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A Review of The Use Of Recycled Materials in Rigid Pavements

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Abstract

Road Construction events in India have undergone significant variations over the last two decades owing to the huge investments made and due to the implementation of state-of-the-art construction technology and design principles. Adoption of advanced practices is on the increase due to the relative freedom available to private investors. The use of waste and recycled materials in construction applications has many environmental welfare including cost saving in terms of their disposal, dumping and potential recyclability. Examples of such waste materials include recycled crushed brick, construction demolition materials(C&D), factory-waste roof shingles, reclaimed asphalt shingles (RAS), cement kiln dust (CKD), etc. The need to manage these materials has led to environmentally-friendly actions that promote the reuse and recycling of this type of waste. The use of secondary (recycled) materials instead of primary (virgin) materials helps easing landfill pressures and reducing demand of extraction. This is one way of getting the road construction industry on track towards sustainable construction practices. Scarcity of natural resources is increasingly encountered around the world because of increasing population. Also by adopting the usage of recycled materials the wastage coming out from different industries, factories can be utilized and the total cost of the construction of road can be reduced. This paper will poke around the feasibility of such materials in different layers of rigid pavements to improve the properties of the fine soil that could constitute the subgrade or the fine fraction of the subbase.

***Key words**: rigid pavement, recycled crushed brick, construction demolition materials, cement kiln dust, factory-waste shingles, reclaimed asphalt shingles, construction management and waste management.*

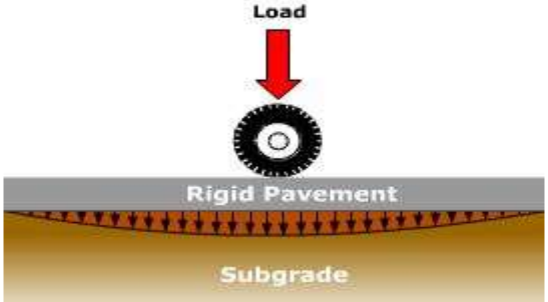

Fig1: Load distribution in Rigid Pavement

1. Introduction:

Pavements are multilayered structures with an asphalt or concrete slab resting on a foundation system comprising layers of geomaterials such as the base, subbase, and subgrade. In rigid pavements structure deflects very little under loading due to the high modulus of elasticity of their surface course, this is the reason behind the naming of this structure. A rigid pavement structure is typically composed of a PCC surface course built on top of either the subgrade or an underlying base course. Because of its relative rigidity, the pavement structure distributes loads over a wide area with only one, or at most two, structural layers (Fig 1).

In recent years, significant efforts have been made to implement regulations, guidelines, and research studies with the purpose of managing construction and demolition waste (Molenaar and van Niekerk 2002). Current research and practice tends to concentrate on the use of waste materials in the lower courses (base, sub-base, etc.) of the road as these absorb materials in larger quantities than the upper courses. (Y. Huang et al., 2007). In the present days researches are made on an alternative material made from cement stabilized recycled crushed aggregate, fly ash and any other materials. The current researchers are focusing on the development of the recycling technology of construction and demolition waste (C&D) for obtaining recycled aggregates with physical and mechanical characteristics suitable for use in the construction of plain cement concrete pavements (PCC) and roller compacted concrete pavements (RCC). Also, for improvement of the behavior in exploitation stage, steel fiber reinforcement of PCC/RCC with recycled aggregates will be studied (Marius-Teodor Muscalu and Radu Andrei, 2011). Generally the bi-products which come from industries, the waste materials are available of lower costs when compared to those materials which are used in pavements.

There are some materials which can also increase the sustainability of the structure by decreasing the environmental impact on it. Some of those kind of materials are construction and demolition (C&D) materials. C&D material is the excess or waste material associated with the construction and demolition of buildings and structures, including concrete, brick, steel, timber, plastics, and other building materials and products (WorkSafe Victoria 2006). The urgency and significance of recycling C&D material has been raised because of scarcity of natural aggregates, difficulties in finding landfill, and other environmental concerns. The increased growth of construction works worldwide, in building and infrastructure, has resulted in the consumption of a vast amount of virgin aggregates, sources of which are limited. More and more land has been acquired by means of residential, commercial, agricultural, and infrastructure purposes, with their increasing demand with global population, and these lead to difficulties in finding suitable landfill areas. In India, agricultural activities plays major role, hence the bi-products, wastage coming out from this will also be more, the usage of which can be done in construction activities. Moreover, environmental considerations play a major role because recycling waste materials saves energy, reduces greenhouse emissions, and delivers a more sustainable future. Although there exist some measures taken by governments at national and/or regional levels to recover the C&D waste to a certain extent, plenty of room still exists to extend the recovery of C&D waste. Without finding sustainable alternatives for recycled C&D waste materials, it will be difficult to encourage or enforce the recovery of C&D waste (A. Arulrajah et. al., 2011).

Recycled crushed brick is another material which can be used here. It is particular interest in this study. A. Arulrajah et. al., in 2011 had studied the properties of the recycled crushed brick were compared with the local state road authority requirements to assess its performance as a pavement subbase material. This research is significant because it investigates the sustainable reuse of recycled crushed brick, potentially as a pavement subbase/light duty-base material. Although recycled crushed concrete is used in pavements, the use of recycled crushed brick in pavement subbases has been limited because of lack of standardized guidelines or performance-based specifications for recycled crushed brick.

Another material that can be used is Cement kiln dust (CKD). It is an industrial waste from cement production. Cement Kiln Dust (CKD) consists primarily of calcium carbonate and silicon dioxide which is similar to the cement kiln raw feed, but the amount of alkalies, chloride and sulfate is usually considerably higher in the dust. CKD from three different types of operations: long-wet. long-dry, and alkali by-pass with precalciner were characterized for chemical and physical traits by Todres et al. (1992). Studies had been made on the usage of this material in subgrade of the pavements.

The majority of CKD is recycled back into the cement kiln as raw feed. In addition, new technology has allowed the use of previously landfilled CKD to be use as raw feed stock. Recycling this by-product back into the kiln not only reduces the amount of CKD to be managed outside the kiln, it also reduces the need for limestone and other raw materials, which saves natural resources and helps conserve energy (Wayne S. Adaska et. al., 2008)

2. Materials and their characterization:

Secondary materials can be defined as by-products from industrial processes or other human activities. It can also be described as materials which had manufactured from used or waste materials that have been reprocessed. The different materials used are listed below

2.1 Construction and Demolition materials(C&D):

During the past decades, in most industrialized countries, a large number of old buildings have been demolished and millions of tons of construction debris have been produced. Demolition wastes around cities have become a serious environmental issue and a threat to underground water quality and result in unpleasant views (Jafar Bolouri Bazaz et. al., 2012).

In most developing countries, the process of replacing old structures with new urban fabrications is the most sophisticated characteristic of urbanization and modernization. This pattern of urbanization in these countries is more evident in the central parts of large and developing cities. The most developing countries like India, Iran has been facing rapid population growth during recent decades, resulting in more housing demands and new industrialization. The modern urbanization causes environmental degradation and pollution in large cities (Hadizadeh and Afchangi 2005).

Construction and demolition materials are normally referred to as solid waste that is generated by various construction and demolition activities. C&D material is the excess or waste material associated with the construction and demolition of buildings and structures, including concrete, brick, steel, timber, plastics, and other building materials and products (WorkSafe Victoria 2006). Construction waste is produced during different phases of construction, such as transportation, stocking, or working. Demolition waste materials arise from demolition activities and their main components include concrete, brick, and glass.

During the construction of a structure many of the bricks goes as waste, which can be used here in the base or sub base. According to Sustainability Victoria, 2009's report around 3,00,000 tons of brick waste were recovered in the state of Victoria, Australia during the period of 2007–2008. This waste is of just Victoria City and of one year. It can be imagined in the country like India, where construction of buildings plays a vital role, the waste generated from this construction will be more. This waste is dumped in landfills. The application of industrial waste in earth construction is not a recent development. The Romans were already using brick rubble and slag from forges in roads and buildings (Lidelow 2004).

Fig 2: Construction and Demolition materials(C&D) which can be used after getting recycled

Hansen in 1992 had reported that the first use of crushed brick with Portland cement was recorded in Germany in 1860 for the manufacturing of concrete products, but the first significant use of crushed brick as aggregates in new concrete has been recorded for reconstruction after World War II.

Fig 3: Concrete waste obtained after the demolition of a structure

The above fig 3 shows the waste obtained when a structure containing concrete is demolished. Bakoss and Ravindrarajah in 1999 mentioned the lack of existing guidelines and requested the need for a new generation of performance-based specifications for C&D sourced recycled concrete, masonry, and reclaimed asphalt pavement materials linked to particular applications, such as nonstructural concrete road fitments, low volume/load concrete pavements, unbound and concrete road bases, drainage, and filter layers.

Sivakumar et al. in 2005 reported on the performance of construction waste, such as recycled concrete and brickwork sized 20–40 mm under repeated loading in a large (305 × 305 mm) shear box. Performance of this construction waste was compared with crushed basalt rock. The samples were tested under initial vertical stresses of 60–300 kPa and subjected to repeated shear loading for up to eight cycles. The internal friction angle reduction of basalt was reported from 47° to 45° after eight loading cycles. The internal friction angle reduction from 43° to 38° was reported for crushed concrete, and a reduction from 43° to 39° was reported for brickwork under repeated loading. The reductions in the frictional resistance of recycled material were primarily because of the particle crushing under repeated loading.

A. Arulrajah et.al in 2011 had done the experimental investigation on the crushed brick samples collecting from recycling site in the state of Victoria, Australia which included laboratory tests, such as particle size distribution, modified Proctor compaction, particle density, water absorption, California bearing ratio, Los Angeles abrasion, pH, organic content, static triaxial, and repeated load triaxial (RLT) tests. The recycled crushed brick had a maximum aggregate size of 20 mm.

Table1: Geotechnical Characteristics of Recycled Crushed Brick (A. Arulrajah et.al, 2011)

Geotechnical parameters		Crushed brick
Particle density—coarse (kN/m^3)		26.19
Particle density—fine (kN/m^3)		25.8
Water absorption—coarse (%)		6.15
Water absorption—fine (%)		6.87
Organic content (%)		2.47
pH		9.13
Fine content (%)		6.6
Hydraulic conductivity (m/s)		4.5×10^{-9}
Flakiness index		14
Los Angeles abrasion loss		36
California bearing ratio (%)		123–138
Compaction (modified)	Max dry density (kN/m^3)	19.82
	Optimum moisture content (%)	10.7
Triaxial test (CD)	Cohesion (kPa)	41.1
	Internal friction angle (degree)	48.8
Resilient modulus (MPa)	Moisture ratio ¼ 84% (% of OMC)	301–319
	Moisture ratio ¼ 80% (% of OMC)	303–361
	Moisture ratio ¼ 65% (% of OMC)	280–519

From the above results the corresponding authors found that the grading limits of crushed brick before and after compaction when compared and found to be within the local state road authority specified upper and lower bounds for usage of aggregates as a pavement subbase material. Other geotechnical experimental tests on the recycled crushed brick, including the CBR results, were found to satisfy the local state road authority requirements for a lower subbase material. The Los Angeles abrasion loss value obtained was just above the maximum limit specified for pavement subbase materials. The repeat load triaxial testing established that crushed brick would perform satisfactorily at 65% moisture ratios. At higher moisture ratio levels, shear strength of the crushed brick was found to reduce beyond the acceptable limit. The results of the repeat load triaxial tests indicate that recycled crushed brick at a moisture ratio of around 65% is a viable material for usage in pavement subbase applications. The properties of the crushed brick could be enhanced further by blending it with other recycled aggregates to improve its performance in pavement subbase applications. Furthermore, crushed bricks in the subbase materials can be successfully utilized by reduced stress magnitudes of the subbase layer by using stronger or thicker overlaying layers.

The other main material included in C&D is the cement concrete from which, by application of appropriate recycling technologies, recycled aggregates result they can successfully substitute crushed/quarry natural aggregates to the construction of rigid pavements (Muscalu & Ţăranu, 2010). Thus, by limiting the consumption of natural aggregates and use of recycled cement concrete from C&D, an important impact reduction of the construction on the environment is achieved. The practical experience has demonstrated that the extraction of cement concrete from C&D is relatively simple, operation that does not require special equipment. In the case of building demolition sites it is recommended that materials other than cement concrete are removed as much as possible to avoid contamination. The cement concrete crushing operation should be preceded, where appropriate, by removal of reinforcements and other embedded materials (Poteraş, 2006). For both demolished cement concrete and recycled aggregates measures should be taken to prevent contamination with soil or other materials from demolition process. Documents and drawings from the construction of the demolished buildings, in particular those detailing the quality and composition of the cement concrete, are of important significance because they contain information regarding the performance characteristics of the concrete (Marius-Teodor Muscalu and Radu Andrei, 2011). These materials can be used by crushing them. Different crushing equipments are available in the market.

2.2 Cement Kiln Dust (CKD) and Factory-Waste Shingles:

Cement kiln dust is created in the kiln during the production of cement clinker. The dust is a particulate mixture of partially calcined and unreacted raw feed, clinker dust and ash, enriched with alkali sulfates, halides and other volatiles. These particulates are captured by the exhaust gases and collected in particulate matter control devices such as cyclones, baghouses and electrostatic precipitators (Wayne S. Adaska et. al., 2008). The samples of CKD are shown in fig 4.

Fig 4: Cement kiln dust (CKD)

Cement kiln dust (CKD) is an industrial waste from cement production. The quantities and characteristics of CKD generated depend upon a number of operational factors and characteristics of the inputs to the manufacturing process. Although the relative constituent's concentrations in CKD can vary significantly, CKD has certain physical characteristics that are relatively consistent. When managed on site in a waste pile, CKD can retain these characteristics within the pile while developing an externally weathered crust, due to absorption of moisture and subsequent cementation of dust particles on the surface of the pile (Liman, 2009). It primarily consists of calcium carbonate and silicon dioxide which is similar to the cement kiln raw feed, but the amount of alkalies, chloride and sulfate is usually considerably higher in the dust. CKD from three different types of operations: long-wet. long-dry, and alkali by-pass with precalciner were characterized for chemical and physical traits by (Todres et al., 1992).

Napeierala (in 1983) examined the possibility of using CKD in stabilizing sandy soils for pavement subgrade applications. It was reported that an addition of 15% CKD having 5.9% free CaO and MgO, and 0.97% total alkalies (K_2O + Na_2O) ensured a compressive strength of 2.5 MPa, which is a standard practice in Poland for the subgrade within 14 days of the treatment. Aly Ahmed et. al. (in 2009) conducted an experimental work to study the use of factory-waste roof shingles and CKD to enhance the properties of fine-grained soil used in road works. CKD, a cogenerated product of Portland cement manufacturing, was used as a stabilizing agent while the processed shingles were added to enhance the soil tensile strength. The results showed that the use of CKD alone resulted in a considerable increase in the unconfined compressive strength but had a small effect on the tensile strength.

The shingles obtained from the destroyed bituminous layer are taken and crushed. Fig 5 shows the shingles obtained before the crushing and after the crushing.

Fig 5: Shingles obtained before recycling and after recycling

The use of shingles in road construction focused in two areas: the asphaltic pavement layer and the subgrade. Here we are focusing on the usage of these materials in subgrade of rigid pavements. The environmental effects on the durability of aggregates stabilized with CKD and other coetaneous material have been evaluated (N. N. Khoury et.al, 2007). Generally adding a small amount of any cementation material increased the strength of the granular material, and this improvement increased when fibers are included.

The results found by Aly Ahmed et. al., in 2009 are

1. The Reclaimed Asphalt Shingles RAS and CKD materials were found to be effective in enhancing the performance of fine grained subgrade.
2. The compressive strength increased with the increase in the CKD content. On the contrary, CKD had no effect on the splitting tensile strength. Adding shingles increased both the compressive and splitting strengths. However, the shingles had a more significant positive

effect on the splitting tensile strength compared to the compressive strength.

3. The results showed that using a 10% shingle content passing sieve no. 4 (4.75mm) and retained on sieve no. 8 (2.36mm) resulted in the best results in terms of CBR (stability), tensile strength, and compressive strength. The permeability of the samples containing 10% shingles was very close to that of the untreated materials.
4. The large shingle size increased the splitting tensile strength, while the small shingle size had a better effect on the compressive strength.

3. Conclusions:

1. The compaction of the artificial C&D aggregate at the jobsite is more difficult because it requires more water. Consequently, this aggregate needs a greater amount of water initially and progressively as it is being spread before compaction. This allows the homogenization of the water and the aggregate mix.
2. Rosario Harader et. al., in 2012 in their experimental study observed that the load-bearing capacity of the recycled artificial CDW aggregate was satisfactory.
3. Cement kiln dust (CKD) is a significant by-product material of the cement manufacturing process. Over the past several years dramatic advances have been achieved in the management and use of cement kiln dust, thus reducing its dependency on landfill disposal.
4. Recycled Concrete Aggregates (RCA) can be used as base and subbase materials, in place of Crushed Stone Aggregates (CSA), for supporting a concrete pavement system (Taesoon Park, 2003)

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