Construction and Demolition Waste as an Alternative of Rigid Pavement Material: A Review

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Abstract. Current study involves review of waste material from construction and demolition activities, further utilised in construction of rigid payment. Recently Government has placed strong emphasis to utilize solid waste in different manner to reduce or decrease their negative environmental impacts, in Indian context such type of work is limited, and we are progressively working toward it. This study presents a summarised overview of studies conducted in India using RCA (Recycled concrete aggregate), RAP (Recycled Asphalt Pavement) and WFS (Waste Foundry Sand). Research has reported effective use of RAP, RCA or WFS with partial replacement of aggregates and cement, however workability issue has to be identified and further research may be done.

Keywords. RAP, RCA, WFS, Rigid pavement

1. Introduction
Growth of a nation mainly depends on the development of industry based on various aspects, one of the such industry is construction industry which not only a back bone of all the development activities but also proved to a major source of solid waste from demolition as well as construction activities itself. A systematic disposal of Construction and demolition (C&D) waste still has scope of work because of its very less engineering utilization. Other industries like coal-based industry, fertilizer industry, metal-based industries and textile industry etc. directly or indirectly contributes generation of C &D waste, which has alarming effects on environment. Current study mainly focused on the solid waste produced by construction related activities mostly from demolition and construction waste. In the recent few decades population over globe has increased many folds, thus the increased urbanization can be seen all around the world. India, who has a renowned place among the developing nations, faced tremendous changes in field of infrastructure development which contains destruction of old and useless buildings, roads, bridges, fly-overs etc. as per requirement and government’s guidelines and construction of many more to feed the demand. Infrastructure development has also utilized the needs of current scientific and economic facilities like research centres, laboratories, stone modelling & smoothening units, craft industries etc. which produces considerable amount of solid waste, some of which has adverse environmental impacts. So it becomes mandatory to have effective waste management involving good coordination of industrial and academia professionals, business tycoons and government agencies. Handling and utilization of solid waste considered as a best practice of disposal as a construction material [1]. Pursuance to the Indian Government estimation, India generates at present time around 165-170 million tonnes (MT) of waste yearly and as par Union Ministry of Urban Development, India generated 12-14.7 MT of C & D waste per year. Anwar et al. 2014 reported that Marble dust powder danger for environmental, additionally to forming dust in summer and threatening agriculture and public goodness [2]. According to Shen et al. 2004, “C & D waste is as a mixture of remaining components produced from construction, destruction and
renovation activities such as land excavation, site clearance, demolition and roadwork”[3]. The Solid Waste Management guidelines (2015) also defined C & D waste as “Waste containing of building materials rubble and debris causing from construction, restoration, destruction and remodelling of any civil construction”. Concrete is the most useful construction material in all worlds and used in all type construction of civil engineering works. C & D waste had been utilized effectively as a replacement material for concrete constituents. Mehrjard et al. 2020, assessed the possibility use C&D waste in road construction [4]. R.V. Silva et al. used C&D waste materials in new construction application like a, hydraulically-bound, unbound, bitumen-bound applications, as well as non-structural concrete in building and road construction[5] Junhui Zhang et al. studied the feasibility of C&D waste in highway embankment. Thus, C&D waste used as opposed to soil would increase the structural ability and decrease rutting damage [6]. The typical composition of the demolition waste in Indian context has been summarized in table 1

| Sr. No. | Components | Percentage |
|---------|------------|------------|
| 1       | Concrete   | 40%        |
| 2       | Ceramics   | 30%        |
| 3       | Wood       | 10%        |
| 4       | Plastics   | 5%         |
| 5       | Metal      | 5%         |
| 6       | Others     | 10%        |

Above table shows that major components of demolished waste material consist of concrete and ceramics, which together contribute 70% in its whole volume produced. Ceramics involve waste bricks, tiles, glass etc. which are made of inorganic and non-metallic compounds such as clay. Al Bakri et al. 2006 has done experimental research for replacing waste ceramic partially with aggregates and he found that compressive strength of concrete with quarry dust as aggregates is the highest with 30.82 MPa with density 2251.85 kg/m$^3$. which strongly recommend that waste ceramic and quarry dust can be used as an substitute source of aggregates [7].

2. Reclaimed Asphalt Pavement (RAP)

Highway projects are the most widely spread construction projects, which utilises thousands of tonnes of aggregates every year. It imposes huge load on natural resources. Though the natural resources are very limited, use of reclaimed asphalt in pavement construction proved to be very effective as studies has suggested. The various properties of RAP have been summarized in Table 2. During the restoration of prevailing asphalt pavement, removed old materials while reconstruction and resurfacing of the road surface. The removed top surface material consists of bitumen and aggregate, it becomes recycled asphalt pavement (RAP) [1]. However, replacement of reclaimed asphalt has restricted to some amount only and it is advisable to use 50% RAP and 50% CSA (Crushed stone Aggregate) with 2% of cement to get a CBR value more than 100%, which is well in criteria described by IRC (30% for granular sub base and 100% for granular base) [8][9]. However, the use of RAP alone does not satisfy IRC recommendations for strength of base and sub-base material, due to gap gradation of aggregate sand that’s why crushed stone aggregates are mixed in right proportion to achieve desired strength.

| S. No. | Parameters          | Values    |
|--------|---------------------|-----------|
| 1.     | Unit Weight (kg/m$^3$) | 1900-2500 |
| 2.     | Asphalt content     | 5-6%      |
### Table 1: Tensile Strength of Compacted Pavement Materials

| Description                                | Values               |
|--------------------------------------------|----------------------|
| Moisture content                           | Max 3-5%             |
| Compacted unit weight (kg/m³)              | 1500-1950            |
| Asphalt penetration (%) at 25°C             | 10-80                |
| California Bearing Ratio (CBR)             | 100% RAP: 20-25%     |

Figure 1. Demolished Asphalt Pavement (Mahal Road, Jaipur)

A another study by Zeeshan et al. 2017 which utilised demolished brick an marble as a partial substitution of aggregate for concreting, has stated a reduce in compressive strength with time [11]. Lower strength 22.01 to 27.07% of conventional concrete were produced by replacing coarse aggregates 20 and 10% respectively, it sounds to be unsuitable for concreting works where there strength requirements are more than 25-30MPa. Construction of concrete pavements rely on PPC having a strength ranging from 20.68MPa to 34.47MPa (as per IRC: SP 62 - 2004), may provide a platform to utilize demolished brick and marble with corrected proportions. The results indicate that compressive strength, flexural strength, splitting tensile strength and modulus of elasticity was reduced as the increased percentage of RAP in concrete [12]. However there is no major effect on the thermal expansion and drying shrinkage of concrete.

Micro coating of asphalt in RAP aggregate (about 6 to 9 μ m thick) acts like asphalt interface layer when mixed in concrete between aggregate cement mortar, it restricts propagation of micro cracks, and slower the widening process of cracks [12]. Finite element analysis by Hossiney et al. 2010, to assess the maximum stress in characteristic concrete pavements in grave temperature and load condition, ratio of maximum stress to flexural stress found to be reduced as compared to reference concrete with no RAP[9]. Hence use of RAP with concrete may improve performance of concrete pavement.
3. Recycled Concrete Aggregates (RCA) for Rigid Pavements

Concrete is the major construction material used around the globe, without it application, construction of any cannot be imagined. It most widely adopted for civil engineering works. In developing countries like in India, generally C&D waste is not properly disposed in an unorganized manner thereby leading the problem of environmental issues [13]. Recycle concrete aggregate are produced from construction and demolition activities, it has been utilized as partial or fully replacement of fresh aggregates. However recycle concrete aggregate based concrete has lower Elastic modulus, and strength with increased porosity when 20mm size aggregate are used[14]. RCA can be effectively use in Rural Road construction which have very less traffic load, thus very less amount of strength is required. Compressive strength equal to 30N/mm$^2$ was reported sufficient for rural roads. However proportion of recycled aggregate is not more than 50%. A proportion of 30% RAC with 70% NAC gives maximum strength 32.10N/mm$^2$ according to Verian et al. 2013[14]. Though specific gravity of recycled concrete aggregates lower than natural aggregate which lowers the unit weight of concrete made of recycle aggregate. And water absorption is slightly higher in comparison to natural aggregate based concrete (more than 5%). Rakesh et al.[15] evaluated the slump, fresh density, abrasion resistance, compressive and flexural strength of concrete. In this study, NCA was 100 percentage substituted by RCA at in paving concrete[15].

3.1 Physical properties of RCA

Following are the physical properties reported by Shinde et al. 2013[16]. They have prepared 3 mixes for M25, M020 and unknown proportion to analyse these physical properties of reclaimed crushed stone. They founded that RCA have higher amount of water absorption then natural aggregates and its 3-5% more than natural aggregate. Which have negative impact on strength of concrete so, it should be carefully determined. RCA based concrete have low value of compressive strength a compare to normal concrete. The different physical properties of RCA has been summarized in Table 3.

| Sr. | Particulars          | N.A  | RA1  | RA2  | RA3  | RA4  |
|-----|----------------------|------|------|------|------|------|
| 1   | Water absorption     | 0.6% | 2.05%| 2.4% | 3.5% | 3.7% |
| 2   | Abrasion value       | 18.9%| 21.2%| 22.6%| 25.4%| 36.6%|
| 3   | Impact Value         | 9.5% | 12.50%| 16.2%| 19%  | 26.4%|
| 4   | Agg. Attrition value | ---  | ---  | ---  | 2.72%| ---  |
|     | With ball            | 1.4% | 4.6% | 5.36%| 7.63%| 9.12%|
|     | Without ball         | 0.4% | 2.0% | 2.4% | 2.72%| 2.8% |

4. Waste Foundry Sand

Sand base modelling and casting has been done from ancient time, foundry sand is one of the finest sands which effectively utilised in metal casting. WFS is characterised as high quality silica sand, having uniform size will high cleanliness produced as a by-product of ferrous and non-ferrous metal casting industry. WFS show very good thermal conductivity property, hence best suits as moulding material[17]. Ferrous or non-ferrous material may be utilised in concrete after it becomes a refused material for reuse in foundry, the en product renowned as WFS. Sometimes also known as SFS (Spent foundry sand) or UFS (use foundry sand).
WFS may further classify based on binder system used in metal casting:

a) Clay bounded Sand, containing natural binder materials (like silica sand: 85-95%, bentonite clay: 4-10%), an carbonaceous additive (2–10%) to facilitate casting process. Clay bounded WFS content upto 90% carbon.

b) Chemically bonded WFS effectively used where there strength matters, to withstand the heat of molten material as a mould. It consists of silica and chemical binder, 93–99% and 1–3% respectively.

4.1 Physical and chemical properties of WFS

Different researcher studied WFS and its application in concrete time to time, it was reported that specific gravity of WFS particles vary from 2.39 to 2.79, with low absorption which shows its non-plastic behaviour. Other important physical properties are summarized in Table 4.

| Properties                  | Naik  | Goney | Javed & Lovell | Siddique |
|-----------------------------|-------|-------|----------------|----------|
| Specific gravity            | 2.79  | 2.45  | 2.39-2.55      | 2.61     |
| Unit Weight (kg/m$^3$)      | 1784  | ---   | ---            | 1638     |
| Fineness modulus            | 2.32  | ---   | ---            | 1.78     |
| Moisture content (%)        | ---   | 3.25  | 0.1-10.1       | ---      |
| Absorption(%)               | 5.0   | -     | 0.45           | 1.3      |
| Materials finer than 75 µm (%) | 1.08  | 24    | ----           | 18       |
| Clay lumps and friable particles | 0.4   | ---   | 1-44           | 0.9      |

Chemical properties of WFS affect performance of concrete in which it is utilised. Major component of WFS is reported to be silica followed by aluminium oxides as shown in Table 5. Silica and aluminium play very important role in properties of concrete. Aluminium’s compound imparts strength in concrete. Researcher may use knowledge of its composition for further work.

| Constituent | Etxeberria | Guney | American Founday | Siddique |
|-------------|------------|-------|------------------|----------|
| SiO$_2$     | 95.10      | 98    | 87.91            | 78.81    |
| Fe$_2$O$_3$ | 0.49       | 0.25  | 0.94             | 4.83     |
| Al$_2$O$_3$ | 1.47       | 0.8   | 4.70             | 6.32     |
| SO$_3$      | 0.03       | 0.01  | 0.09             | 0.05     |
Environmental Intervention of RCA, RAP and WFS

Intensive quarrying of stones to fulfil the demands of infrastructure development activities across the India has imposed threat of environmental imbalance, measure studies in past continuously reported that excessive quarrying such a study was documented by Lad & Samant 2014[19]. Main environmental effects are annihilation of vegetation, disturbance of animal habitats, change and blockage of natural drainage systems, river siltation and soil erosion, vibration and noise; and dust pollution. It is to be renowned that in spite of its notable direct and indirect involvement towards development, mining and quarrying is also accountable for several socio-economic impacts and negative environmental, particularly, when the mining activities is carried out casually and not as per the recommended norms and rules[19].

Recycling of C&D waste denotes one way to change a waste product into a resource but the environment profits through energy consumption, fallouts reductions and emissions are not certain. Marinković et al. 2010 used recycled aggregate of coarser size in concrete and compared it with concrete based on natural aggregated; they found that mechanical properties of concrete and durability of RAC are lesser than NAC when water cement ratio was kept constant[20]. To achieve same amount of compressive strength a slight addition about 5% of cement was required. Mechanical and durability related issues restrict use of RAC in actual concrete. For measure projects of high impotence recycled aggregate concrete has restricted use, due to low strength produced. Structures subjected to moderate to extreme exposure conditions (like corrosive acidic environment) again restrict use of RAC due to uncertainty in durability. However in the structural element which requires low strength, RAC has tremendous scope.

5.1 Environmental Impact assessment

Assessment of the environmental reactivity of concrete made of natural aggregates and recycled aggregate remained very popular research topic among the researchers. Whole environmental impacts in terms of energy use, eutrophication, global warming, photochemical oxidant and acidification creation depend on transport distances and types which were analysed and following are the key points:

1. RAC transported at small distance compare to NAC; Both NAC & RAC have same impacts.
2. RAC & NAC transported at same distance; RAC has larger impacts ranging 11.3% to 36.6% depending on impact category.
3. Energy saving in recycling is only possible if recycling unit is located nearer to construction site.

6. Conclusion
After reviewing literature for recent uses of RCA, RAP and WFS in Rigid Pavement, following conclusion points could be drawn:

1. Studies reviewed has reported that recycled concrete aggregates can be utilized for rigid pavements subjected to lower amounts of loads. For rigid pavement roads which requires compressive strength less than 30kN/mm², could effectively use RCA.

2. Village roads such as “Gaurav Path” may be best suitable for utilising RCA, RAP or WFS based concrete roads as per suggested by studies that these concrete gives good results for low volume roads.

3. Water absorption for RCA has found to be more than the normal concrete, though it affects the strength of concrete negatively. However, it may facilitate reduction of cost of admixtures if use for high slump value.

4. Use of RCA, RAP, & WFS replaces aggregates required for normal concrete, therefore decreasing the environmental effects of aggregate quarrying.

5. Local available waste material if used as replacement of aggregates, transportation cost of fresh aggregates may be saved and waste also dispose.

6. RAP, WFS & RCA based concrete can be proven as cost cutter for Transportation and Hauling costs, if locally available.

7. In addition to the resource management aspect, RCA and RAP absorb a huge quantity of carbon dioxide from the nearby environment.

8. Though the waste produced by the construction activities has negative effect on environment which has proven by different studies, emphasis has been given to minimize the amount of waste production, an optimum production analysis may help us to get rid of excess waste generation. However, it seems to be very tricky task to optimize the quantity of waste generated; so, reuse and recycling of waste material gives us an effective way to reduce or refuse the waste generated.

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