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USE OF RECYCLED WASTE IN HIGHWAY ENGINEERING

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ABSTRACT

Increase generation of waste from human and construction activities with significantly increase number of global population becomes major issues over disposal space. The reuse of waste material is an important topic from the point of sustainability. Some types of waste such as tyre bales, construction and demolition materials, recycled glass and biosolids were studied to investigate the possibility for reuse in highway construction. It was found that tyre bales are useful for embankment stabilization especially on highly compressible soil , construction and demolition material such as brick and and recycled glass were found to be suitable for embankment and pavement base applications. Preliminary studies on biosolids indicate they are useful as embankment material provided which can be treated with suitable additives. This paper discussed the types of waste which are usable with or without treatment in highway engineering, their characteristics and their expected performance in their design life.

KEYWORDS

Recycled, waste, geotechnical, highway

INTRODUCTION

Extensive amounts of waste are generated daily from various industries and human activities. Waste materials is defined as any type of material by-product of human and industrial activity that has no lasting value (Tam & Tam 2006). The disposal of solids waste is a major problem throughout the world. The sustainable usage of waste materials in engineering applications is of social and economic benefit to industrialized nations. Due to the shortages of natural mineral resources, available land space and increasing waste disposal costs, recycling and reuse of solids wastes has become significant in recent years. There are various types of waste which are reusable in construction industry especially in highway engineering with no or little environmental impact. These wastes can be reused in many aspects of highway infrastructure developments such as embankment construction, retaining structures along cut and fill of highway sections, replacement sub-grade materials, base and sub-base materials. Examples of such materials are; demolition bricks and rubbles, recycled glass, bio-solids and tyre bales. Key aspects of assessing reusability of these materials are compliance of the characteristics of these materials to the acceptable local and nationally adopted specifications of intended usage and their expected performance during the design life. Despite some of the waste are not feasible to use as it is, it may become usable as engineering material upon improvement or treatment with a suitable additives. This paper discussed the types of waste which are usable with or without treatment in highway engineering, their characteristics and their expected performance in their design life.

TYPES OF WASTE AVAILABLE FOR HIGHWAY ENGINEERING

There are many types of recycled or non-recycled waste which are available to be used as engineering material in highway engineering. Some types of waste are reusable after reprocessing to be as original materials such as recycled steel, plastics, any types of metals etc. Some types of waste are reusable as it is or after the treatment process. This paper will only discuss on the types of waste fallen under latter categories.

Before exploring available and reusable wastes for highway engineering, it is first worth looking at what are the engineering materials generally required for various infrastructures in highway development. Following table1 show various types of engineering materials used in various types of highway infrastructures:

Table 1: Materials Used in Highway Construction

Infrastructure	Structural Elements	Engineering Material
Highway Embankment	Engineered Fill	Aggregates, geotextiles
	Light weight Fill	EPS
	Retaining Structure	Concrete wall, Gabion wall, Steel Sheet Pile, Continuous Bored Piles, Geogrids etc:
Bridge	Beams & Columns	Concrete, Steel, Timber
	Piles, Caissons, Piers	Steel, Concrete, Timber
	Approach Abutments	Aggregates, Concrete, Steel, Timber
Crossing	Culverts	Steel, Concrete, Timber
Tunnels	Liners	Steel, concrete
	Covers	Aggregates
Pavement	Subgrades, Base, Subbase, paving materials	Aggregates, Asphalts and concrete

Among the materials listed above some types of waste material could be used as replacement materials provided their characteristics complies with required specifications (Table 2). Therefore this paper will present types of waste which are reusable in certain aspects of highway engineering and will discuss about their characteristics.

Table 2: Types of Waste which will be explored as Reusable Material for Highway Engineering

Waste	Infrastructure	Replacement of
Tyre bales	Embankment	Light weight fill
	Retaining Structure	Gabion
Demolition Bricks and Rubbles	Embankment	Engineered Fill
	Base, Sub-base	Aggregate
Recycled Glass	Embankment, Base, Sub-base	Aggregate
Bio-solids	Embankment	Engineered Fill
	Base, Sub-base	Aggregate

TYRE BALES

Characteristics of Tyre Bale

Tyre bale is made up of approximately 100 old car tyres, which are compressed to form a bale. The dimension of the bale is generally 1.2 to 1.5 m in length and 1.0 to 1.3 metres in width with a height of about 0.7 to 0.8 m. Tyre bales have a high porosity of between 50 and 60 %. The Specific Gravity, in other words particle density, of used tyre material was reported to be about 1.31. Given their high porosity of 50 to 60 %, the tyre bale has a dry and saturated unit weight of 6.42 and 11.33 kN/m3 respectively. (HR Wallingford, 2005). Therefore they also have a very high hydraulic conductivity. Hydraulic conductivity is the order of 0.1 m/s (HR Wallingford 2005, Simm et.al 2004). Although tyre bales are highly compressible under unconfined conditions, they are expected to have low compression under confined conditions. They also have high interbale friction (greater than 40 degrees), allowing the embankment to be constructed with steeper side slopes. In addition tyre bales are environmentally and economically beneficial, using recycled waste car tyres.

Application in Highway Engineering

Due to their low unit weight and high interbale friction angle, they can be used as replacement of light weight fill to minimize the primary and secondary consolidation settlements of underlying compressible soils. Example of successful application of tyre bales as embankment fill to minimize footprint area and post construction settlement was implemented in River Witham Flood Mitigation Project in UK (Bo & Yarde 2004 & 2006) (Figure 1a). In addition, due to their high porosity and highly permeable nature tyre bales can be used as retaining materials in lieu of stone gabion. Such type of use can be found in Tarrant County, Texas, USA (Prikryl et.al 2005) (Figure 1b).

Figure 1: Tyre bales as embankment fill (a) Application in Flood Embankment (b) Highway Embankment.

CONSTRUCTION AND DEMOLITION MATERIALS

Many demolitions of buildings are being carried out in these decades with many of which produce wastes and recycled materials. Recycled concrete, brick rubble and glass for instance are viable substitute materials for natural construction materials in engineering applications such as pavement sub-base.
These materials can be either used as it is or after blending with some other additives or each others.

Characteristics of Construction & Demolition (C & D) Materials

Studies on C & D materials have been carried out in several countries such as Australia, United States and Europe. Despite brick rubbles has reasonably good aggregate characteristics, crushed concrete has substantially high content of fine especially due to grain crushing and breakdown after compaction. As such blended materials with certain blending ratios have been studied to assess their suitability as a road sub-base. The engineering properties of brick rubble with and without blending with crushed concrete were investigated. A suite of laboratory tests were conducted on blend mixes of 10%, 15%, 20%, 25% and 30% of brick rubble with crushed concrete. The suite of laboratory tests undertaken included particle size distribution, modified compaction and California Bearing Ratio (CBR). Both grain size distribution and CBR results show the blended mixtures are within the local road authority specification in the state of Victoria, Australia.

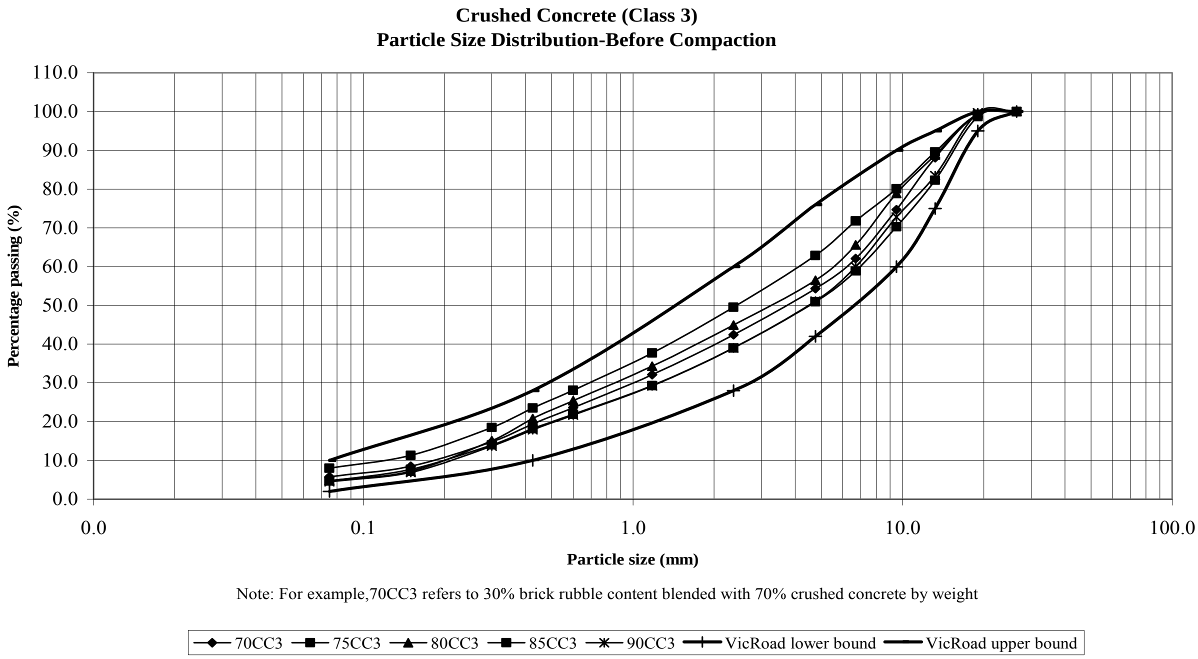

Figure 2: Particle size distribution for brick rubble blended with crushed concrete (Aatheesan et al.,2007)

Table 3: Summary of optimum moisture content and maximum dry density for brick rubble blended with crushed concrete (Aatheesan et al, 2007)

Sample Description	Brick Content (%)	Optimum moisture Content (%)	Maximum dry Density Mg/m^3
70CC3*	30	12.5	1.95
75CC3	25	12.0	1.94
80CC3	20	11.7	1.95
85CC3	15	11.7	1.99
90CC3	10	12.0	1.95

* For example, 70CC3 refers to 30% brick rubble content blended with 70% crushed concrete by weight

RECYCLED GLASS

Recycled glass is a waste material produced in large amounts in municipal and industrial areas worldwide. Recycled glass is a mixture of different coloured glass particles which consists of a wide range of debris (mainly paper, plastic, food remaining and metals). The presence of different coloured glass and diverse types of debris are the primary obstacles in reusing recycled glass in bottle production industries.

Research has been previously carried out to study the feasibility of using recycled glass in different geotechnical engineering applications. This includes using recycled glass as asphalt aggregate, as backfill material, in embankments, as drainage material, as filter media and in road pavements especially in USA (Landris T L 2007, Pratt 1993, Halstead 1993).

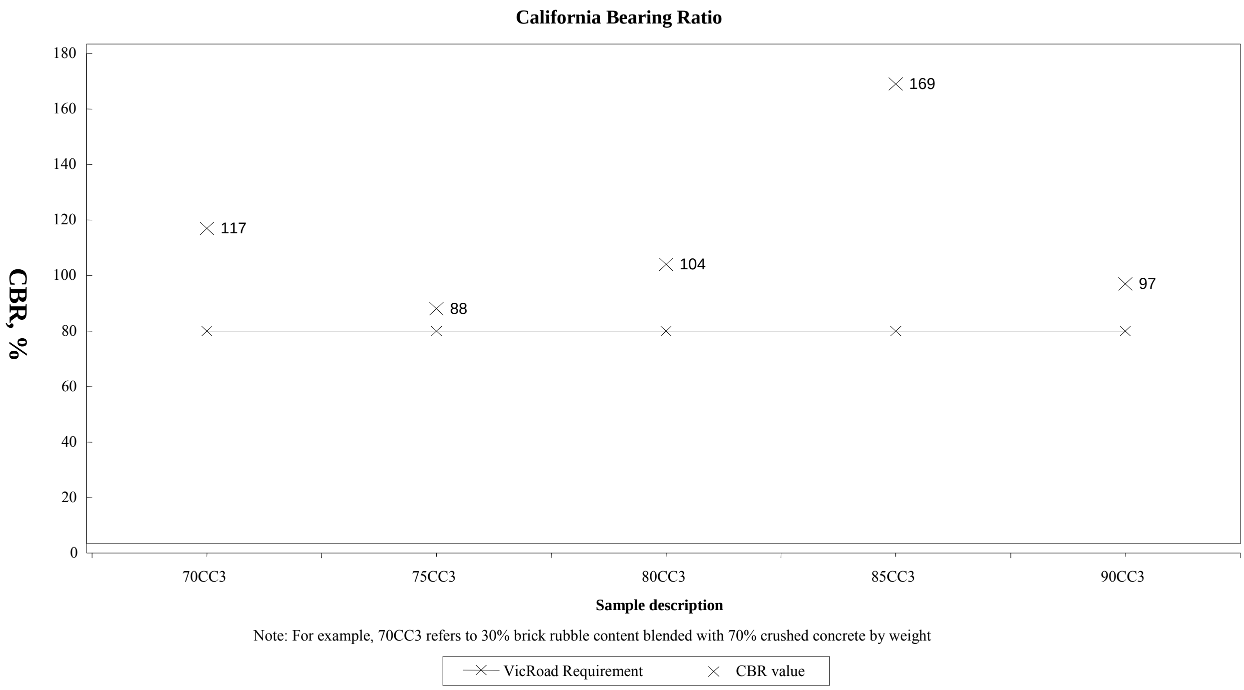

Figure 3: CBR values for brick rubble blended with crushed concrete (Aatheesan et al. 2007)

Analysis of Gradation Curve

Figure 4 shows particle size distributions of three type of recycled glass sources in as-received and post compaction (for both standard and modified compaction tests) situations. Three types of recycled waste glass is found in Australia, Fine Recycled Glass (FRG), Medium Recycled Glass (MRG) and Course Recycled Glass (CRG).

FRG is classified as a well graded sand size mixture with little amount of silt size particles. MRG is classified as well graded gravel size mixture due to dominant gravel content (53% for MRG compare to 9.2% for FRG) with some silt size glass particles. CRG is classified as poorly graded gravel size glass.

Compaction Results of Recycled Glass

The compaction curves of FRG and MRG are similar to characteristic convex shape of natural aggregates such as poorly graded sand. The main reason that both FRG and MRG show the behaviour of poorly graded sand in the compaction tests, (although they both have been classified as well graded mixtures) would be the poor ability of the glass particles in holding and absorbing water.

Geotechnical Characteristics of Recycled Glass

The test results indicate that the all three sources have specific gravities about 15% less than natural aggregate, though there is little difference between specific gravity values of FRG, MRG and CRG. Table 4 presents the result of hydraulic conductivity and shear strength test results obtained for FRG and MRG.

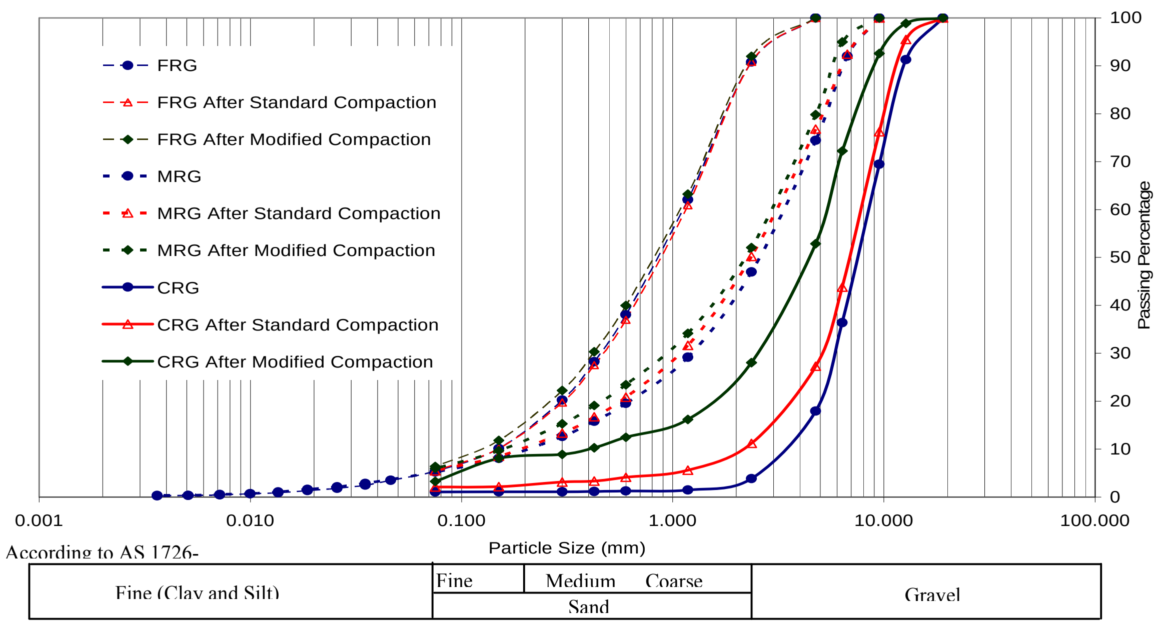

Figure 3: Particle size distribution curves of as-received and post compaction glass (Disfani et al., 2009)

Application in Highway Engineering

Both FRG and MRG sources satisfy the requirements for earthwork material to be used in embankment including particle size distribution. Both FRG and MRG can meet the required specification to be used as drainage material in backfilling for stormwater pipes and sewer pipes or sub-surface drainage lines.

Table 4: Hydraulic conductivity and shear strength parameters of FRG and MRG (Disfani et al., 2009)

Test	standard	FRG	MRG
Hydraulic conductivity (m/s)	BS 1377-5	1.7 E -5	2.85 E -5
Direct Shear Test (DST)	BS 1377-7		
Internal friction angle (degree)			
σ_n (30-120 kPa)		45-47º	----
σ_n (60-240 kPa)		42-43º	----
σ_n (120-480 kPa)		40-41º	----
California Bearing Ratio (CBR)	AS 1289.6.1.1	45-50	----

BIOSOLIDS

Biosolids refers to dried sludge having the characteristics of an oven dried solid typically containing 50% to 70% by weight of bulk solids. Sludge refers to solids-water mixture pumped from wastewater treatment lagoons having the characteristics of a liquid or slurry typically containing between 2% to 15% of oven dried solids.

The characteristics of the biosolids vary around the world as the properties of biosolids depend on factors such as the type of waste which varies with life style, method of treatment process and age of the biosolids. The current knowledge of the geotechnical engineering properties of human waste biosolids is relatively limited or unknown. Biosolids were sampled from a wastewater treatment plant in Melbourne, Australia and the geotechnical properties of the biosolids were determined in this research.

Geotechnical Characteristics of Untreated Biosolids

Some physical, strength and compressibility tests were carried out to characterise biosolids obtained from Melbourne wastewater treatment plant and found that biosolids contain approximately 50 % sand size and 50 % fine material with high value of uniformity coefficient.

The natural moisture content of biosolids is usually high at 50 to 60 %. Specific Gravity of those biosolids are low at around 1.8 Mg/m^3. The organic content for the biosolids ranged between 24.4% to 28.1%. Based on the Atterberg limit test results on three replicate samples, it can be concluded that the biosolids largely comprised organic silt-sized particles. The biosolids in western treatment plant in Melbourne, Victoria can therefore be classified according to the Unified Soil Classification System (USCS) as organic silt of medium to high plasticity.

Biosolids is highly compressible and have low coefficient of consolidation and hydraulic conductivity. Compacted untreated biosolids has undrained shear strength of approximately 25 kPa and drained internal friction angle of 17 degrees. The California Bearing Capacity (CBR) values of untreated biosolids after standard compaction effort varies from 0.8% to 1.1% and also the swell value of untreated biosolids varied from 0.30% to 0.73%. Test results clearly indicate that untreated biosolids should be stabilized before application as an engineered fill.

However biosolids could be useful as an engineered fill for road embankment provided their strength can be increased and compressibility can be reduced by treating with suitable additives. Possible additive materials are lime, cement and fly-ash.

Table 5 and 6 show comparison of CBR values of untreated biosolids and biosolids treated with cement. Similar works have been undertaken with biosolids and other additives such as lime. It seems that biosolids is useful waste to be utilized as engineered fill after treatment with suitable ratio of additives.

Table 5. Laboratory CBR test results for untreated biosolids (Suthagaran et al, 2008).

Test		Unit	Stockpile 1	Stockpile 2	Stockpile 3
California Bearing Ratio Test	CBR Value*	%	0.8 - 0.9	1.0	0.9 - 1.1
	CBR Swell**	%	0.36 – 0.47	0.43 – 0.56	0.3 – 0.73

* - CBR value at 95 % of MDD at OMC
** - CBR swell at end of four days soak period also load applied during end of soak period

Table 6. Laboratory CBR results for biosolids mixed with 5% cement (Suthagaran et al, 2008).

Test		Unit	Stockpile 1	Stockpile 2	Stockpile 3
California Bearing Ratio Test	CBR Value*	%	4.1	4.6	3.8 - 4.5
	CBR Swell**	%	0.59	1.29	0.28 - 0.52

* - CBR value at 95 % of MDD at OMC
** - CBR swell at end of four days soak period also load applied during end of soak period

CONCLUSION

Increase generation of waste from human and construction activities with significantly increase number of global population becomes major issues over disposal space. On the other hand extensive use of natural resources for infrastructure construction could also affect the limited reserve of natural aggregate resources. Therefore it is deemed necessary to explore the possible reuse of waste material from the point of sustainability. Some types of waste such as tyre bales, construction and demolition materials, recycled glass and biosolids were studied to see possibility to be used in the highway construction. It was found that tyre bales are useful for embankment stabilization especially on highly compressible soil due to their low unit weight and high internal friction angle where as C & D material and recycled glass is useful as either embankment fill or road base and sub-base materials. Biosolids are useful as embankment material provided which can be treated with suitable additives to increase their strength and to reduce their compressibility.

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