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A comprehensive study on recycling of road construction materials

Amit Kumar[1], Shekhar[2]

[1]Department of Civil Engg., SBMNEC, Rohtak, Haryana
[2]Department of Civil Engg., Geeta Group of Institutions, Panipat, Haryana

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Abstract: **This study finds out the feasibility of recycling construction waste for road rehabilitation by determining the causes of failure, and the viability of recycling the failed material. Visual assessment, traffic counts, field and laboratory tests were conducted. The field test comprised of Benkelman beam, curvature metre and straight edge tests. The laboratory tests included full gravel and aggregate material classification. Asphalt was recycled by adding additional binder content on the original material thus replacing lost volatiles. Cost comparison was also carried out between conventional and recycled method of construction. This study also portrays the use of industrial materials in hot-mix asphalt pavement (HMA); however, industrial materials have very similar applications in traditional portland cement concrete pavement (PCC). Both HMA and PCC pavements require aggregates, and the list of aggregates under the "Concrete Retaining Wall" and "Asphalt Base" applications can be used in both HMA and PCC roads. PCC roads can incorporate ground granulated blast furnace slag and reclaimed concrete aggregate (RCA) more easily and in larger volumes than HMA can.**

Keywords: recycling, construction, HMA, PCC, RCA.

Introduction

Recycled aggregates are aggregates derived from the processing of materials previously used in a product and/or in construction. Examples include recycled concrete from construction and demolition waste material (C&D), reclaimed aggregate from asphalt pavement and scrap tyres. The road transportation system in India is dominated by coal haulage due to mining and energy generation activities conducted around the area. The coal haulage is done by means of heavy loaded 2 trucks. The haulage system has adverse effects to the roads integrity hence most of the roads required massive rehabilitation or reconstruction. The conventional method of cutting to spoil damaged material and importing of new virgin material for rehabilitation has adverse effect on the environment and not always cost effective. Recycling of waste material has become a common practice for the reduction of waste disposal produced by different consumers from different fields. The introduction of new or alternative (recycled waste) materials in road construction may have benefits in terms of cost reductions, improved surfacing or pavement performance. However, it is essential to ensure that such innovations do not result in long-term negative impacts on the environment e.g. through the leaching of toxic chemicals into waterways. These environmental considerations arise from the government strategies, policies and statutory obligations of various organizations.

Coarse recycled concrete aggregate (RCA) is produced by crushing sound, clean demolition waste of at least 95% by weight of concrete, and having a total contaminant level typically lower than 1% of the bulk mass. Other materials that may be present in RCA are gravel, crushed stone, hydraulic-cement concrete or a combination thereof deemed suitable for premix concrete production. In Australia, RCA has been the most common construction and demolition waste used in concrete production both as coarse and fine aggregate. About five million tonnes of recycled concrete and masonry are available in Australian markets principally in Melbourne and Sydney, of which 500,000 tonnes is RCA

The economic and environmental benefits of recycling to the community include but are not limited to the following:

(i) The reduction of need for new landfill sites
(ii) Protects population and improves quality of life for people living in areas where natural resources are located,
(iii) From community and environment perspective it conserves green space,
(iv) Protect habitants and improve quality of life for residents in natural resources location,
(v) It can support industrial development as the recycled material serves as raw material for manufacturing and other uses,

(vi) It conserves resources by reducing the need to extract virgin resources or introduce new chemical to the environment,

(vii) It saves energy as it does not involve extraction and manufacturing process. Construction waste is one of the major contributors to congestion of landfill sites hence there are various technologies of construction which involves waste 3 recycling.

Recycling and reuse of construction material is a benefit since it reduces:

(i) cost of material
(ii) Shortage of quality aggregates
(iii) Haulage cost of new material
(iv) Ecological concern regarding convection of natural resources
(v) Energy cost
(vi) Negative consequence on landfills.

As a result of the above benefits, all the governments are stressing to promote the reuse of construction waste. This study investigates recycling of construction waste as an alternative raw material for roads rehabilitation.

Materials that have been investigated for their appropriateness and use in road building and maintenance activities include:

- Construction and demolition (C&D) waste, including concrete, brick, tiles and asphalt can be used in roadbase, drainage aggregate and replacement aggregate in concrete manufacture.
- Glass can be used in asphalt and can be added to recycled comingled roadbase.
- Tyres can be used as crumb rubber in asphalt.
- Used oil and coolants can be used in road asphalt when blended into modified and multi-grade bitumen.
- Container and plate glass can be used as an aggregate in roads and footpaths.

The study outlines that there can be significant cost savings in the use of recycled materials rather than virgin product. This is due to low material and transport costs at the recyclers, as well as the opportunity for savings from the re-use of 'box out' materials on site.

Environmental Effects of Using Traditional Highway Materials

Different sources of information and analytical methods are used to characterize the environmental implications of alternative road construction projects. The framework draws on two LCA procedures that capture impacts from every material and energy input during the service lives of civil engineering infrastructure, including raw materials extraction, manufacturing, on- and off-site construction, use, maintenance, and end-of-life. One is based on environmentally augmented economic input-output analysis (EIO-LCA), a Leontief general equilibrium model of the entire U.S. economy that has been used in a number of environmental and economic systems analyses. The economy is divided into a square matrix of 480 commodity sectors. Each row and column represents a sector, and each cell represents the economic transactions in dollars between two respective sectors. Thus the matrix presents total sales from a sector to others, purchases from another sector or from the sector itself (circularity effects in the economy) to produce a dollar of output. The economic model is augmented by a number of environmental vectors in order to quantify energy (petroleum distillates, electricity, coal) and material (ore, fertilizer) and water inputs, as well as emissions (greenhouse gas, toxic, ozone depleting chemical, water) and wastes (hazardous). Input-output modeling is linear, so the effects of a $1,000 purchase from a sector are ten times larger than the effects of a $100 purchase from the same sector. Because EIO-LCA emission factors are available in metric tons per dollar of sector output, the present framework uses average U.S. producer prices in $/metric ton for each material (from [Means 1997] and other sources) in order to calculate emissions per mass of material used.

The tool calculates cumulative environmental effects such as:

- energy consumption
- water consumption
- CO_2 emissions
- NO_x emissions

- PM10 emissions
- SO2 emissions
- CO emissions
- Lead emissions
- Mercury emissions
- Potential leachates
- RCRA hazardous waste generated
- Human Toxicity Potential (cancer and non-cancer)

Broad Objectives

To investigate the feasibility of recycling construction waste for re-use as raw material in rehabilitation of roads. Some of the objectives are as follows:

(a) To identify the causes of roads failure within the study area.
(b) To assess feasibility of reuse of construction waste and propose method of road rehabilitation.
(c) To recycle unsuitable material through characterization of the construction waste
(d) To compare the cost implications when recycled construction waste is used with that of normal roads' rehabilitation.

For Local Governments committed to sustainable practices and policies, the use of recycled materials in road construction offers many benefits. A variety of factors that should be considered in purchasing decisions include:

- Transport costs for demolition/ box out materials;
- Option for back-loading road making materials.
- Long term performance of raw materials;
- Water use and energy used to work raw materials;
- Energy used to extract the raw materials;
- Loss of habitat in producing the raw material;
- Transport costs;
- Cost of raw materials;
- Energy used in transporting materials;
- Disposal of demolition/ box out materials;

Recycled materials used in road construction

In India & various countries, alternative uses for waste materials are being sought in an effort to reduce the amount of wastes going into landfills. This is integral to the national waste strategy (Ministry for the Environment. Thus, waste producers are being encouraged to reduce the production of wastes and to identify mechanisms through which their waste materials may be recycled or reused. The re-use of materials such as building and demolition wastes, slags, fly ashes and others in the construction of roads can provide an attractive alternative means of disposal, provided, of course, that engineering performance is not compromised. Internationally, recycled materials used in road construction generally fall into one or more of the following categories:

- mineral filler,
- aggregates for chipsealing, asphalt mixtures for pavement construction, basecourse stabilisers, and
- bitumen additives and modifiers.

Presently, the only materials recycled into the road structure on a regular basis are waste rock, asphalt millings, waste concrete and waste oil, although it is likely that a wider variety of materials will be considered in the future. Based on overseas practice, a number of potentially recyclable materials are discussed in the remainder of this chapter.

Waste rock

Most material in this category is basecourse aggregate from failed pavements that is recycled in situ by adding stabilisers. Some waste rock from mineral processing may be used in the same way as conventional aggregates are in the base, sub-base and subgrade layers. However, waste rock from mining operations needs careful screening to ensure that the geochemistry and physical characteristics are favourable. For example, trace metal leachability and acid-generating potential would limit the use of pyrite-rich rock from coal mining.

Reclaimed Concrete

Reclaimed concrete material (or crushed concrete) consists of high-quality, well-graded aggregates (usually mineral aggregates) bonded by a hardened cementitious paste (Turner-Fairbank Highway Research Foundation (TFHRF) 2006). The aggregates comprise approximately 60–75 % of the total volume of concrete. Crushed concrete can be used as aggregate material in basecourse and sub-base layers. To be used as an aggregate, foreign debris and reinforcing steel must be removed. Possible contaminants in reclaimed concrete that could affect the environment include calcium hydroxide that can leach from unweathered broken surfaces and cause an increase in alkalinity.

Reclaimed chipseal

A relatively recent innovation involves breaking up old chipseal surfacings into <50 mm fragments and reincorporating them in situ into the basecourse as aggregate (Gray & Hart 2003). The process does not involve the addition of any new material to the basecourse (other than possible fresh basecourse aggregate), so chipseal should not present any environmental contamination risk.

Crushed bricks

Crushed bricks can be used as alternatives to aggregates in the sub-surface layers. The issue of contaminants being released should not arise, provided the bricks originate from an uncontaminated clay source and are not made from recycled waste material such as fly ash.

Container glass

In the early 1980s, a large part of the container glass stream was reused. Soft drink, beer and milk was supplied in heavy duty glass bottles that were collected by shops, milk vendors and mobile contractors and sorted and returned to the factory for washing and re-filling. The move to single-use containers has made it possible for manufacturers to use thinner, lower cost glass bottles, plastic or cardboard containers with the associated convenience for retailers and manufacturers. Until 2002, container glass collected from kerbside recycling was processed, but due to the low volume, this was discontinued. For Local Governments practical applications for reuse of container glass include as a replacement aggregate in concrete, drainage, roadbase and asphalt applications. There are, however, energy and carbon dioxide implications when reprocessing and reusing waste glass as aggregates.

Plate glass

Plate glass is not recycled in WA. Plate glass waste is generated from demolition sites, renovations, home repairs and window manufacturers. There are no accurate figures to indicate the quantities that are disposed to landfill in each year, but it is estimated to be around 9,000 tonnes annually. This material will be largely concentrated in the Perth to south region. No further information could be found on this issue.

Tyres

Unlike glass, tyres are easily separated, as most tyre changes are carried out by tyre dealers and can be stockpiled until a load sufficient for transport is available. Many trucks travel full to the Pilbara, and return empty, and if a recycling facility was available with the required capacity in the Perth region, tyres could be back-loaded and processed with little change to the current energy expenditure. Baled tyres and shredded tyres encased in a geotextile can be used as lightweight fill for access roads and roads across marginal soils. Baled tyres can also be used for retaining structures on road widening operations. The use of tyres for these purposes requires changes to current legislation. Whilst not a road application, crumb rubber can be used to manufacture soft paving for children's play areas. It can also be used to manufacture temporary and permanent traffic calming devices and for bases for temporary bollards.

Used oil

Under the Product Stewardship for Oil (PSO) scheme, grants have been allocated to a consortium of Wren Oil and Nationwide to establish an oil bottoms to bitumen plant in WA (Department of the Environment, Water, Heritage and the Arts 2009). Wren Oil and RNR Contracting are planning to establish a lube-to-lube oil re-refining plant. There is potential for Local Government to utilise bitumen sourced from used oil bottoms in road construction, and to utilise recycled oils in road construction equipment.

Recycling Methods used in Road Construction

Not only disposal costs but the objective and the technology used affect the economic performance of aggregates recycling. For example, reclaimed asphalt pavement (RAP) is processed differently depending on the type of facility and what the recycled aggregate will be used for. The following describes various recycling methods applied to road construction and maintenance:

• Cold Mix Asphalt (In-Place Recycling): Specialized plants or processing trains are used to mill the existing pavement surface up to 6 inches, mix with asphalt emulsion (or foamed asphalt), and place and compact in one pass. As with HIPR, no processing is required before recycling begins.

• Granular Base Aggregate: RAP is crushed, screened, and blended with virgin granular aggregate or reclaimed concrete material (RCM).

• Stabilized Base or Subbase Aggregate: RAP is crushed, screened, and blended with stabilization reagents (for increased strength when compacted).

• Hot Mix Asphalt (Central Processing Facility): Crushers, screeners, conveyors, and stackers produce and stockpile RAP. The RAP is later transported to a batch plant or drum-mix plant for use as an aggregate substitute in hot mix asphalt.

• Hot Mix Asphalt (In-Place Recycling): Specialized heating, scarifying, rejuvenating, laydown, and compaction equipment is used in one or more passes. No processing is required before recycling begins. One pass can remix up to 2 inches of existing pavement.

• Cold Mix Asphalt (Central Processing Facility): Same as for hot mix RAP processing except the RAP is used in an aggregate substitute in cold mix asphalt.

• Embankment or Fill: RAP is rarely used for embankment or fill unless the stockpiled material has been stockpiled for a long time and would otherwise be disposed of in a landfill.

• Full Depth Reclamation (FDR): FDR penetrates the entire flexible pavement section and a predetermined portion of the base material, uniformly pulverizing and blending them together to produce a stabilized base course, and can correct deficiencies in the base as well as the bound asphalt layers.

• Rubblization: This maintenance technique breaks concrete pavement into pieces and then overlays the road with Hot Mix Asphalt. The concrete is broken into pieces ranging from 2 to 6 inches by either a multiple head breaker or a resonant breaker. The former piece of equipment uses large hammers to strike the pavement surface, while the latter piece of equipment uses vibratory hammers to break up the pavement. Rollers are used to further break up the concrete, and then an asphalt overlay is placed. The process is relatively quick (up to one mile per day), and costs less than some other options. Environmental savings occur because the concrete is not landfilled and transportation during construction is less.

Conclusions

The review presented in this paper clearly indicates an increasing trend and incentive for the greater use of manufactured and recycled aggregates in construction. There are, however, limitations to the use such materials. This report focuses on known benefits and limitations of a range of manufactured and recycled aggregates. Successful strategy must be based on both cost and performance. Natural resources are limited in nature and will be depleted with time. In order to conserve the natural resources, unnecessary wasting of natural resources should be restricted and regulated. Formulation and implementation of proper waste management plan throughout the life cycle of the projects can minimize C&D waste. With an integrated resource management scheme, most of the construction and demolition material can be recycled or reuse and more natural resources can be conserved for our next generations. The success of recycling requires promotion by means of education and information, in addition to judicial rules from the concerned governing body.

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