Sustainable Construction Strategies: A Singapore Perspective

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Abstract
This paper presents an overview of the Sustainable Construction Master Plan envisaged by the Building and Construction Authority (BCA), Singapore. Various initiatives that are currently being pursued to drive sustainable construction are discussed. To highlight strategic Thrust 3, one of the projects funded by the Ministry of Development's Research Fund for the Built Environment is briefly described. The project utilizes microwave heating to increase the yield and quality of recycled concrete aggregates. The preliminary results obtained using the proposed system is briefly reported in this paper.

Keywords:
Sustainable construction, Singapore, Waste to resource, Microwave heating, Recycled concrete aggregates

1 INTRODUCTION

Singapore is a small city state sited on about 700 km^2 of land, supporting a population of 4.6 million people. With one of the highest population densities in the world but practically no natural resources, the development of the city has to be undertaken in a sustainable manner to ensure a first-rate living environment not only for current, but also future generations of Singaporeans.

As most construction materials are imported, concrete has been the construction material of choice due primarily to its lower cost and the availability of low-cost migrant labour employed in the construction industry. Construction materials are generally sourced from regional countries and till recent times, recycled materials were not commonly used in the production of concrete [Annex A].

The global economic crisis notwithstanding, the phenomenon of spiraling construction cost has been attributed to increased global demand and rising costs of construction materials. Coupled with the need to preserve the environment, unlimited supplies of construction materials for urban infrastructure are now no longer viable and sustainable construction is the way forward.

2 SUSTAINABLE CONSTRUCTION MASTER PLAN

Singapore launched the Sustainable Construction Master Plan in 2008 to reduce the use of natural aggregates in building projects through a combination of recycling and more efficient use of materials. To deliver on the twin targets, six strategic thrusts have been identified to drive the industry towards sustainable construction. The six strategic thrusts are:

(1) Public sector taking the lead;

(2) Promoting sustainable construction in the private sector;

(3) Collaborative research & development with industry;

(4) Building industry capabilities;

(5) Strategic profiling and raising awareness to generate sustained demand; and

(6) Setting minimum standards through legislative requirements.

2.1 THRUST 1: Public sector taking the lead

Sustainable development has been and will continue to be a national issue in Singapore and the government will continue to take the lead in efforts to address environmental challenges. An Inter-Ministerial Committee on Sustainable Development comprising government leaders from key sectors, champions the national effort on developing holistic strategies towards sustainable development for Singapore. At the industry level, a Steering Group, comprising representatives from regulatory and government procurement agencies, as well as industry associations, drives policies and other initiatives to encourage the adoption of sustainable construction practices. As the public sector currently accounts for about 30-40% of the total construction demand, it is important for government agencies to take the lead in adopting sustainable construction practices in their projects and showcase these efforts to the industry.

2.2 THRUST 2: Promoting sustainable construction in the private sector

Promotion of sustainable construction in the private sector is mainly being done through BCA's Green Mark Scheme. The Green Mark Scheme is a locally-developed green building rating system to evaluate a building for its environmental impact and performance. Since April 2008, the Green Mark basic standard has been legislated as the minimum mandatory standard for all building works with a gross floor area of 2,000 m^2 or more. Recognition is given in the Green Mark Scheme for the adoption of sustainable construction practices, such as use of construction products made using recycled or environmentally friendly materials.

2.3 THRUST 3: Collaborative R&D with industry

In 2007, Singapore launched a S$50 million Research Fund for the Built Environment, managed by the Ministry of National Development (MND). Research projects that have been approved for funding include the use of recycled concrete aggregates in structural concrete, the conversion of dredged materials and selected industrial waste into synthetic sand and aggregate materials, and the use of microwave technology to improve the quality of recycled concrete aggregates (RCA). To supplement research and development efforts and to test the effectiveness and commercial viability of new recycled products, BCA works with the industry to conduct pilot projects involving the use of recycled products. Examples of pilot projects include the use of recycled materials in an office building project and the extensive use of RCA in a commercial building project for long term monitoring purposes.

2.4 THRUST 4: Building industry capabilities

The success of sustainable construction in Singapore will not be possible without the partnership of the industry in actively adopting best practices. BCA has worked with the Waste Management and Recycling Association of Singapore (WMRAS) to upgrade the standards of RCA-recyclers and accredit them under an industry-led accreditation scheme. The scheme aims to upgrade the capabilities of recyclers, encourage greater self-regulation, and improve the quality and consistency of recycled aggregates. The accreditation scheme was launched in November 2008. BCA is also in the midst of formulating suitable incentive schemes to build up the industry's capability in sustainable construction.

2.5 THRUST 5: Strategic profiling and raising awareness to generate sustained demand

The sustainable construction movement itself will not be sustainable if the demand and awareness within the construction industry cannot be sustained. As part of BCA's efforts to continually educate the industry on the benefits of sustainable construction, conferences and exhibitions have been organized to provide a platform for knowledge-sharing, such as the recent International Solid Waste Association (ISWA)/WMRAS World Congress held in Singapore in November 2008. Singapore will also be holding the International Green Building Conference in October 2009 to showcase and discuss the latest developments.

2.6 THRUST 6: Setting minimum standards through legislative requirements

Although the role of education and promotion is necessary, legislative requirements remain fundamental in determining the advancement of new methods and materials. Previously, the national standard for aggregates was the Singapore Standard (SS) 31: Specification for Aggregates from Natural Sources for Concrete, which covers only the use of natural aggregates in concrete. In March 2008, a move was made to adopt the local equivalent of BS EN 12620: Specification for Aggregates for Concrete, which has provisions for the use of manufactured and recycled concrete aggregates as well. The recognition of the new Standard is crucial for providing guidelines to the industry on the performance of new construction materials from non-natural sources.

In Singapore, older buildings are often demolished to make way for new ones as land use intensifies. As part of BCA's efforts to encourage recovery of higher quality recycled materials, a Demolition Protocol for Resource Recovery, which covers issues such as pre-demolition audits and procedures for sequential demolition and sorting of waste on site, was incorporated into the local code of practice for demolition works. Going forward, BCA will assess the need to implement the submission of a waste management plan for demolition projects, where selected demolition waste materials have to be sorted and sent to accredited recycling firms. This would then ensure a constant stream of recycled materials that can be further channeled for value-added applications.

To highlight the types of projects funded under Strategic Thrust 3 one of the projects funded by the Ministry of Development's Research Fund for the Built Environment is described briefly in the following section.

3 RESEARCH ON MICROWAVE HEATING FOR RCA PRODUCTION

This project is one of a slew of projects funded through Strategic Thrust 3 under the MND's Research Fund for the Built Environment. The main objective of the project is to improve the quality and yield of the recycled concrete production plants in Singapore.

The use of recycled aggregates in structural applications is limited due to the presence of adhering cementitious mortar on the individual recycled aggregate particles. The adhering mortar has been reported to result in higher porosity, higher water absorption, lower modulus of elasticity and weaker interfacial zone (ITZ) between the newly cast cementitious mortar and the recycled aggregates. The method under investigation takes advantage of the differences between the electromagnetic and thermal properties [1 to 8] of the coarse aggregate and adhering cementitious mortar to cause delamination at the ITZ, separating the aggregate from the adhering cementitious mortar. The results of both experimental and analytical studies show that microwave heating is effective in increasing the yield and quality of the recycled concrete aggregates compared to more traditional methods of recycling.

3.1 Analytical results

Analytical modeling was used for the microwave decontamination system shown in Figure 1. The system utilizes three frequencies 2.45, 10.6 and 18 GHz representative of the characteristics of typical low, intermediate and high frequencies together with a constant incident microwave power of 1.1 MW/m^2.

Some of the results obtained are presented in Figures 2 to 4. For clarity Figures 2 to 4 show only the temperature developed within the first 10 cm thick surface layer of the concrete block when subjected to microwave heating.

The amount of energy dissipated in the concrete specimen varies dramatically with its electromagnetic properties. The electromagnetic properties of concrete are a function of factors including concrete ingredients and mix proportions, water content, microwave frequency, temperature, etc. The significant effects of concrete water content (Figure 2 to 4) and microwave frequency on the heating process are confirmed.

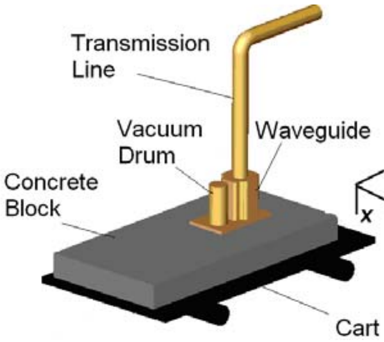

Figure 1: Sketch of the microwave heating system

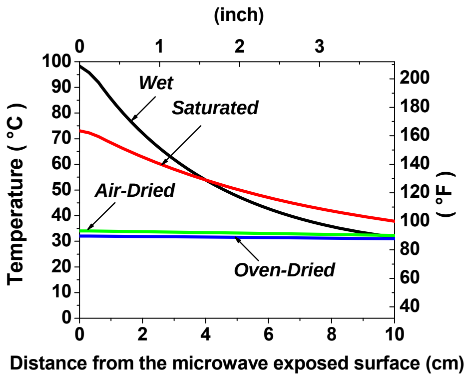

Figure 2: Temperature distribution in concrete after 5 seconds of microwave heating at 2.45 GHz frequency

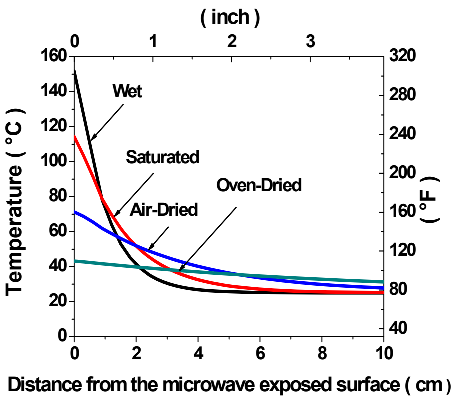

Figure 3: Temperature distribution in concrete after 2 seconds of microwave heating at 10.6 GHz frequency

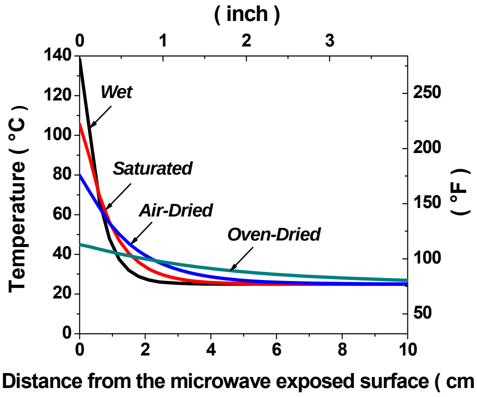

Figure 4: Temperature distribution in concrete after 1 second of microwave heating at 18 GHz frequency

The results indicate that drenching of the concrete surface may be used to increase the efficiency of the microwave decontamination process as considerably higher stresses in a thinner surface layer may be generated in a wet concrete when compared to a dry concrete. However excessive amounts of water may not be desirable as energy would be unnecessarily consumed in generating steam from the surface water present. The temperature reached and the stress generated in the concrete seemed to vary proportionally with the microwave initial power and heating duration.

Typical results plotted in Figure 5 shows the thermal stress development developed within the concrete block. The results confirmed that the stresses developed were significant and sufficient to cause delamination at the concrete surface. The model was expanded to study the concomitant contribution of pore pressure (Figure 6) developed due to microwave heating until concrete surface delamination occurs.

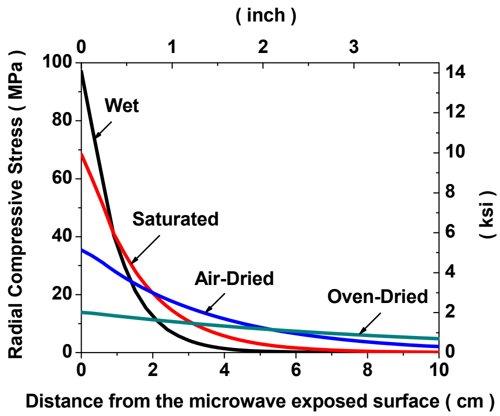

Figure 5: Radial compressive stress in concrete after 2 seconds of microwave heating at 10.6GHz frequency

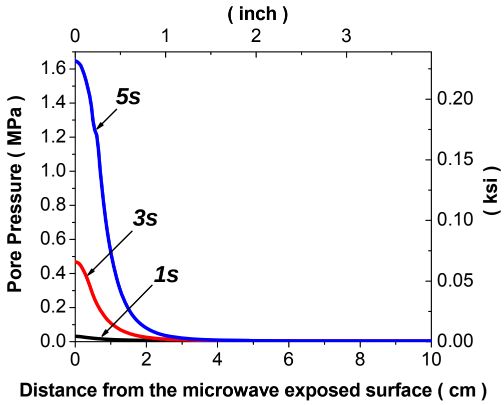

Figure 6: Pore Pressure in saturated concrete after 5 seconds of microwave heating

The feasibility of the new pilot microwave heating system to improve the quality of recycled concrete aggregates (RCA) was investigated by modeling the temperature rise and plotting the temperature distribution in individual RCA particles when subjected to high frequency microwave heating. Typical results (Figure 7) shows that a high temperature differential may be developed in the layer of adhering cementitious mortar, especially at the interface between the natural granite aggregate and the adhering cementitious mortar. These high temperature differentials are expected to result in high thermal stresses at the interfacial zone ITZ and thus are effectively harnessed in detaching the adhering cementitious mortar from the RCA. The spalling depth of the surface layer of the aggregate particle and the microwave exposure time for spalling to take place are inversely proportional to microwave frequency. Once the adhering cementious mortar is delaminated from the surface of RCA, the yield and quality of the resultant aggregates would improve significantly.

Besides numerical modeling, an experimental study is also on-going to verify the numerical results. Preliminary experimental results obtained confirmed the capability of the microwave heating system to remove the adhering mortar within a very short period of exposure. Figure 8 and 9 show samples of aggregate particles after being subjected to microwave heating. The aggregate particles are sieved into various sizes and showed that in most cases the adhering cementitious mortar detached cleanly from the granite aggregates. Light brushing is sufficient to dislodge the loosely attached mortar after microwave heating. The original surface of the granite aggregate was clearly visible under closer examination.

The analytical results obtained yielded results which were of much use as background information for the design of the pilot microwave heating facility to improve the yield and quality of RCA. The processes involved will be further fine tuned to address various decontamination, handling, production, storage and safety issues before a fully functional system may be incorporated for actual production of RCA using microwave heating. This next phase would involve the active participation of an industrial collaborator.

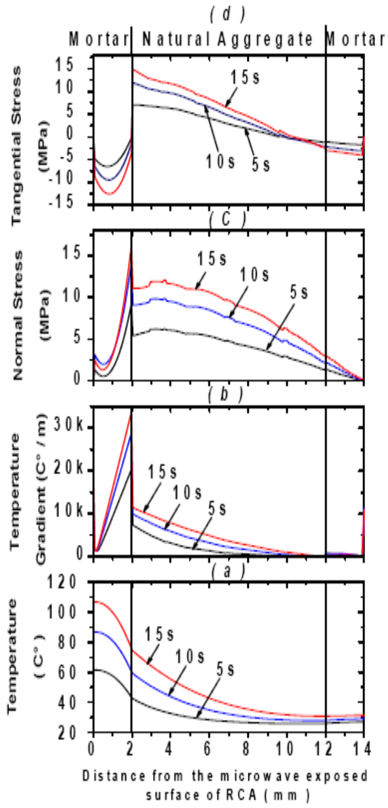

Figure7: Temperature, temperature gradient, normal stresses and tangential stresses developed in a RCA particle subjected to microwave heating at 2.45 GHz frequency and 10 kW power

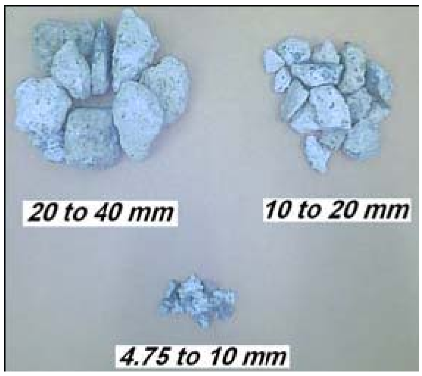

Figure 8 : Granite aggregates obtained after removal of adhering mortar from RCA

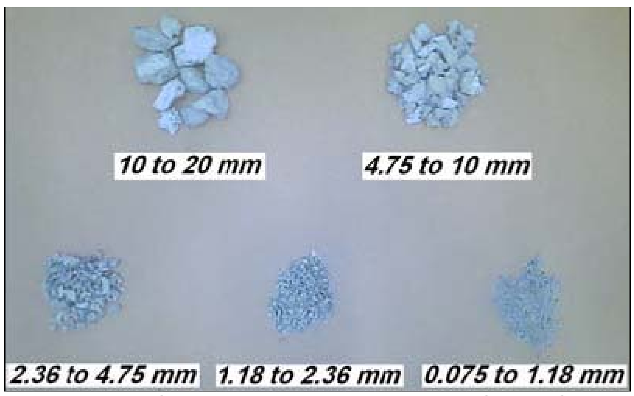

Figure 9: Cementitious mortar detached from RCA

4 SUMMARY

A concerted and holistic approach that covers the whole construction value chain is currently taking shape in Singapore to sustain the supply and demand for recycled materials. BCA has been working closely with the industry to shift from conventional construction methods to sustainable construction. Through tackling design and regulatory issues related to sustainable construction and encouraging the use of recycled materials, the industry has increased its awareness and receptiveness to alternative construction materials and methods. Besides minimizing depletion of natural resources, sustainable construction strategies will also enhance sustainability and preserve natural resources for use by future generations.

5 ACKNOWLEDGMENTS

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<u>ANNEX A</u>

CURRENT USAGE OF RECYCLED MATERIALS

The various types of waste materials available for recycling and its current usage in Singpaore's construction industry are briefly discussed below.

A.1 Demolition waste

Demolition waste is the material resulting from the demolition of buildings and other structures. As Singapore's infrastructure ages, demolition waste can be expected to increase. It consists of a mixture of hardcore (concrete, masonry, bricks, tiles), reinforcement bars, gypsum boards, wood, plastic, glass, and other metals etc. The average amount of demolition waste generated is estimated to be 2 million tons per year (based on construction demand of S$17 billion), of which concrete waste makes up about 70% (or 1.4 million tons) of demolition waste. The bulk of concrete waste generated from demolition works is normally used either as hardcore for construction of temporary site access in new construction sites or as materials for road sub-base layer.

Demolition waste in Singapore is relatively uniform based on type of coarse aggregate since granite is the main type of coarse aggregate used for concreting here. Concrete waste, which was manufactured originally with natural aggregates, can be processed into Recycled Concrete Aggregates (RCA) to supplement the use of natural aggregates. However, currently only a small portion of the concrete waste is processed into RCA for use in non-structural precast components such as road kerbs, paving slabs, small drains, etc. Going forward, BCA will introduce various measures and initiatives to promote the up-cycling of RCA obtained from demolition waste for a range of structural and non-structural concrete applications.

A.2 Milled waste

Milled waste is asphalt that has been machine-milled from existing roads. It is bitumen-based and is commonly recycled and reused as a sub-base material for the construction of new roads. The amount of milled waste generated per year is estimated to be 0.5 million tons. Milled waste is currently being explored for recycling under a closed-loop concept where it is processed into Recycled Asphalt Pavement (RAP) to replace part of the aggregates and bitumen used in the manufacturing of asphalt concrete for the wearing and binder courses.

A.3 Spent copper slag

Copper slag is a by-product formed during the copper smelting process. In Singapore, copper slag is imported from various countries by shipyards for grit-blasting to remove rust and marine deposits accumulated on ships. The spent copper slag is then treated and washed to meet criteria imposed by the National Environment Agency (NEA). It can then be explored for further use in other applications or disposed off if no suitable use can be found. NEA requires spent copper slag recycling companies to submit regular Toxicity Characteristic Leaching Procedure (TCLP) test results to ensure that the copper slag has been processed properly. The amount of spent copper slag available for reuse is estimated to be 0.4 million tons per year.

Since 2005, spent copper slag has been used as fine aggregates or sand replacement for concrete production. In using spent copper slag, it is allowed to replace up to 10% by mass of sand (fine aggregates) in the production of structural grade concrete. For non-structural concrete, BCA encourages the use of RCA and spent copper slag to a greater degree, with a replacement rate of 50% by mass of total aggregate content, recognized under the Green Mark Scheme.

A.4 Steel slag

Steel slag is a by-product formed during the steel-making process. It further undergoes a physical process of crushing and separation to produce the required gradation for further use. The amount of steel slag available locally for reuse is estimated to be 0.1 million tons per year. Steel slag can be beneficially used for road surfacing aggregates when it has been properly processed. 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.

A.5 Incineration ash

In view of the constraints of limited land, Singapore has adopted waste-to-energy incineration as a waste disposal method. Incineration ash, the residual product from the combustion of local municipal solid waste, is currently disposed at Singapore's only offshore landfill at Pulau Semakau. Incineration ash comprises about 15% fly ash and 85% incineration bottom ash (IBA). IBA has to be processed to render it suitable as an aggregate. The amount of incineration ash generated per year is estimated to be 0.5 million tons.

The use of IBA for road construction is currently at the pilot project stage. Successful trials for road usage by the Land Transport Authority (LTA) have been conducted and it was found that treated IBA may be suitable for use as a road base material. However, further long-term tests may be needed to monitor the impact of its use on groundwater.

A.6 Excavated & Dredged Materials

Excavated materials are land-based soils generated mainly from construction activities, e.g. earthwork, tunneling. It can be further categorized into 2 groups, namely Good Earth and Soft Clay. Good Earth is used directly as backfill materials or for reclamation purposes while Soft Clay can be mixed with cement to produce a highly flowable grout material (also known as liquid soil) for backfilling and soil stabilization applications. The amount of excavated materials is estimated to be about 3.8 million tons per year. Currently all excavated materials are reused.

Dredged materials are soils excavated under water which consist mostly of marine clay and may contain organic material. The amount of dredged materials ranges from 0.5 to 4 million tons per year, depending on capital and maintenance dredging activities for that particular year. While the non-contaminated dredged materials can be used in land reclamation projects, the contaminated dredged materials are currently disposed at the offshore Semakau Spoil Ground. BCA is currently exploring the use of dredged material for non-structural concrete applications through a R&D project. A new crystallization technology has been developed and patented by a local company to treat and convert dredged marine clay into a ceramic-based product. The newly developed technology is also able to encapsulate contaminants in the materials and covert them into ceramic matrices. On-going research has shown that dredged materials can be manufactured into engineered aggregates with properties similar to lightweight aggregates through a series of physical, chemical and thermal processes. Trial projects will be conducted to determine suitable applications of the material.