposal. Also, 30% of survey respondents agreed that the cost of CWDCS was not high enough to raise awareness about waste management at construction sites.

Sustainability actions during execution of the project in 54 phases would reduce waste generation could be reused of C D waste [8]. These actions help in reducing, reuse and recycling of CD waste. The feasibility of a C D waste recycling program in Bangkok, Thailand, using a system dynamics (SD) modeling technique [3]. Saving in landfill charges and green image are the two key benefits in the recycling program that yielded the high impact of the recycling rate and green image rate parameters on the recycling program. The Developed dynamic model provides a better understanding of the CD waste situation in Bangkok, and plans for an effect the long-term waste management plan.

The suitability of CD waste as coarse aggregate in new concrete production has been examined [1]. Three sets of concrete materials considered are fresh concrete, waste concrete, and waste concrete strengthened with admixtures. All mixes were designed for original strength M20, and it is found that strength variation between the mixes were less than 10 %. Hence study recommends the recycling of waste concrete as an aggregate in the production of new concrete.

A previous study investigated the suitability of recycled CD materials as an alternative to sub-base material for permeable pavements and also used in urban stormwater management systems [4]. Three commonly found recycled CD waste materials, crushed brick (CB), recycled concrete aggregate (RCA), and reclaimed asphalt pavement (RAP) were investigated to assess their suitability as permeable pavement subbase materials. RCA was found to be a suitable alternative construction material for permeable pavements, while CB was borderline and RAP did not meet some of the specified requirements.

The reuse of recycled CD materials has significantly lower carbon footprints compared to traditional quarried materials, which will consequently lead to a more sustainable environment [5]. CD materials can be used as alternatives to quarry-based products for road pavements and other civil works. It is verified the technical viability of using construction waste as material for the base pavement layers of road surfaces [6]. Field study includes testing the performance of pavement composed of concrete, asphalt mix, and ceramic waste aggregate.

This was done by analyzing the characteristics of the recycled material on a section of an actual road under real vehicle traffic conditions. It was observed that the load-bearing capacity of the recycled artificial CDW aggregate was satisfactory. Different approaches to managing construction waste developed based on available research works and practices [7]. They classified these into three areas mainly waste classification, waste management strategies in reducing, reusing, and recycling waste and waste disposal technologies.

Construction wastes passed through some processes from generation to final disposal, and proper flow of these processes can improve waste management effectiveness. They examined the waste handling process during construction by mapping six cases selected in Hong Kong construction, with the assistance of the free-flow mapping presentation technique. The examination leads to developing a waste management mapping model which incorporates the proper operations embodied in the existing practices providing an alternative tool assisting in planning waste management procedures on construction sites.

Also, the model serves as a vehicle for comparing the waste management practices between construction sites. Thus both good practices and weak areas can be identified. Variational methods are formulated as optimization problems and provide a good solution to image demolishing. Three such variational methods Tikhonov model, ROF model and Total Variation-L1 model for image demolishing are studied and implemented.

Performance of these variational algorithms is analyzed for different values of the regularization parameter. It is then developed in experimental design using a statistical tool, and actual machining is carried out to record the surface roughness, variations on the surface hardness and dimensional stability. Available Literature indicates that the work done hitherto in the field of CD waste in concrete is limited, and full potential of the material is not explored. Keeping in view the lacunae in the literature the research has been taken up.

III. Result and Discussion

A. *Preliminary Investigations conducted on C D waste and Blended concrete mixes*

Materials used in this study include cement, fine aggregates, coarse aggregates and recycled coarse aggregates. OPC of 53 Grade confirming to BIS:8112-1989 was used. Manufactured sand having bulk density 1754 kg/m3 is used for the present study. Regular coarse aggregates (NCA) are obtained from a nearby quarry, and recycled aggregates are procured from three different sources has been used. The details of the source is given below.

- Source 1: Recycled coarse aggregate (RCA) collected from demolished Building of about 20 years old at Banashankari 2nd stage, Bengaluru.
- Source 2: Recycled coarse aggregate (RCA) collected from the demolished building of about 15 years old at ITPL, Bengaluru.
- Source 3: Recycled coarse aggregate (RCA) collected from demolished Building of about 12 years old at ITPL, Bengaluru

The collected aggregates were broken to the small size of about 50 mm using Hammer and then passed through Jaw crusher to get further down ranges between 20 mm to 10 mm. The physical and mechanical properties are conducted on natural and recycled coarse aggregates, and test results are presented in Table No I.

TABLE I
CHARACTERIZATION OF NATURAL AND RECYCLED COARSE AGGREGATES

PROPERTIES	**NCA**	**R CA**		
		Source 1	**Source 2**	**Source 3**
IS2386:1963- Part III Specific gravity	2.6	2.4	2.6	2.56
IS2386:1963-Part III Water absorption	0.28%	4.4%	3.7%	3.8%
IS2386:1963-Part IV Crushing test value	21.3%	38%	36%	32%
IS2386:1963-Part IV Impact value	21.2%	39%	34 %	32.1%
IS2386:1963-Part IV Abrasion resistance	26 %	42 %	47%	39.2%
IS2386:1963-Part I Angularity number	9	11	10	9
IS2386:1963-Part I Flakiness Index	14%	16 %	8 %	11 %
IS2386:1963-Part I Combined Index	34%	32%	28%	22%

A general observation is that water absorption is more compared to NCA due to the presence of mortar on the aggregate surface that indicates the retention of water by a mortar in RCA surface treatment may reduce the water absorption. Indian Standard Code did mix design of concrete (IS: 10262- 2009) and Guidelines for Cement Concrete Mix Design for Pavements (IRC 44:2008.Second Revision)**.** The grade of the concrete selected for the present study is M40 as per the requirements of Pavement quality concrete. Fresh concrete properties were tested to achieve required workability of 50 -75 mm slump by varying water-cement ratio. Conplast SP430 based on Sulphonated Naphthalene Polymers is used as a super plasticiser.

TABLE II
COMPRESSIVE STRENGTH RESULTS FROM SOURCE 1

Proportion	**Compressive Strength MPa**		
RCA: NCA	**Seven days**	**14 days**	**28 days**
0:100	28.1	45.8	52.1
25:75	16.7	38.8	46.5
30:70	16.1	31.4	43.8
35:65	15.2	29.3	37.2
40:60	15.8	27	30.3
100:0	11.6	17.3	21.4

Concrete cubes of 150mm size and beams of 100*100*500 mm size were used to determine the compressive strength, and Flexural strength of both control concrete and RCA modified concrete from source 1 and source 2. Cubes and Beams were cast with a recycled aggregate of varying percentage ranging from 25 to 40% with 5% increment levels. Two control mixes, one with 100 % Recycled concrete aggregate and other with 0 % recycled concrete (i.e., 100 % natural aggregate) was prepared. The results of compressive and flexural strength are given in Table II, III, IV and V. Graphical representation of the results are presented in Fig 1, 2, 3 and 4.

TABLE III
COMPRESSIVE STRENGTH RESULTS SOURCE 2

Proportion	**Compressive Strength MPa**		
RCA:NCA	**7 days**	**14 days**	**28 days**
0:100	17.8	25.3	40.3
25:75	25.6	30.6	42.3
30:70	34	36	40.7
35:65	31	34	39.2
40:60	30	32.2	37.5
100:0	24	29	32.3

TABLE IV
COMPRESSIVE STRENGTH RESULTS FROM SOURCE 1 AND SOURCE 2

Proportion	**Compressive Strength(28 days) MPa**	
RCA: NCA	Source 1	Source 2
0:100	52.1	40.3
25:75	46.5	42.3
30:70	43.8	40.7
35:65	37.2	39.2
40:60	30.3	37.5
100:0	21.4	32.3

TABLE IV
COMPARISON OF 28 DAYS FLEXURAL STRENGTH

Proportion	**Flexural Strength MPa**	
RCA: NCA	**Source 1**	**Source 2**
0:100	7.1	6.2
25:75	6.4	4.7
30:70	4.7	5.2
35:65	3.8	6.8
40:60	3.1	4.8
100:0	4.5	5.2

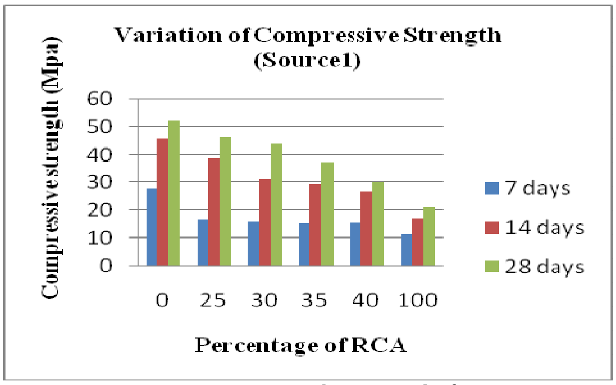

Fig. 1 Compressive Strength Test Results from Source 1

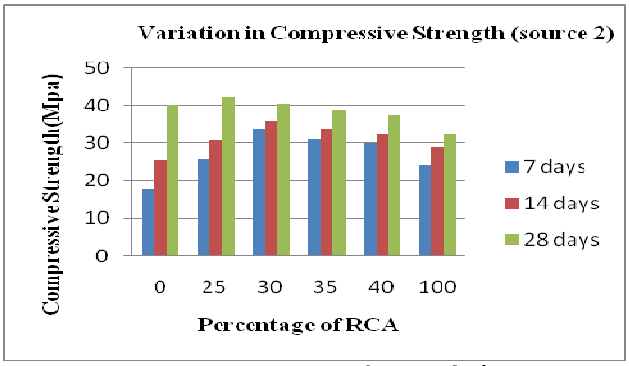

Fig. 2 Compressive Strength test results from source 2

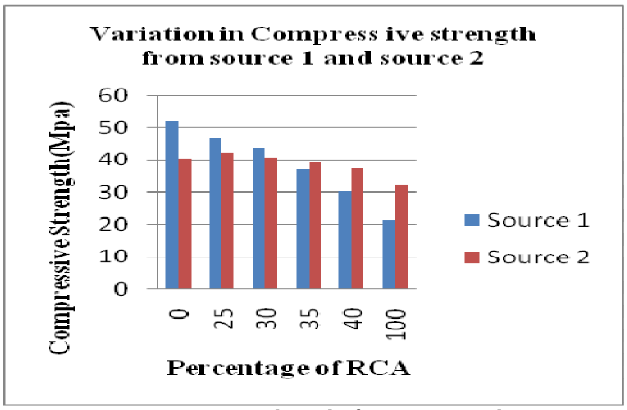

Fig. 3 Compressive strength results from source1 and source 2

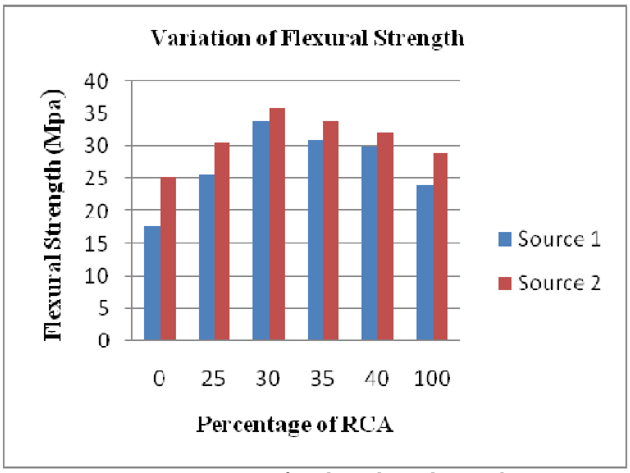

Fig. 4 Comparison of 28 days Flexural strength

B. Limitations of using RCA

This sections deals with some limitations using RCA as follows:

- Significant heterogeneity in the materials, lack of a proper systematic approach for identification, demolition, collection, separation, transportation and deriving the benefits of CD waste.
- Negative perceptions by the construction industry in using recycled materials that it would result in inferior quality concrete.
- The absence of precise technical knowledge, local availability of equipment and establishment of recycling plants in the country.
- Nonavailability of proper specifications and Guidelines with regards to identification, demolition, collection, separation, transportation and deriving the benefits of CD waste.
- No separate regulatory framework for the management of CD waste.
- Nonavailability of adequate data on CD waste generation and its composition in metropolitan and small cities
- Nonavailability of proper space in cities to have a centralized plant for segregation of CD waste
- Labor cost in handling and management of CD waste may add to the overall cost component.

IV. CONCLUSIONS

Tests conducted on Recycled concrete aggregates indicate a distinct physical difference between recycled aggregate and natural aggregate in the percentage of water absorption. Water absorption of the RCA is in the range of 3.7 to 4.75 which is high compared to natural aggregates which are between 0.5 to 1.0 % which is in usual range. Specific gravity tests conducted on recycled aggregates indicate that a slight decrease in the value is observed compared to standard aggregate which may be due to aging. This can be improved by cleaning the aggregates /complete removal of mortar present which may add to the cost of processing of RCA. A decrease in crushing strength (32-38%), impact value (32-39%) and abrasion resistance (39-47%) is observed for RCA due to the presence of coated cement mortar around RCA.

A marginal variation is observed in the compressive strength and flexural strength values among two different sources of recycled aggregates. The compressive strength of RCA concrete mix from source 1 and 2 are 43.8 and 40.7 MPa respectively at 30 % replacement of RCA which is only 10% higher between the two values (provide standard flexural values for CC). Flexural strength of the Recycled aggregate concrete mix from source 1 and 2 are 4.7 MPa and 5.2 MPa respectively at 30 % replacement of RCA which is more than 4.5 MPa, the minimum requirement as per IRC 44 for normal concrete of M40 mix.

At 100 % replacement of RCA, both compressive strength and flexural strength has reduced by 59 % and 20 % respectively for source 1 and 2 compared to control Mix. Flexural strength is reduced by 37 % and 16% respectively for source 1 and 2 compared to control Mix. This can be improved by adding any mineral admixtures available in the market. The variations in the test results among different sources of RCA could be due to reasons such as age, original strength of the mix/mix proportion of the concrete, quality of the materials used/ degree of quality control adopted during concrete making etc. Arriving at an appropriate percentage or amount of RCA replacement for the structural application is therefore difficult in the present situation with lack of a database. New techniques for removal of surface mortar to reduce water absorption and pre-wetting of RCA to saturate aggregates could be a solution for preventing water more absorption.

No uniformity in RCA is possible in Indian context in general, and it is difficult to bring in any standardization either for procurement/ selecting/ processing of RCA for concrete as a replacement to conventional aggregates in practice. The acceptance criteria for RCA and concrete made from RCA may be decided based on strength, durability and flexure strength tests. The strong statistical database needs to be generated based on extensive experimentation to determine followed by Advanced Statistical Analysis for taking decisions regarding the acceptance of demolition waste aggregate as a blending material with conventional concrete. This could be achieved by testing a minimum of 30 samples of standard cubes to study the statistical variation of parametric variations.

Demolition waste should be regarded as an additional substitutable source of construction material available for a replacement to that of conventional aggregates. Pre-qualification recommended tests on aggregate is essential based on some defined tests as that of standard aggregates and a marginal reduction test values should be acceptable as both the types of aggregates form the concrete matrix.

ACKNOWLEDGMENT

The Authors thankfully acknowledge Head of the Civil Engineering Department, Principal, and management for their encouragement and support in writing this technical paper. Also, the Authors all the people involved in carrying out the experimental studies, analysis and completing the Research paper in the presentable form.

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