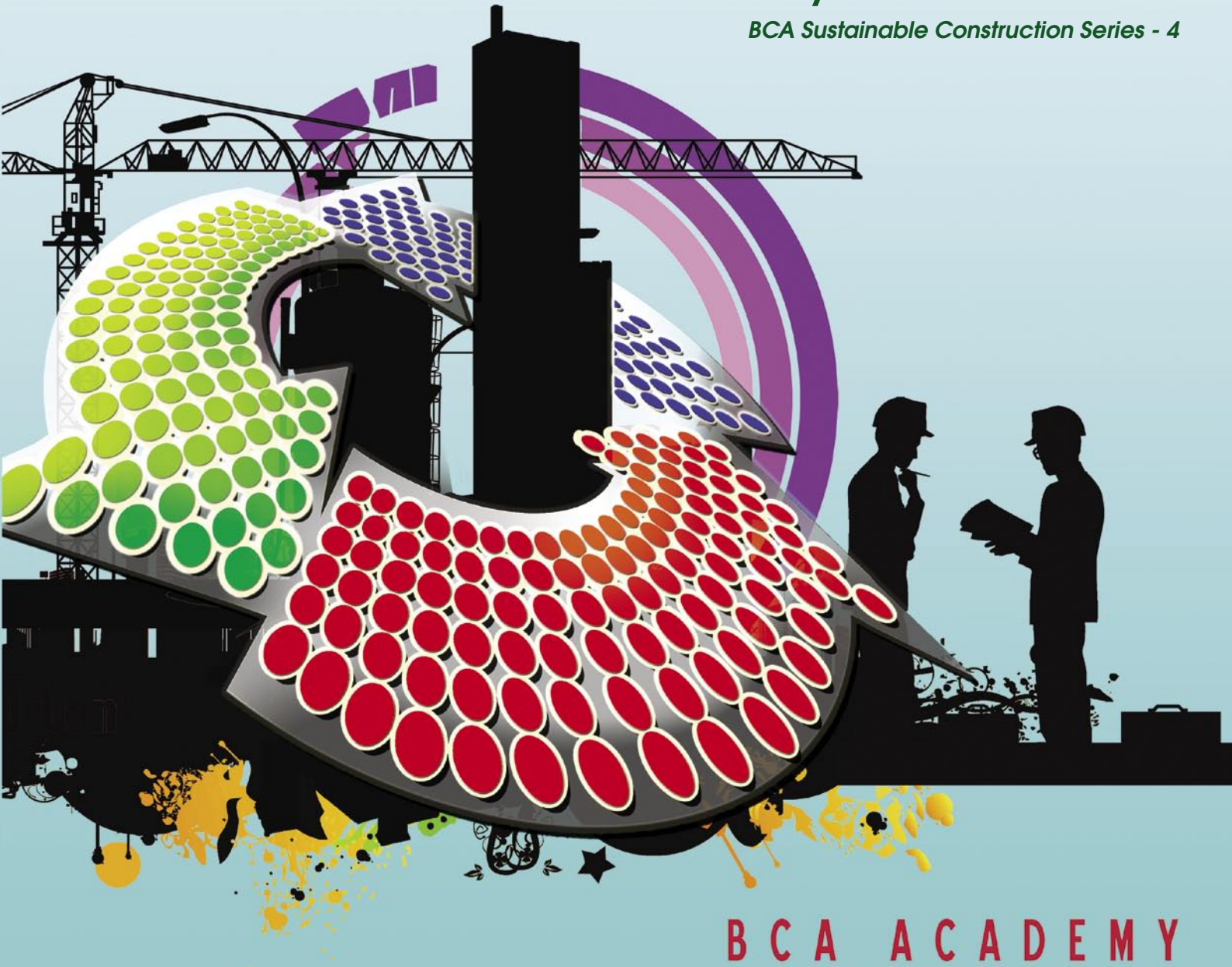
SUSTAINABLE CONSTRUCTION

A Guide on the Use of Recycled Materials

BCA Sustainable Construction Series - 4



BCA ACADEMY

of the built environment

SUSTAINABLE CONSTRUCTION

A Guide on the Use of Recycled Materials



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FOREWORD

Scarcity of land and other resources is a reality, particularly in a small country like Singapore. It is therefore critical for us to make the best use of limited resources, and at the same time be prepared to tackle any challenges that may arise in the future.

Through Sustainable Construction, we can do our part to optimise the use of natural resources and pursue the greater use of recycled materials. Besides reducing our dependence on natural building materials, this will also help to safeguard our quality of life and make provision for the continuing growth of our built environment.

The Building and Construction Authority (BCA) has been working closely with industry partners to promote wider adoption of sustainable materials in our built environment. The completion of SS EN 12620: Specification for Aggregates for Concrete, has paved the way for the use of alternative substitutes to natural aggregates, and it is timely for industry professionals to adopt this new Singapore Standard in the design and construction of buildings.

This publication provides useful information on recycled materials and technical considerations for their applications. I urge all stakeholders in the industry to make a concerted effort to adopt the use of recycled materials in their building projects. I believe that with the greater use of recycled materials, the industry will reach another significant milestone in contributing to a sustainable built environment.

Dr John Keung
Chief Executive Officer
Building and Construction Authority

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DEFINITION OF TERMS

The following terms and definitions are used in this guidebook:

- **Eco-concrete**
  Eco-concrete is defined as concrete with at least 50% by mass of total aggregate content replaced by recycled materials, used for non-structural applications. Typical materials used for aggregate replacement include washed copper slag or recycled aggregates or a combination of both

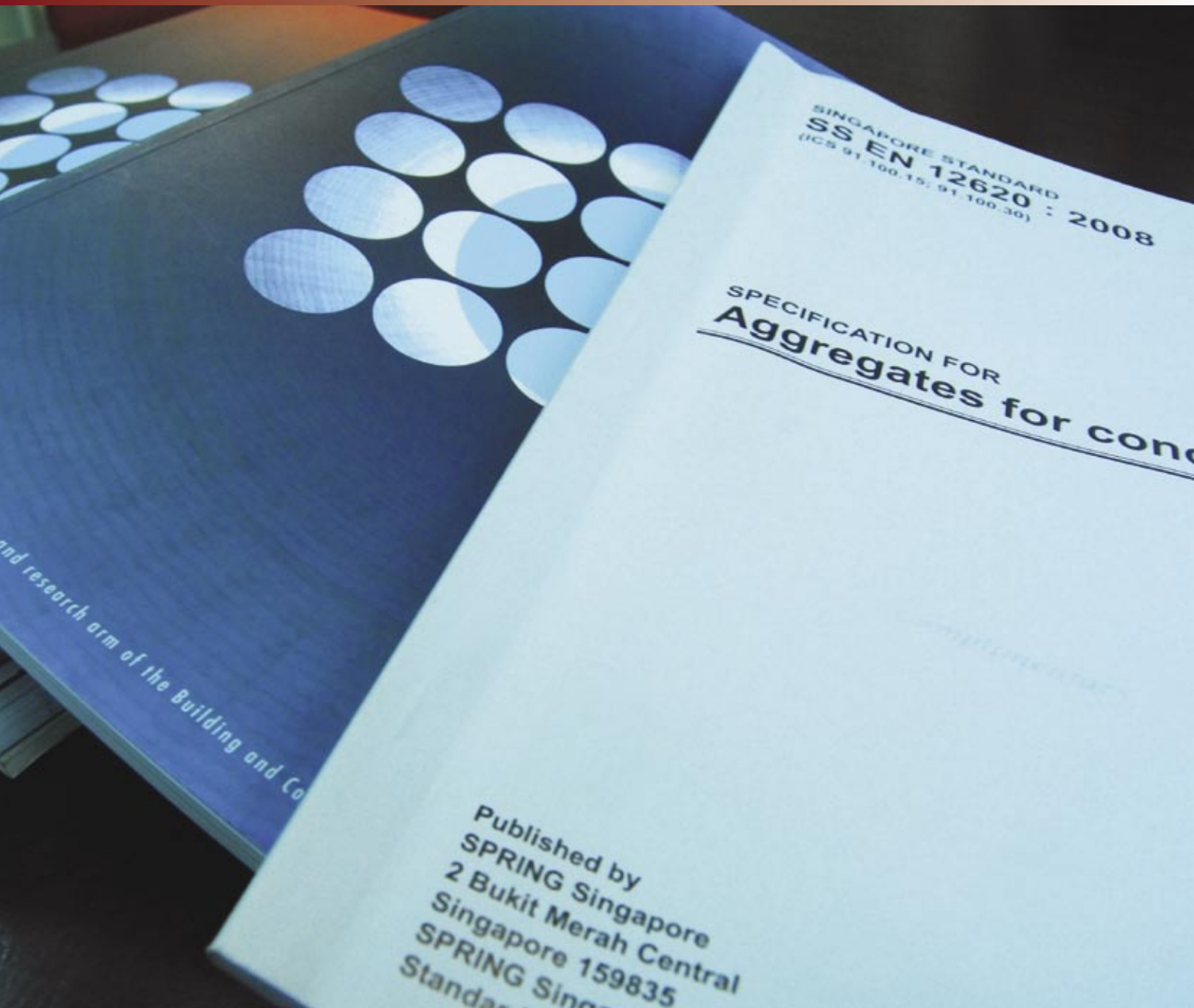
- **Recycled Aggregate (RA)**
  Aggregate resulting from the processing of inorganic material previously used in construction

- **Recycled Concrete Aggregate (RCA)**
  Recycled aggregate comprising principally of crushed concrete

- **Manufactured aggregate**
  Aggregate of mineral origin resulting from an industrial process involving thermal or other modification

- **Structural Works**
  Works in relation to those parts or elements of a building which resist forces and moments and includes foundations, beams, columns, shear cores, slabs, roof trusses, staircases, load-bearing walls and all other elements designed to resist forces and moments

SS EN 12620: SPECIFICATION FOR AGGREGATES FOR CONCRETE



SS EN 12620: SPECIFICATION FOR AGGREGATES FOR CONCRETE

Background

The quality and grading requirements of natural aggregates for concrete are currently specified by Singapore Standard SS 31: Specification for Aggregates from Natural Sources for Concrete. SS 31 is generally based on the British Standard and pertains to aggregates obtained by mechanical processing of natural aggregates.

With United Kingdom's adoption of the European Standard (EN), the British Standard (BS) will eventually be withdrawn and its publications discontinued. With this in mind, Singapore has decided to follow suit with the adoption of EN standards. Hence, BCA initiated a working committee under the auspices of SPRING Singapore to review BS EN 12620: Aggregates for Concrete, on its suitability (and make modification, if necessary) for use in Singapore. The committee has concluded its work with the publication of SS EN 12620: Specification for Aggregates for Concrete.

The new SS EN 12620 will eventually replace SS 31. It is similar to the BS EN 12620 but has additional guidelines on an alternative testing scheme for factory production control of natural aggregates that are imported into Singapore from sources without a system of product quality control.

New Requirements

SS EN 12620 covers a wide range of aggregates (i.e. as compared with SS 31 which specifies aggregates from natural sources only). It permits the use of aggregates (including filler aggregates for concrete) from natural and manufactured sources, including recycled materials and mixtures of these aggregates. Unlike SS 31 which prescribes quality and grading requirement of aggregates, the specification of aggregates under SS EN 12620 is based mainly on performance with limiting values on certain aggregate properties.

For natural aggregates, there is a requirement for producers of aggregates to have a system of factory production control to monitor conformity of the aggregates with the relevant requirements of the standard. However in the case of Singapore where aggregates are imported from sources without a system of product quality control, SS EN 12620 requires importers of aggregates to undertake an alternative testing scheme in lieu of factory production control.

It is recommended that SS EN 12620 be read in conjunction with PD 6682-1: Guidance on the Use of BS EN 12620 as this UK guidance provides recommendations on limiting values for aggregate properties within the ranges permitted in SS EN 12620. The recommended values given in PD 6682-1 are also specified in SS 31 and BS 1047: Air-Cooled Blastfurnace Slag Aggregate for Use in Construction. Further guidance on limiting values for aggregate properties can also be found in BS 8500: Concrete - Complementary British Standard to BS EN 206-1, particularly for the use of recycled aggregates in concrete. BS 8500 contains requirements for both the use and testing of recycled concrete aggregates and recycled aggregates.



New Test Methods

Another key change resulting from the use of SS EN 12620 is that aggregates will be subjected to a new series of European test methods. This new series of test methods are more comprehensive than those referred in SS 31. However not all test methods will be routinely specified for use in Singapore as some of these tests are only required when needed to meet user's requirements in specific applications.

For a better understanding of the European test methods, PD 6682-9: Guidance on the Use of European Test Methods Standards gives a description of each European test method standard along with guidance on their relevance and familiarity to users of test methods specified in British Standards. As Singapore test methods are generally based on British Standards, PD 6682-9 will also serve as a guide on the use of European test methods in Singapore.



TYPES OF MATERIALS



TYPES OF MATERIALS

Washed Copper Slag

DESCRIPTION

Copper slag is a by-product formed during the copper smelting process. The molten copper forms at the bottom of the furnace while molten slag is formed on top. The molten copper slag is then drained off and quenched with water or left in the air to cool.

In Singapore, treated and processed copper slag (Mohs Hardness ≥6) is imported from various countries by shipyards for grit blasting to remove rust and marine deposits accumulated on ships (Refer to Figure1).



Figure 1. Grit blasting at the shipyard

During blasting, copper slag breaks into smaller particles on impact with metal surfaces. After several rounds of reuse, the copper slag gets contaminated with rusts and paints and becomes a waste material but without any change in its chemical composition. The contaminated copper slag has to be properly treated or washed to meet certain recycling criteria (as listed in the next section), before it can be further used for other applications. The amount of washed copper slag available for use is estimated to be 0.4 million tons per year. In Singapore, a typical spent copper slag recycling and processing plant setup is shown in Figure 2.



Figure 2. Copper slag recycling and processing plant



Figure 3. Typical washed copper slag

Table 1 shows the typical metal content of washed copper slag. These metals exist in the forms of oxides. Washed copper slag has a high percentage of iron (Fe) followed by aluminium (Al), calcium (Ca), copper (Cu), zinc (Zn) and magnesium (Mg). The predominant chemical compositions are mainly iron compounds (eg. ferrosilicate, $Fe_2Si_2O_6$).

Washed copper slag has a density of about 3200 to 3500 kg/m^3. Therefore, compared to sand and granite (density of about 2600 kg/m^3) it is denser and heavier per unit volume. It is inert, has negligible water absorption (thus lowering water demand when used as aggregates in concrete), is less angular and absorbs less heat.

Table 1. Typical Metal Composition of Washed Copper Slag

Element	Weight%	Element	Weight%
Ni	0.02	As	0.12
Co	0.02	Pb	0.25
Cd	0.03	Mg	0.77
Mo	0.05	Zn	1.33
Cr	0.07	Cu	1.61
Ba	0.09	Ca	2.01
Mn	0.10	Al	3.08
		Fe	48.72

CONDITIONS FOR USE

The quality control acceptance criteria for the use of washed copper slag in concrete include:

a) No visible foreign material like glass, metal wires, barnacles / shells etc. This can be achieved by dry sieving through large sieve shaker to remove the larger particles. Sieve aperture size should not be greater than 2.0 mm.

b) Water soluble chlorides shall not exceed 0.01% m/m in accordance with SS 73-17: Methods for Determination of Water Soluble Chloride Salts, tested weekly by third party accredited laboratories

c) Water soluble sulphates shall not exceed 0.03% m/m in accordance with SS 73-18: Methods for Determination of Sulphate Content, tested monthly by third party accredited laboratories

d) National Environment Agency (NEA) requires copper slag recycling companies to submit regular Toxicity Characteristic Leaching Procedure (TCLP) test results to NEA to prove that the copper slag has been processed properly. The TCLP is an internationally recognised leachate test that helps to determine the potential amount of heavy metals and contaminants that test can be performed by accredited laboratories locally. The TCLP [1] limits are as shown in Table 2.

Table 2. TCLP Limits for Heavy Metals

Element	Criteria (mg/L)		
	Landfill	Sewer	Water course
Ca			-
Mg			-
Cd	1	1	0.1
Cr	5	5	1
Cu	100	5	0.1
Mn	50	10	5
Ni	5	10	1
Pb	5	5	0.1
As	5	5	0.1
Zn	100	10	1
Ba	100	10	2
Fe	100	50	10

Washed copper slag, being inert, is approved for use as a partial substitute for sand in the production of concrete for building structures.

For Structural Works

Washed copper slag may be used to replace up to 10% by mass of sand in the production of structural grade concrete subject to the following:

- Quality control acceptance criteria have been met
- The supplier of concrete has to inform BCA of the location of batching plant and provide records of building projects supplied with concrete using copper slag
- The supplier of concrete has to inform the purchaser/builder and consultant and obtain their consent before supplying concrete with copper slag. A copy of the consultant's consent letter has to be copied to BCA for record if the use of such concrete has not been specified by the consultant.
- Other project-specific requirements that may be imposed by the consultant

For Non-structural Works

Washed copper slag is commonly used in Eco-concrete for non-structural works. Eco-concrete and all forms of concrete containing washed copper slag should generally comply with the requirements of SS 289: Specification for Concrete, for non-structural elements in buildings or for other building elements not subject to approval of plans by BCA. The supplier is advised to obtain the consent of the client before using the material.

Key Features of Copper Slag

- Composed predominantly of iron compounds
- Density of about 3200-3500 kg/m^3 compared to sand and granite of about 2600 kg/m^3
- Denser and heavier per unit volume
- Inert
- Has negligible water absorption
- Less angular
- Absorbs less heat
- Approved as a partial substitute to fine aggregates in production of concrete
- Approved as replacement for up to 10% by mass of sand in production of structural grade concrete
- Commonly used in production of Eco-concrete

Steel Slag

DESCRIPTION

Steel Slag is a by-product formed during the steel-making process. It is formed from the reaction of flux such as calcium oxide with inorganic non-metallic components present in the steel scrap. It further undergoes a physical process of crushing and separation to produce the required gradation for further use. The amount of steel slag available for reuse is estimated to be 0.1 million tons per year.



Figure 4. Conventional granite and steel slag

Table 3 shows the typical chemical properties of steel slag. It has a high percentage of oxides of calcium (Ca), silica (Si) and iron (Fe).

Table 3. Chemical Composition of Steel Slag

Constituent	Composition (%)
CaO	25-50
SiO_2	<20
FeO	22-35
MnO	6-8
MgO	4-7
Al_2O_3	3-9

Some of the physical properties of steel slag are:

- Good resistance to stripping and high Polished Stone Value (PSV), thus making the material superior to natural granite as road surfacing material.
- Steel slag is hydrophobic in nature (better adhesion with bitumen) while natural granite is generally hydrophilic (has affinity for water). The superior adhesion of the steel slag with bitumen minimises potential moisture damage of the steel slag mix.
- The Flakiness Index, Aggregate Crushing Value (ACV), Los Angeles Abrasion Value (LAAV), soundness, PSV and resistance to stripping of the steel slag are also better than granite and comply with necessary specifications. The typical values are as shown in Table 4.
- Steel slag fulfills leaching properties of an environmentally sound material.
- Compared to natural aggregates the particle density of the steel slag aggregate is higher by about 20% (i.e. about 3200 kg/m^3).

Table 4. Physical Properties of Steel Slag

Parameters	Property
Water absorption (20 mm)	1.2 %
Water absorption (10 mm)	2.8 %
Flakiness Index	4
ACV	26.05
Aggregate Impact Value (AIV)	17.20
LAAV	9.8
Soundness	No disintegration
PSV	56.6%
Resistance to stripping	No stripping observed

CONDITIONS FOR USE

Steel slag can be beneficially used as road surfacing aggregates when it has been properly processed. The formulation of road mixes using steel slag as aggregates has shown to give better rut resistance and mechanical stability, thereby making the wearing course of the road more durable. Since 1994, 100% of steel slag generated in Singapore has been fully recycled into aggregates used in the asphalt mix for the wearing course of roads.

Road works should generally conform to the Land Transport Authority (LTA)'s Materials & Workmanship (M & W) Specification for Civil & Structural Works [2]. Steel slag can be used as a coarse aggregate for asphalt pavement if it meets the Technical Specifications of LTA.

Key Features of Steel Slag

- Has high percentage of oxides of calcium (Ca), silica (Si) and iron (Fe)
- Approved for use as coarse aggregate for asphalt road works
- Good resistance to stripping and high PSV
- Better than granite in terms of Flakiness Index, ACV, LAAV, soundness. The superior adhesion of the steel slag with bitumen minimise potential moisture damage of the steel slag mix
- Density of about 3200 kg/m^3 compared to sand and granite of about 2600 kg/m^3

Construction & Demolition Waste

DESCRIPTION

Construction and demolition (C&D) waste is the material resulting from the construction, alteration or demolition of buildings and other structures. It consists of a mixture of hardcore (concrete, masonry, bricks, tiles), reinforcement bars, dry walls, wood, plastic, glass, scrap iron and other metals etc. Hardcore makes up about 90% of the total weight of C&D waste, with the unit weight or density of hardcore estimated to be between 2100 to 2300 kg/m^3. The average amount of C&D waste available for reuse is estimated to be 2 million tons per year.



Figure 5. C&D waste at demolition site

CONDITIONS FOR USE

For C&D waste to have meaningful applications, it is vital that the waste is properly managed and sorted on site. Once the waste has been properly sorted, it can be channeled to appropriate recycling facilities for further processing into useable products.

Materials such as reinforcement bars and scrap metals have traditionally enjoyed a high recycling rate due to their high residual economic value. In recent times however, more of the various constituents of C&D waste have attracted viable recycling efforts focused on creating new value for C&D waste. Examples include recycled concrete aggregate and wood waste (to be discussed in the following sections), which can be recycled into compressed wood for a wide range of applications from fire doors, laminate flooring to packaging pallets. A proper waste management system must first be instituted at the worksite to ensure maximum material recovery.

CP11: Code of Practice for Demolition, provides guidance on waste minimisation and recycling. Generally, all reusable parts of a building have to be identified, dismantled and removed prior to the commencement of demolition work. This includes building parts such as M&E equipment, fittings, piping and wiring. Next, other parts of the building that may contaminate the concrete debris and make it difficult for reuse, such as ceiling boards, timber and tiles, have to be identified beforehand and removed. Separate bins have to be provided for recyclable wastes so that these can be sent to a recycling facility. Demolition work may then commence once the building has been stripped to its bare frame. Brick debris should be separated on site from concrete debris to facilitate the recycling of concrete debris into recycled concrete aggregates.

The Code of Practice also requires contractors to document the quantity of output and types of waste produced, the movement of the waste from the site to approved disposal facilities, and reconcile the output and disposal amounts weekly.

Key Features of C&D Waste

- 90% of the total C&D waste quantity by weight is made up of hardcore (concrete, masonry, bricks, tiles)
- Density of hardcore is estimated to be between 2100 to 2300 kg/m^3
- Proper sorting is necessary for C&D Waste to have meaningful applications



Recycled Concrete Aggregates

DESCRIPTION

Recycled concrete aggregates (RCA) is derived mainly from the crushed concrete from demolition waste. 70% or more of demolition waste is made up of crushed concrete. A typical process to reclaim RCA is as follows:

- Primary crushing with the help of jaw crushers
- Removal of ferrous metals with the help of magnetic separators
- Screening and removal of foreign materials such as bricks, plastics and asphalt
- Secondary crushing and
- Screening of RCA into various sizes



Figure 6. Typical process to reclaim RCA



Figure 7. Recycled concrete aggregates

As RCA is reclaimed from waste concrete made with natural aggregates, their strength can be expected to be better compared to manufactured aggregates. With the introduction of performance-based standards like SS EN 12620: Specification for Aggregates for Concrete, recycled and manufactured aggregates can be adopted for a range of structural and non-structural applications.

The main difference between RCA and natural aggregates is that RCA has a thin layer of remaining cement paste adhering to it after processing. Because of this, the water absorption is 3-5 times higher than natural aggregates; otherwise the density and other physical properties are similar to natural aggregates. Therefore, prior to their use in concrete production, the water absorption performance of RCA must first be determined in order to avoid large variations in the properties of hardened and fresh concrete, such as the concrete workability.

The durability of concrete is generally determined by the cement type, the cement content and the water-cement ratio (w/c). When using RCA, the cement content is usually increased (some companies use Ground Granulated Blastfurnace Slag or Silica Fume in addition to Ordinary Portland Cement) thereby reducing the effective w/c. Special admixtures can also be employed to improve the strength development of the paste matrix. Durability of the concrete is therefore unlikely to be impaired [3]. By adjusting the w/c, which has the dominant effect on compressive strength, concrete strength is also not compromised.

CONDITIONS FOR USE

As part of the accreditation framework for recycled aggregates suppliers (Refer to next Chapter), quality standards have been introduced to ensure that RCA and recycled aggregates (RA) produced in Singapore adhere to a certain standard and are consistent in quality. This is to enable users to have confidence in the use of recycled materials. The following criteria have been adopted as recommended in SS EN 12620: Specification for Aggregates for Concrete.

Coarse Aggregates

Type of Test	Reference Test Method	Sample Size (kg)
• Max masonry content • Max lightweight material content • Max asphalt content • Max foreign material (e.g. glass, plastics, etc)	Annex B* and Table 2 of BS 8500-2 *(Refer to Figure 8)*	8
Max fines content	BS 812-103.1	10
Max acid-soluble sulphate (SO_3) content	SS 73-18	15
Max chloride content	SS 73-17	15
Alkali Silica Reaction (ASR)	ASTM C295 and C1260	For C1260- 3nos of 25mm x 25mm x 285mm prism bars at each test age

* N.B. Some test methods quoted in Annex B are EN test methods. All BS and SS test methods will be replaced with EN Standards in phases

Type of Aggregate	Requirement [A]					
	Maximum Masonry Content	Maximum Fines	Maximum Lightweight Material [B]	Maximum Asphalt	Maximum Other Foreign Material (e.g. glass, plastics, metals)	Maximum Acid-soluble Sulphate (SO_3)
RCA [A), C)]	5	5	0.5	5.0	1.0	1.0
RA	100	3	1.0	10.0	1.0	— [D]

A) Where the material to be used is obtained by crushing hardened concrete of known composition that has not been in use, e.g. surplus precast units or returned fresh concrete, and not contaminated during storage and processing, the only requirements are those for grading and maximum fines.

B) Material with a density less than 1000 kg/m^3.

C) The provisions for coarse RCA may be applied to mixtures of natural coarse aggregates blended with the listed constituents.

D) The appropriate limit and test method needs to be determined on a case-by-case basis.

Figure 8. Table 2 of BS 8500-2

For Structural Works

The use of RCA may be considered subject to BCA's approval. Consultants should contact BCA for further information.

For Non-structural Works

RCA may be used in Eco-concrete for constructing non load-bearing walls, small drains, kerbs, footpaths, non-suspended slabs, lean concrete etc. Depending on the application and requirements, RCA can also be used to replace natural aggregates by a high percentage for the construction of precast concrete components, so long as the performance of the product is maintained.

For Road Works

RCA may be used for the sub-base if it complies with the criteria in LTA's M & W Specification for Civil & Structural Works [2].

Key Features of RCA

- Water absorption 3-5 times higher than natural aggregates
- Similar physical properties as natural aggregates
- Adjustments to w/c, cement content in the concrete mix design may be necessary to achieve similar performance in strength and workability
- Commonly used in production of Eco-concrete

Wood Waste

DESCRIPTION

Wood waste constitutes about 3% to 30% of construction and demolition (C&D) waste. The quantity of waste generated per year is about 0.1 million tons. Better resource management and conservation can be achieved through innovative processing of timber as well as optimizing the use of wood waste.

With technological means, wood waste can be converted to wood-based products with enhanced properties. The process involves shredding the wood waste into chips, mixing the chips with binder to be compressed and moulded under high heat and pressure to become useful products. A typical process is shown in Figure 9. By having a controlled and consistent assembly process, products can be assured of better precision and quality. Compressed wood products have the added benefit of being pest-free, fire retardant, denser, stronger, more consistent in texture and color, and lower in moisture content as compared to natural wood.



Figure 9. Process flow for converting wood waste into useable products

CONDITIONS FOR USE

To improve the reusability of wood waste, on-site sorting of C&D waste is necessary. The moisture content of the shredded wood must be controlled by means of a dryer.

Wood waste can be processed into products suitable for furniture, building material and industrial use. It can also be used as fuel in cogeneration plants (Refer to Figure 10).



Figure 10. Shredded wood for cogeneration

Key Features of Wood Waste

- Compressed wood made from wood waste is pest-free, fire retardant, denser, stronger, more consistent in texture and color, and lower in moisture content than natural wood
- Moisture content of the shredded wood has to be controlled to reap the full benefits of this material

Milled Waste

DESCRIPTION

Milled waste is asphalt that has been machine-milled from existing roads. It is bitumen-based and is commonly recycled and reused as sub-base material for construction of new roads. The amount of milled waste generated per year is estimated to be 0.5 million tons.



Figure 11. Crushed asphalt



Figure12. Milled waste

Figures 13 and 14 show the process of extracting milled waste.



Figure 13. Asphalt pavement machine-milled by breaker



Figure 14. Milled waste from resurfacing of roads

CONDITIONS FOR USE

Milled waste need not be processed before reuse and is commonly used in the sub-base layer. Milled waste can be used so long as it complies with LTA's M & W Specification for Civil & Structural Works [2]. Grading and California Bearing Ratio (CBR) tests are not required for milled waste when used as sub-base material. However, 100% of the material must pass the 63 mm sieve.

Key Features of Milled Waste

- Machine-milled from existing roads
- Bitumen-based
- Need not be processed before reuse and is commonly used for the sub-base layer
- Can be fully recycled and reused as road sub-base material

Incineration Bottom Ash

DESCRIPTION

Incineration Bottom Ash (IBA) is a residual product from the combustion of municipal solid waste (MSW). To overcome the constraints of limited land, Singapore has adopted waste-to-energy (incineration) as a waste disposal method. Incineration reduces waste volume by a drastic 90%. The ensuing incineration ash thus occupies only 10% of the landfill space needed.

Incineration ash comprises about 15% fly ash and 85% Incineration Bottom Ash (IBA). It is largely inert. The amount of incineration ash generated per year is estimated to be 0.5 million tons. About 1,250 tons of IBA is generated daily and disposed off at the offshore Semakau Landfill as shown in Figure 15.



Figure 15. Semakau Landfill

Maximum dry density of the manufactured aggregate using IBA is about 1700 kg/m^3 and moisture content is up to about 20%. The Los Angeles Abrasion Value (LAAV) is about 40%.

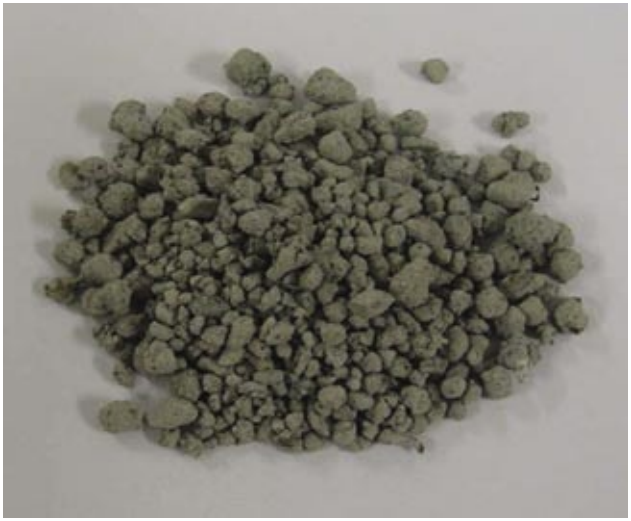


Figure 16. Incineration Bottom Ash

There are 4 incineration plants in Singapore. The chemical composition of the ash varies from source to source but the major components are silicon (Si), aluminium (Al) and iron (Fe).

CONDITIONS FOR USE

IBA has to be processed to render it suitable for use as an aggregate as it may contain heavy metals like cadmium and lead.

There are currently no applications for IBA but successful trials for road usage have been conducted.

Key Features of IBA Manufactured Aggregate

- Major chemical components are silicon (Si), aluminium (Al) and iron (Fe)
- Maximum dry density is about 1700 kg/m^3
- Moisture content is about 20%
- LAAV is about 40%
- IBA needs to be properly treated and stabilised before it can be safely used

Excavated/ Dredged Materials

DESCRIPTION

Excavated materials can be classified into the following categories [4]:

- Good Earth
- Soft Clay and
- Contaminated Material

Materials classified as Good Earth and Soft Clay may be disposed off at designated areas, such as Changi Staging Ground (Refer to Figure 17), for further use as reclamation material.



Figure 17. Aerial view of Changi Staging Ground

Good Earth

Good earth is material that is compactable to form a stable fill. It comprises generally of soil meeting the requirements of Table 5.

Soft Clay

Clay is generally defined as fine-grained, natural, earthy material which is plastic at appropriate water contents and hardens when dried or exposed to fire. It has unique chemical and physical characteristics depending on the source of the material. Soft clay comprises generally of Kallang Formation cohesive soils and marine clay, with limits as shown in Table 5. It is generated mainly from excavation works as well as dredging activities during the maintenance of ports, basins and rivers.

Table 5. Soil Classification System

Material		63 mm sieve (% passing	63 µm sieve (% passing)	2 µm sieve (% passing)	Liquid Limit (LL) (%)	Plasticity Index (PI) (%)	Moisture Content (%)
Good Earth	Coarse-grained[1)] soil	100	≤35	-	≤70	≤40	-
	Fine-grained soil[2)]	-	>35	≤80	≤60	≤30	≤40
Soft Clay	Kallang Formation Cohesive Soils	-	>30	-	>60	-	-
	Marine clay[3)]	-	-	-	>60	>30	>40

Remarks:

1) Includes all sand and gravel passing through a 63 mm BS sieve; does not include all forms of rocks
2) Includes silt and clay with >35% passing the 63 μm BS sieve.
3) Has a wet density less than 18 KN/m^3

Contaminated Materials

Contaminated Materials may be defined as any excavated earth or dredged materials that contain amounts of any of the contaminants listed in the guidelines on metal content given by the Maritime and Port Authority of Singapore (MPA). These include chromium, nickel, copper, zinc, arsenic, cadmium, mercury and lead. Contaminated materials need to be subjected to tests on heavy metals by an accredited laboratory using US Environmental Protection Agency (EPA) testing methods to ensure that the heavy metals concentrations are within limits. These methods are the EPA 3051: Microwave Assisted Acid Digestion of Sediments, Sludges, Soils, and Oils, and EPA 6010B: Inductively Coupled Plasma-Atomic Emission Spectrometry.

Contaminated materials can be manufactured into ceramic aggregates through a series of physical, chemical and thermal processes which remove the organic contaminants, encapsulate the heavy metals contained in the materials and convert them into ceramic matrices. Ceramic aggregates are classified as lightweight aggregates and are a type of manufactured aggregates.



Figure 18. Ceramic aggregates

Ceramic aggregates are generally inert and non alkali-silica reactive. Compared to natural aggregates they are more angular, have 2-5 times higher water absorption, are lower in density by 3% to 20% and thus lower in strength.

CONDITIONS FOR USE

Soft Clay

Soft clay can be transformed into highly flowable grout material (also known as liquid soil) with the introduction of Ordinary Portland Cement and additives. For backfilling and soil stabilisation applications, the grout material must meet the specifications as shown in Table 6.

Table 6. Specifications for Liquid Soil

Properties	Specifications
Unconfined compressive strength	≥ 2 N/mm^2 after 1 day curing
	≥ 7 N/mm^2 after 7 days curing
Density	≥ 1.90 tons/m^3
Bleeding	≤ 2%
Flowability at site (diameter of flow test)	≥ 10 cm

Contaminated Materials

Contaminated materials must be treated first before reutilisation to address the organic compounds and heavy metals contamination. Appropriate treatment methods can be used to destroy, reduce, separate, immobilise and/or detoxify the contaminants. Thermal treatment is one effective method to engineer the end product to meet the physical and environmental conditions for reuse.

Acceptance criteria for use of ceramic aggregates include:

- No visible foreign material, like glass, metals, rubber, etc
- Organic content shall not exceed 0.5% by mass of concrete (w/w) for every batch of concrete produced
- Toxicity Characteristic Leaching Procedure (TCLP) test shall be conducted to assess the leachability of heavy metals content whose limit shall satisfy and comply to NEA regulations
- For application on roads as coarse aggregates, fine aggregates or fillers, LTA's M & W Specification for Civil & Structural Works [2] should be referred to
- SS 73: Methods of Sampling and Testing of Mineral Aggregates, Sand and Fillers or SS EN 12620: Specification for Aggregates for Concrete, may be used for other applications in structural and non-structural works

ACCREDITATION SCHEME FOR RECYCLED AGGREGATE SUPPLIERS



ACCREDITATION SCHEME FOR RECYCLED AGGREGATE SUPPLIERS

Background

The accreditation scheme [5] for recycled aggregates suppliers is an industry-led effort initiated by the Waste Management and Recycling Association of Singapore (WMRAS) together with BCA. The scheme is the result of a year-long effort by WMRAS and the C&D waste recycling plants to set standards and guidelines for the processing of C&D waste into recycled aggregates. Inputs from industry associations and government agencies were sought through the BCA-WMRAS Recycling Workgroup.

The scheme is managed by WMRAS as part of the effort to promote greater self-regulation by the industry. It also provides recognition to C&D waste recycling plants that are committed to quality, consistency and safety of the production plant and products.

The scheme aims to improve the quality and consistency of recycled aggregates by establishing an assessment framework for C&D waste recycling plants and by adopting testing standards as specified in the SS EN 12620: Specification for Aggregates for Concrete. This will enhance user confidence and acceptance of recycled aggregates. C&D waste recycling plants will also benefit through improved company image and marketability.

The scheme is open to C&D waste recycling companies with facilities located within Singapore.

Accreditation Criteria

The accreditation criteria take into account the following:

- Company Financial Status
- Facilities & Equipment
- Human Resource
- Quality Assurance Testing
- Quality Management System & Documentation

Applicants will be subjected to an audit, after which a certificate will be issued upon meeting the accreditation criteria. As part of the requirements for continued accredited status, waste recycling plants will be required to subject their recycled concrete aggregates to third party accredited laboratory-testing periodically. Accreditation is also subject to periodic renewal.

Two categories of accreditation are available:

- **Class 1 Recycler** - For recycling plants supplying recycled concrete aggregates meeting requirements of SS EN 12620: Specification for Aggregates for Concrete
- **Class 2 Recycler** - For recycling plants supplying aggregates for general use, such as in road sub-base construction, hardcore for construction use, landscaping etc.



Enquiry

For more information on the accreditation scheme, please refer to the website:
http://www.wmras.org.sg/

For application procedures and enquiries, please contact WMRAS Secretariat at
Tel: 6377 6631.

APPLICATIONS OF RECYCLED MATERIALS



APPLICATIONS OF RECYCLED MATERIALS

Eco-concrete

ECO-CONCRETE FOR IN-SITU USE

Eco-concrete is used mainly for non-structural applications. It can be used to replace conventional ready mixed concrete for all non-suspended slabs and slabs on grade, e.g. lean concrete, apron slabs and footpaths.

All the local Ready Mixed Concrete (RMC) suppliers are generally able to supply Eco-concrete.



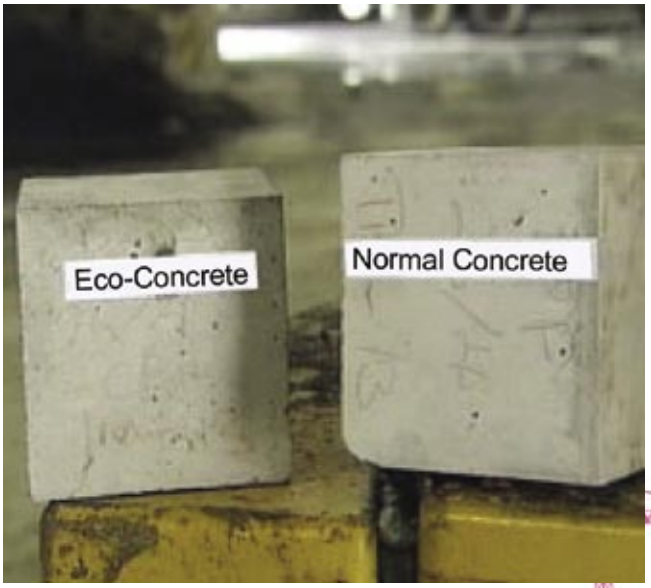


Figure 19. Conventional concrete compared to Eco-concrete

HDB has completed a trial using Eco-concrete for casting of walkways (Refer to Figure 20).



Figure 20. HDB Walkway being cast with Eco-concrete

ECO-CONCRETE FOR PRECAST CONCRETE

Precast concrete civil engineering products using Eco-concrete are already available and have been used in the drainage systems for various projects. The materials used for these works must comply with PUB's specifications [6]. Figures 21 to 26 show some precast products that can be constructed using Eco-concrete.



Figure 21. Precast kerb



Figure 22. Precast wheel stopper



Figure 23. Precast open drains



Figure 24. Precast drop-Inlet chamber



Figure 25. Precast slab



Figure 26. Precast concrete components with RCA

Products Using Recycled Materials

Concrete pavers can be made using recycled materials such as washed copper slag and ceramic aggregates. Figure 27 shows a residential driveway using concrete pavers incorporating washed copper slag.



Figure 27. Concrete pavers at residential area

Other illustrations on the use of recycled materials are shown in Figure 28 and 29. Contaminated soft clay was manufactured into ceramic aggregates to fabricate concrete pavers as shown in Figure 28 and concrete blocks and bricks as shown in Figure 29.



Figure 28. Concrete pavers made with ceramic aggregates



Figure 29. Concrete blocks and bricks manufactured with ceramic aggregates

AIRCRAFT PAVEMENT CONSTRUCTION

The Civil Aviation Authority of Singapore (CAAS) carried out a field trial in 2007 on the use of RCA for aircraft pavement in Changi Airport. A high performance base course constructed of RCA and cementitious additives was designed to provide a high bearing capacity for the base course layer in the aircraft pavement. Structural field monitoring was carried out for more than nine months. The base course constructed of RCA with cementitious additives offered a more economical solution and exhibited better structural performance compared to the conventional granular base course. Base courses constructed of RCA have since been adopted for the taxiway.



Figure 30. Paving of the base course with RCA for taxiway

ROAD CONSTRUCTION

The Land Transport Authority (LTA) conducted a successful trial together with industry members in 2001 for copper slag to be used as an alternative to natural aggregates for road construction.

In another pilot project, 1,200 tons of treated IBA was used as the road base material along a 150 m stretch of Jalan Buroh in Jurong. The ridability was assessed to be as good as roads built with conventional construction materials. The road has been in use since May 2002 and found to be structurally sound.

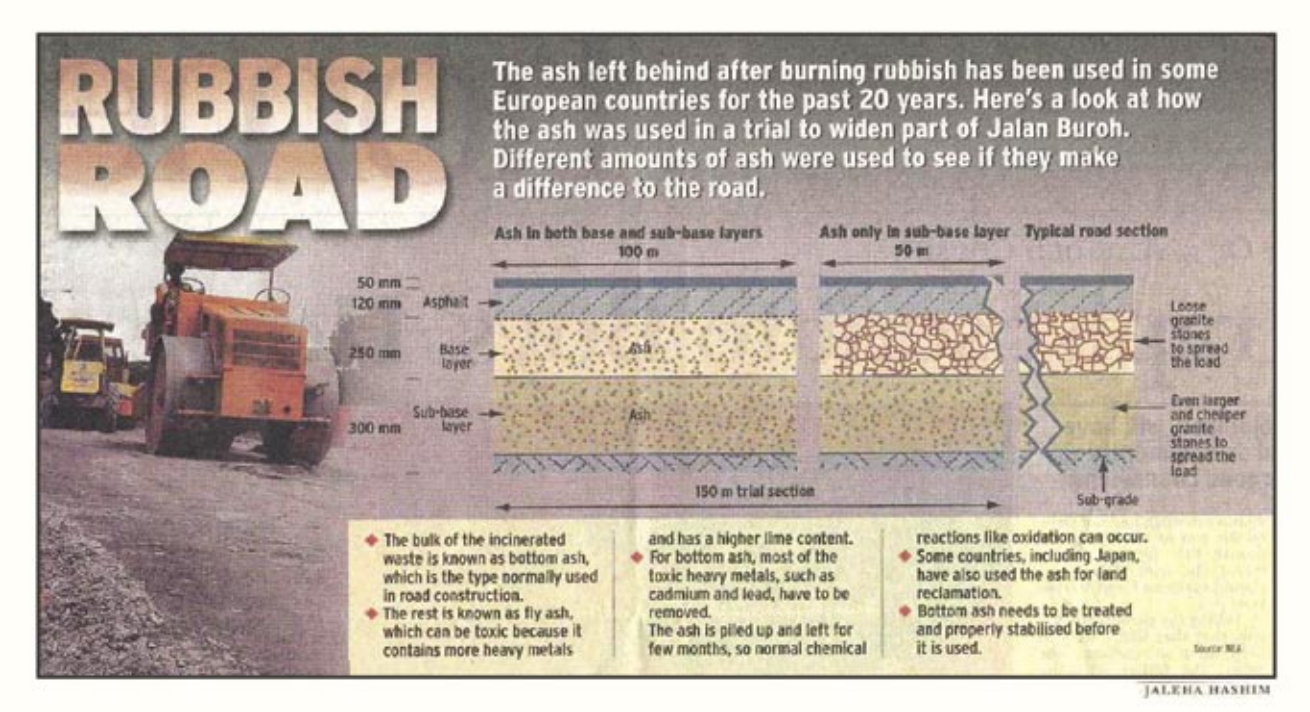


Figure 31. Pilot project where IBA was used along a stretch of Jalan Buroh

Steel slag is another common material used in road surfacing works. The following figures show some places where steel slag has been used.



Figure 32. International Road traffic junction



Figure 33. AYE-Jurong Town Hall Exit



Figure 34. Boon Lay Way traffic junction

Backfilling and Soil Stabilisation

Other than for use as a reclamation material, soft clay can also be used for backfilling, soil erosion control and slope stabilisation after processing. Technology is available to convert soft clay into self-compacting, highly flowable grout with waterproofing characteristics (Refer to Figure 35). It can also be re-excavated easily with digging tools for reuse.



Figure 35. Self-compacting, highly flowable liquid soil

The hardened grout is able to provide support for sheet piles and diaphragm walls as shown in Figures 36 and 37. It minimises settlement and has a higher load-carrying capacity compared to fill material.



Figure 36. Support between sheet pile and tunnel wall



Figure 37. Filling up diaphragm walls from the top with liquid soil

GREEN MARK RELATED INFORMATION



GREEN MARK RELATED INFORMATION

Point Allocations

Under the Green Mark Scheme [7], projects specifying the use of sustainable construction materials or environmental friendly products certified under the Singapore Green Label Scheme [8] will be awarded points. The allocation of points is to recognise efforts in construction sustainability with respect to the type of materials used in the design and construction of buildings.

For Residential buildings, under Part 3, Environmental Protection, material usage is allocated up to 6 points out of 12 under Part 3.1 of Sustainable Construction (Refer to Figure 38).

For Non-Residential buildings, under Part 3, Environmental Protection, material usage is allocated up to 8 points out of 14 under Part 3.1 of Sustainable Construction (Refer to Figure 39).

Part 3 - Environmental Protection	Green Mark Points
3-1 Sustainable Construction Encourage the adoption of building designs, construction practices and materials that are environmentally friendly and sustainable	
(a) More efficient concrete usage for building components	0.1 point for every percentage reduction in the prescribed Concrete Usage Index (CUI) limit for residential building (Up to 4 points)
(b) Conservation of existing structure. Applicable to existing structural elements or building envelope	Extent of Coverage: Conserve at least 50% of the existing structural elements or building envelope (by area) 2 points
(c) Use of sustainable materials and products in building construction such as:	
(i) Environmental friendly products that are certified under The Singapore Green Labelling Scheme (SGLS)	1 point for high impact item 0.5 point for low impact item (Cap at 3 points)
(ii) Products with at least 30% recycled content by weight or volume	1 point for high impact item 0.5 point for low impact item (Cap at 3 points)
Note (2): For products that are certified under SGLS and with at least 30% recycled contents, points can only be awarded either from item (c)(i) or (c)(ii)	(Up to 6 points)

Figure 38. Green Mark points allocation for residential buildings (Effective date: 31 Jan 2008)

Part 3 - Environmental Protection	Green Mark Points
3-1 Sustainable Construction Encourage the adoption of building designs, construction practices and materials that are environmentally friendly and sustainable	
(a) More efficient concrete usage for building components	0.1 point for every percentage reduction in the prescribed Concrete Usage Index (CUI) limit for the respective building categories (Up to 4 points)
(b) Conservation of existing structure. Applicable to existing structural elements or building envelope	Extent of Coverage: Conserve at least 50% of the existing structural elements or building envelope (by area) 2 points
(c) Use of sustainable materials and products in building construction such as:	
(i) Environmental friendly products that are certified under The Singapore Green Labelling Scheme (SGLS)	1 point for high impact item 0.5 point for low impact item (Cap at 4 points)
(ii) Products with at least 30% recycled content by weight or volume	1 point for high impact item 0.5 point for low impact item (Cap at 4 points)
Note (5): For products that are certified under SGLS and with at least 30% recycled contents, points can only be awarded either from item (c)(i) or (c)(ii)	(Up to 8 points)

Figure 39. Green Mark points allocation for non-residential buildings (Effective date: 31 Jan 2008)

LIST OF RECYCLING PLANTS



LIST OF RECYCLING PLANTS

No	Waste Type	Company	Contact Person	Remarks
1	Steel Scrap	**Natsteel Asia Pte Ltd** No 22 Tanjong Kling Road Singapore 628048	Mr Chong Pek Hoong Tel : 6660 7840 Fax : 6264 4181 Website: www.natsteel.com.sg Email : cph@natsteel.com.sg	Melting and refinery of steel scrap into steel bars and wire rods
2	Used steel slag	**NSL Chemicals Ltd** No 26 Tanjong Kling Road Singapore 628051	Mr Lawrence Anthony Tel : 6265 2556 / 6265 2181 Fax : 6261 0840 Website: www.nsl.com.sg Email : Lawrence@nslchemicals.com.sg	Recovery and processing of steel slag
3	Used copper slag	**Allibey Services Pte Ltd** No 1 Jalan Samulun Singapore 629119	Mr Tony Lim Tel : 6268 1648 Fax : 6268 1685 Email : allibey@singnet.com.sg	Processing of used copper slag
4	Used copper slag	**JPL Industries Pte Ltd / JPL Concrete Products Pte Ltd** No 11A Jurong Pier Road Singapore 619166	Ms Ho Siew Lian Tel : 6266 2210 / 6867 5272 Fax : 6266 3002 / 6660 0854 Email : hosl@jplind.com.sg	Processing of used copper slag Manufacturing of concrete interlocking pavers

No	Waste Type	Company	Contact Person	Remarks
5	Used copper slag	**EcoWise Materials Pte. Ltd** No 5 Sungei Kadut Street 6 Singapore 728853 Lim Chu Kang Road Sarimbun Recycling Park	Mr Aloysius Chan Mr Kenny Huang Tel : 6365 3288 Fax : 6365 3088 Website: www.ecowise.com.sg Email : enquiries@ecowise.com.sg	Processing of used copper slag
6	Construction and demolition waste	**Hock Chuan Hong Waste Management Pte Ltd** Lim Chu Kang Road Sarimbun Recycling Park	Mr Poh Seng Chung Mr Henry Neo Tel : 6795 4813 / 6582 7183 Fax : 6795 4812 / 6582 9727 Website: www.hchwaste.com.sg Email : psengc@hchwaste.com.sg henryneo@hchwaste.com.sg	Processing and recovery of materials from construction and demolition waste
7	Construction and demolition waste	**HuaTiong Contractor Pte Ltd** Lim Chu Kang Road Sarimbun Recycling Park	Mr Patrick Ng Tel : 6366 5005 Fax : 6368 1391 Email : huationg@singnet.com.sg	Processing of construction and demolition waste

No	Waste Type	Company	Contact Person	Remarks
8	Construction and demolition waste	**ECO CDW Management Pte Ltd** Lim Chu Kang Road Sarimbun Recycling Park	Mr Steven Chan Tel : 6227 3323 Fax : 6222 3577 Email : stevenchan@ecocdw.com.sg	Processing of construction and demolition waste
9	Construction and demolition waste	**Sembwaste Pte Ltd** Lim Chu Kang Road Sarimbun Recycling Park	Mr James Liaw Tel : 6792 0249 Fax : 6465 7721 Email : James.liaw@sembenviro.com	Recovery of materials from construction and demolition waste
10	Construction and demolition waste	**Samwoh Corporation Pte Ltd / SamGreen Pte Ltd** Lim Chu Kang Road Sarimbun Recycling Park	Mr Guah Eng Hock Mr Ronnie Ong Tel : 6269 7288 / 6367 2377 Fax : 6368 2886 / 6365 0512 Website: www.samwoh.com.sg Email : guah@samwoh.com.sg samgreen@singnet.com.sg	Processing of construction and demolition waste

Remark:

- Information correct as of April 2008. Please refer to NEA's website for the full list of local recycling facilities. (http://www.nea.gov.sg/cms/rcd/Local%20Recycling%20Plants.pdf)

SUPPLIERS



SUPPLIERS

Eco-Concrete Ready Mix Concrete Suppliers

No	Company	Name/Designation	Details Contact
1	**Alliance Concrete (S) Pte Ltd** 72 Sungei Kadut Street 1 Singapore 729372	Mr Goh Siew Huat CEO	Tel : 6368 8211 / 6866 2168 Fax : 6368 0691 Email : siew-huat.goh@allianceconcrete.com.sg
2	**G&W Group** 65 Sungei Kadut Drive Singapore 729564	Mdm Koh Siew Kiang Operations Director	Tel : 6365 3388, 6368 2221 Fax : 6365 5866 Email : kohsk@gw-group.com
3	**Holcim (Singapore) Pte Ltd*** 16 Jalan Tepong Singapore 619331	Dr Sujit Ghosh CEO	Tel : 6265 1933 / 6660 4891 Fax : 6268 4027 Email : sujit.ghosh@holcim.com
4	**Island Concrete Pte Ltd** 43/45 Sungei Kadut Street 4 Singapore 729061	Mr Victor Leong General Manager	Tel : 6488 5777 / 6488 5728 Fax : 6368 1837 Email : vleong@hlasia.com.sg
5	**Jurong Readymix*** 17A Pandan Road Singapore 609268	Mr Roland Mathys CEO	Tel : 6261 8016 Fax : 6261 8016 Email : rolandmathys@jurongcement.com

No	Company	Name/Designation	Details Contact
6	**Pan-United Concrete Pte Ltd*** 9 Tampines Industrial Street 62 Singapore 528815	Mr Loh Kah Soon (Ken) Executive Director	Tel : 6582 0377 / 6581 0777 Fax : 6582 9677 Email : ken.loh@panunited.com.sg
7	**RDC Holdings Pte Ltd*** 21 Sungei Kadut Street 6 Singapore 728866	Mr Martin C. N Teo Managing Director	Tel : 6468 3355 Fax : 6468 0548 Email : martin.teo@rdc.com.sg
8	**Star Ready-Mix Pte Ltd** 49 Sungei Kadut Street 6 Singapore 728874	Mr Hong Yong Ming Operation Director	Tel : 6744 1066 Fax : 6842 1066 Email : yongming@hec.com.sg
9	**Samwoh Premix Pte Ltd** 25E Sungei Kadut Street 1 Singapore 729333	Mr Larry Tan Manager	Tel : 6269 7288 ext 625 Fax : 6368 2886 Email : larrytan@samwoh.com.sg
10	**Top-Mix Concrete Pte Ltd** 29 International Business Park #08-05/06 Acer Building Tower B Singapore 609923	Mr D.V.V.S. Raju General Manager	Tel : 6890 8807 Fax : 6562 4068 Email : raju.dvvs@engro-global.com

Remark:

- Information correct as of July 2008.
- *Ready Mixed Concrete suppliers who have obtained BCA's no-objection to use copper slag in structural concrete as of July 2008



Precast & Other Product Suppliers

No	Company	Name/Designation	Details Contact	Remarks
1	**GPac Technology Pte Ltd** 14 Ang Mo Kio Street 63 Singapore 569116	Mr Steven Chiu General Manager	Tel : 6484 0383 Fax : 6484 4548 Website: www.gpac.com.sg Email : enquires@gpac.com.sg	Manufacturing of compressed wood products
2	**Hock Chuan Hong Waste Management Pte Ltd** **Hock Chuan Hong Engineering & Trading Pte Ltd** 18 Pasir Ris Avenue Singapore 519685	Mr Henry Neo Manager	Tel : 6582 7183/ 6795 4813 Fax : 6582 9727 Email : henryneo@hchwaste.com.sg	Manufacturing of precast concrete products from recycled concrete aggregates
3	**JPL Concrete Products Pte Ltd** 29 Tanjong Kling Road Singapore 628054	Ms Ho Siew Lian Asst. GM	Tel : 6867 5272 Fax : 6266 3002 Email : hosl@jplind.com.sg	Manufacturing of concrete interlocking pavers from washed copper slag

No	Company	Name/Designation	Details Contact	Remarks
4	**LHT Holdings Limited** 27 Sungei Kadut Street 1 Singapore 729335	Ms Yap Mui Kee Executive Director	Tel : 6269 7890 Fax : 6367 4907 / 6362 4562 Website: www.lht.com.sg Email : enquiry@lht.com.sg	Manufacturing of compressed wood products
5	**NewEarth Pte Ltd** 167 Jalan Bukit Merah #01-10 HDB Centre Singapore 150167	Mr Roy Tan CEO	Tel : 6271 9476 Fax : 6271 9475 Email : roytan@newearth.com.sg	Manufacturing of standard pavers Supplier of manufactured aggregates from contaminated soft clay
6	**Singapore Precast Pte Ltd** 18A Kranji Way Singapore 739443	Mr Albert Liew Operations Manager	Tel : 6365 9043 Fax : 6365 9042 Email : singcast@singnet.com.sg	Manufacturing of precast concrete products using Eco-concrete
7	**Singapore-U Technologies Pte Ltd** 63 Hillview Avenue #08-07 Lam Soon Industrial Building Singapore 669569	Dr Wee Tiong Huan Consultant	Tel : 6100 5325 Fax : 6760 1040 E-mail : info@singapore-u.com	Manufacturing of precast concrete walls from recycled aggregates

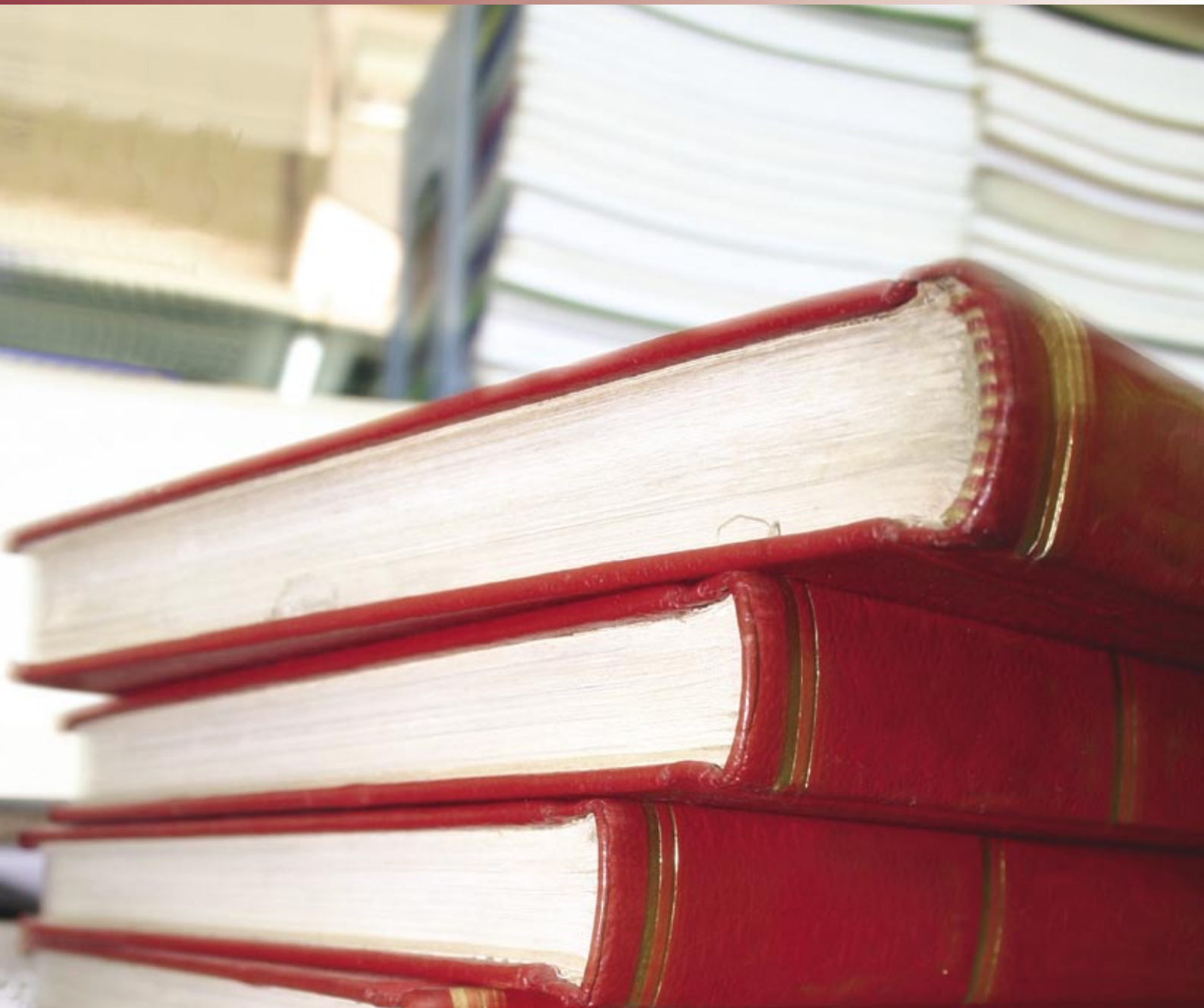


No	Company	Name/Designation	Details Contact	Remarks
8	**Soil Engineering Pte Ltd** 3 Kranji Loop Singapore 739539	Mr Patrick Ng Director	Tel : 6366 5005 Fax : 6368 1391 Email : huationg@singnet.com.sg	Supplier of liquid soil for soil stabilisation & backfilling
9	**Tong Seng Concrete Products Trading Pte Ltd** 18 Kranji Way Singapore 739429	Ms Cynthia Koh Manager	Tel : 6363 4333 Fax : 6363 5133 Email : tongseng@pacific.net.sg	Manufacturing of precast concrete products using Eco-concrete

Remark:

- Information correct as of July 2008.

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   - For discharge to sewer/watercourse/controlled watercourse http://app.nea.gov.sg/cms/htdocs/article.asp?pid=1644

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3. Performance of Recycled Aggregate Concrete, M C Limbachiya, A Koulouris, J J Roberts and A N Fried, RILEM International Symposium on Environment-Conscious Materials and Systems for Sustainable Development, RILEM Publications SARL, Pgs 127-136, 2004

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7. Green Mark Scheme, http://www.greenmark.sg/public/greenmark/en.html

8. Green Label Scheme, http://www.sec.org.sg/greenlabel_htm/greenlable_frameset.htm

RELEVANT SPECIFICATIONS/CODES



RELEVANT SPECIFICATIONS/CODES

Summary of Changes

Previous Standard	Replacement Standard	Uses
BS 882 Specification for aggregates from natural sources for concrete	**BS EN 12620** Aggregates for concrete	• Structural concrete • Roads, pavements • Precast concrete products
BS 5328 Guide to specifying concrete	**BS 8500–2** Specification for constituent materials & concrete. Used in conjunction with **BS EN 206 Concrete – Part 1**	• Structures cast in situ • Precast structures and structural precast products for buildings and civil engineering structures
BS 1199 & 1200 Specifications for building sands from natural sources	**BS 13139** Aggregates for mortar	• Mortar: masonry, floor/ screed, plastering • Rendering of external walls • Special bedding materials
BS 63-1, BS 63-2 Road Aggregates: Specification for single sized aggregates	**BS EN 13043** Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas	• Bituminous mixtures • Surface treatments for roads, airfields and other trafficked areas
BS 3797:1990 Specification for lightweight aggregates for masonry units & structural concrete	**BS EN 13055** Lightweight aggregates- Part 1: Lightweight aggregates for concrete, mortar and grout	• Buildings • Roads • Civil engineering works
None – adopted directly from **EN 13242**	**BS EN 13242** Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction	• Buildings • Roads • Civil engineering works

International Specifications/Codes

1.	**ASTM C295**	Standard guide for petrographic examination of aggregates for concrete
2.	**ASTM C1260**	Standard test method for potential alkali reactivity of aggregates (mortar-bar method)
3.	**BS 812-2**	Testing aggregates. Part 2: Methods of determination of density
4.	**BS 812-103**	Testing aggregates. Part 103: Method for determination of particle size distribution
5.	**BS 1047**	Air-cooled blastfurnace slag aggregate for use in construction
6.	**BS 8500-2**	Concrete- Complementary British Standard to BS EN 206-1- Part 2: Specification for constituent materials and concrete
7.	**BS 13139**	Aggregates for mortar
8.	**BS EN 206-1**	Concrete- Part 1: Specification, performance, production and conformity
9.	**BS EN 933-8**	Tests for geometrical properties of aggregates- Part 8: Assessment of fines- Sand equivalent test
10.	**BS EN 933-9**	Tests for geometrical properties of aggregates- Part 9: Assessment of fines- Methylene blue test
11.	**BS EN 12620**	Aggregates for concrete
12.	**BS EN 13043**	Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas
13.	**BS EN 13055-1**	Lightweight aggregates- Part 1: Lightweight aggregates for concrete, mortar and grout
14.	**BS EN 13242**	Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction
15.	**PD 6682-1**	Aggregates- Part 1: Aggregates for concrete- Guidance on the use of BS EN 12620
16.	**PD 6682-9**	Aggregates- Part 9: Guidance on the use of European test methods standards

Singapore Specifications/Codes

1. **CP 11** Code of practice for demolition
2. **CP 65** Code of practice for structural use of concrete
3. **SS 31** Specification for aggregates from natural sources for concrete
4. **SS 73** Methods of sampling and testing of mineral aggregates, sand and fillers
5. **SS 78** Specification for testing concrete
6. **SS 289** Specification for concrete
7. **SS EN 12620** Specification for aggregates for concrete

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- National Environment Agency - Ms Carrie Wong
- National Parks Board - Mr Goh Seh Nang
- PUB - Mr Devaraj Sanmuganathan
- Association of Consulting Engineers Singapore - Mr Lim Chong Sit
- Institution of Engineers Singapore - Mr Lim Boon Huat
- Ready Mixed Concrete Association of Singapore - Dr Sujit Ghosh
- Singapore Contractors Association Limited - Mr Ng Yek Meng

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- LHT Holdings Limited
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- NewEarth Pte Ltd
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- Soil Engineering Pte Ltd
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PHOTOGRAPHS/GRAPHICS CREDIT

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- NewEarth Pte Ltd
- Samwoh Corporation Pte Ltd
- Soil Engineering Pte Ltd
- Surbana International Consultants Pte Ltd

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