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CONCRETE FOR SUSTAINABLE CONSTRUCTION

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Abstract
Modern concrete consists of a family of materials and designed concrete mixes are used for different engineering applications under service loading and environmental conditions. Its success is due to many reasons including versatility, adoptability, formability and economy. However, sustainability of concrete construction industry is of concern, considering: use of natural materials, energy and manpower, emission of carbon dioxide; and durability failure in concrete structures. Since waste materials and by-products from other industries can be used in the production of concrete mixes, concrete industry is beneficial to the environment. This paper discusses the environmental impacts of concrete production and usage and addresses the approaches to minimize these negative environmental impacts. The roles of concrete specifications and initiatives in Singapore towards achieving sustainable concrete construction are discussed. Finally, current research trends are briefly highlighted.

1. INTRODUCTION

From ancient time, buildings and civil engineering structures shaped our nations and projected their prosperity. Construction industry provides built infrastructure needed for socio-economic development which has positive impact on the quality of life. It provides employment opportunities to millions of workers around the world. Several countries, including Australia and Singapore, had continued with their infrastructure construction projects during the uncertain financial climate and produced positive economical growth. China and India, the most populous nations of the world, are showing outstanding economic growth and spending substantial capital in developing their infrastructures. The growth rate for the construction industry in India is expected to exceed the overall GDP growth in the next few years.

Concrete, a proven building material over hundreds of years, continues to enjoy the status as the most popular and cost-effective construction material. It can be economically produced to meet the performance requirements from locally available component materials. Research and development efforts on concrete technology over the last decades have resulted in improved quality of concrete produced. The existing concrete technology knowledge is allowing the concrete plants to produce high-performance economical concrete mixes with respect to its workability, stability, strength, stiffness and durability. It can be pumped to greater length and heights. The modern concrete is a high-tech complex material consisting of a family of materials, having many types of binder materials, aggregates, admixtures, fibres and others.

This paper discusses the environmental impacts of concrete production and usage and addresses the approaches to minimize these negative environmental impacts. The roles of concrete specifications and initiatives in Singapore towards achieving sustainable concrete construction are discussed. Finally, current research trends are briefly highlighted.

2. SUSTAINABLE CONSTRUCTION

The concept of sustainable construction can be defined as an approach to construction which promotes to attain goals associated with four process oriented "pillars" (Hill and Bowen, 1977).

- Economic sustainability: increasing profitability through efficient use of materials, energy and labour.
- Environmental sustainability: minimizing environmental impact by effective use of natural resources, minimizing wastage and utilizing recycled materials.
- Social sustainability: meeting the peoples" needs at all stages of construction, providing high customer satisfaction and working closely with clients, suppliers, employees and local communities.
- Technical sustainability: responding the availability of materials, technology, education and training, and manpower to sustain construction and maintaining the built infrastructure.

Therefore, sustainable construction had several objectives: (a) promoting resource-efficient building designs with prolonged service life with minimum maintenance; (b) minimizing environmental impact by minimizing the use of energy and natural materials; and (c) reducing the manpower requirement.

3. CONCRETE SUSTAINABILITY AND BINDERS

Portland cement, the most remarkable binding material in concrete, is invented by Joseph Aspdin in 1824. The popularity of concrete, as the material for the construction of civil engineering structures, is mainly due to its ease of production, mouldability and low maintenance. It is easily produced from locally available ingredients, namely cement, aggregates and water, with minimum effort and experience. Over a period of time, through the research and development efforts, improvements in the concrete quality are achieved with respect to its mix design, production, placement, testing and performance.

The binder material used in modern concrete mixes is no longer Portland cement alone and a combination of cement and supplementary cementitious materials (SCM), including fly ash, slag and silica fume, are used. In addition, chemical admixtures are used to achieve improvements in the concrete properties at fresh and hardened states, in a cost effective way. The concrete specifications are moved from prescription-based to performance-based, in order to produce cost-effective concrete mixes to satisfy the required concrete properties and performance. The concrete producers are responsible for the selection of the component materials and their proportion in designing the concrete mixes of varying demands from the clients.

In spite of the advances in concrete technology, the sustainability of concrete construction industry is questioned for a number of reasons (Metha, 2004). Firstly, considerable amount of natural resources, materials, manpower and energy, are consumed for the production of concrete making materials. Secondly, the Portland cement production contributes around 5% of the total greenhouse gas emissions out of all human activities. Finally, durability failures of concrete structures are not uncommon and require significant financial resources for repair and maintenance.

The cement industry is progressing towards reducing the greenhouse gas emission by lowering the clinker contents of the cements produced. The concrete industry is also adopting a number of approaches to minimize the environmental impact of concrete and to make concrete more suitable for sustainable construction. The following sections highlight some of the efforts taken by both cement and concrete industries.

3.1 Low clinker content cement

Worldwide consumption of concrete used for the construction of built infrastructure exceeds 12 billion tons annually and 2.9 billion tons of cement was produced in 2008 (van Oss, 2009). Although the cement comprises 10 to 15% of concrete by weight, its production is responsible for most of concrete‟s negative impacts to the environment. In India, the cement production is predicted to be 262.61 million tonnes (MT) in 2012 (Business Maps of India). Assuming conservative value of 0.82-ton of carbon dioxide liberated per 1-ton of cement produced, the carbon dioxide emission to the atmosphere in 2012 will be 215.3 MT million tonnes. China‟s cement production in 2009 was 1.630 billion tonnes, resulting 1.34 billion tons of carbon dioxide emission. The cement production is responsible for about 5% of carbon dioxide emission and contributes significantly to the global warming.

Table 1: BS EN 197-1 – Portland Composite cements

Cement type		Clinker (%)	Slag (%)	SCM (%)	Limestone (%)
Portland limestone cement	CEM II A-L	80-94	-	-	6-20
	CEM II B-L	65-79	-	-	21-35
Portland composite cement*	CEM II A-M	80 -94	6 -20		
	CEM II B-M	64 - 79	21-35		
Blast-furnace cement	CEM III/A	35 – 64	35-65	-	-
	CEM III/B	20 - 34	66-80	-	-
	CEM III/C	5-19	81-95	-	-
Pozzolanic cement**	CEM IV/A	65 - 89	-	11 - 35	-
	CEM IV/B	45 - 64	-	36 - 55	-
Composite cement***	CEM V/A	40 - 64	18-30	18 - 30	-
	CEM V/B	20 - 38	31-50	31 - 50	-

* Combination of slag, silica fume, fly ash, pozzolans, burnt shale and limestone
** Combination of silica fume, fly ash and pozzolan
*** Combination of slag, low-calcium fly ash and pozzolan

Recognizing the necessity to minimize the environmental impact of cement production, the global cement industry is producing a number of composite or blended cement types with reduced clinker contents, by incorporating SCMs. European cement standard (EN107-1) allows the use of the following SCMs in cement production: (a) fly ash; (b) granulated blast furnace slag; (c) silica fume; (d) natural pozzolans; (e) burnt slate; and (e) limestone. This had resulted in producing a total of 27 cement types with varying amounts of clinker and SCMs.

Table 1 summarizes the clinker contents of some of the European Portland composite cements, as given in EN 197-1. At the extreme, the clinker content in CEM IIIC, blast-furnace cement, is between 5% and 19%. However, the commonly used blast-furnace cement for the production of structural concrete mixes is CEM III/A which has the clinker content between 35% and 64%. It is recognised that properly designed concrete with blended cements can deliver significant durability enhancement over the concrete with cement alone and enabling the structural longevity, thus meeting the sustainable concrete construction requirements.

Canadian cement standards (CSA A3001) allows up to 15% limestone replacement of clinker which reduces the point-source carbon dioxide emissions by 10%. Research had shown that the performance of SCMs in concrete was found to improve their effectiveness when they are combined with Portland-limestone cement rather than Portland cement (Hooton et. al. 2010 and Thomas et. al. 2010).

In Australia, blended cements conforming to AS3972 are produced to consist various specified proportions of Ordinary Portland Cement, ground granulated blast-furnace slag and/or fly ash (in the case of a triple blend). These blended cements have a minimum SCMs component of 30% by weight. AS3972 is allowing up to 10% limestone addition in the cement production. This initiative is estimated to reduce the carbon dioxide emissions between 375,000 to 750,000 tonnes annually at the source, without detriment to the performance of concrete.

3.2 Concretes with blended cements

Total energy required to produce of one tonne of cement clinker is about 7500MJ, whereas, slag and fly ash require only 700 to 1000 MJ per tonne and 150 to 400 MJ per tonne, respectively. Replacing 65% of cement with slag having 15% moisture content, for example, will only require 0.5 tonne of raw materials and about 1500 - 1600 MJ of energy. Therefore, each tonne of cement replaced with slag will save at least 6000 MJ of energy (Swamy, 2000).

The silica in SCMs reacts with calcium hydroxide liberated from cement hydration to convert the large-sized soluble calcium hydroxide crystals into fine-structured C-S-H gel. The pore-size and grain-size distributions in the hardened binder paste are modified. This will improve the later-age strength and reduces the permeability of the hardened paste.

SCMs being industrial by-products creates disposal problem to the authorities and utilization of them as active binder materials in concrete provides the best economic and technological solutions with minimum environmental impact.

3.3 Use of blended cement in pile caps

One of the main applications of blended cement is in the production of concrete suitable for the construction of mass concrete structures. In order to control the temperature rise and related thermal cracking due to temperature gradient, the heat of hydration of binder must be controlled.

In 1990, ANZAC bridge pile caps, having the dimension of 27m by 21m by 5m, were constructed with 40MPa concrete. Each pile cap required 2835m^3 concrete and was completed as a single operation in a 24 hour period at an average rate of 120m^3 per hour, up to a maximum of 180m^3. Type GB cement with 65% slag content was used as the binder. The cement content of the concrete mix was 450kg/m^3 and the water to cement ratio of 0.45. The pile caps were instrumented with thermocouples and temperature histories at several locations were continuously monitored. The results were reported by Sriravindrarajah and Beggs (1998).

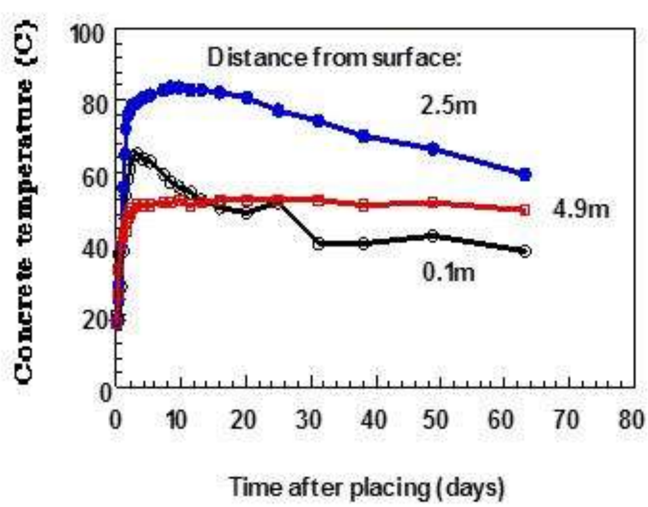

Figure 1: Development of temperature in the pile-cap across vertical cross-sections

Figure 1 shows the typical temperature development at the top, centre and bottom locations across a vertical section. Figure 2 shows the maximum temperature recorded as a function of the distance from the surface. The analysis of the results showed that a maximum temperature of 84ºC was recorded after 10 days at the middle of the pile cap. The use of blended cement has resulted in controlling the temperature gradient and avoiding temperature-induced cracking in the pile caps.

The results also showed that the compressive strength of concrete was increased from 41.7MPa at 28 days to 63.5MPa at 90 days. This significant improvement in the concrete strength after 28 days showed continuing pozzolanic reactivity of the slag component in the blended cement. When the temperature-match curing, using the temperature history in the pile-cap, was used the measured compressive strength was 51.3MPa compared to 41.7MPa under standard moist curing at 20ºC. This shows the high curing temperature in the pile cap had activated the hydration of blended cement.

3.4 Concrete with high volume fly ash (HVFA)

The use of high volume fly ash concrete has recently gained popularity as a resource efficient, durable, cost–effective sustainable option for many types of Portland cement concrete application. Such a concrete reduces the environmental impact of concrete by minimizing the usage of cement as much as 50% by weight and increasing the use waste materials. With the use of superplasticiser, highly durable high volume fly ash concrete can be produced at a low water/binder ratio. The characteristics defining a HVFA concrete mixture (Malhotra and Metha, 2002) are listed below:

- minimum of 50% of fly ash by mass of the cementitious materials
- low water content, generally less than 130 kg/m^3
- cement content, generally no more than 200kg/m^3
- for concrete mixtures with specified 28-day compressive strength of 30MPa or higher, slumps over 150 mm, and water-to-cementitious materials ratio of the order of 0.30, the use of superplasticizers is mandatory.
- for concrete exposed to freezing and thawing environments, the use of an air-entraining admixture resulting in adequate air-void spacing factor is mandatory.
- for concrete mixtures with slumps less than 150 mm and 28-day compressive strength of less than 30MPa, HVFA concrete mixtures with a water-to-cementitious materials ratio of the order of 0.40 may be used without superplasticizers.

Table 2: Relative strengths (%) for high-strength concretes with SCMs

Age (days)	100% cement cube strength (MPa)	25% fly ash	25% slag	15% fly ash + 10% silica fume	15% slag + 10% silica fume
1	60.0	75	81	79	84
2	71.0	76	78	94	94
3	82.0	71	85	91	93
7	86.0	91	94	103	94
14	95.5	92	88	102	96
28	104.0	96	95	104	99
56	112.0	95	91	103	99
90	117.0	97	88	101	97

3.5 High-performance concrete for marine applications with SCMs

Metha and Aitcin (1990) defined the high-performance concrete as a material, which is not only characterized by high-strength and extremely low permeability but also has high dimensional stability. From theoretical considerations, they concluded that 35% cement paste volume represents the optimum for cement paste content in balancing the conflicting requirements of low permeability and high dimensional stability.

Sriravindrarajah, Khan and Pathmasri (2002) studied the binder materials combination on strength development and shrinkage of Grade 90 concrete. The control mix with ordinary Portland cement, the free-water to cement ratio was 0.23 and the cement content was 595 kg/m^3. The cement replacement level was 25% by volume and consists of either fly ash or slag alone, or 15% fly ash/slag and 10% silica fume.

Table 2 summarizes the strength development with age for all five mixes with different binder materials combination. The results showed that high-performance concrete with the specified compressive strength of 90MPa at 28 days can be economically produced by replacing 25% of the cement by volume with either fly ash or slag and no significant long-term strength advantage is achieved by using more expensive silica fume as partial replacement to either fly ash or slag.

The 90-day free drying shrinkage of high-strength concrete varied between 370 and 460 microstrain. This research had demonstrated the ability of using SCMs to produce high-strength high performance concrete with significant reduction in the cement content.

3.6 Low cement concrete

Portland cement produced currently is not exactly the same as those produced fifty years ago, in relation to its chemical and phase compositions. The chemical compositions and fineness of modern cement had been optimized to achieve high early age strength though improved cement production technology (Aitcin, 2008). This led the concrete producers to use reduced amount of cement for the same concrete strength grade. The improved early age strength of concrete allows early formwork removal, needed for rapid concrete construction and improved productivity. However, improved early cement hydration increases the heat of hydration which may contribute to thermal cracking in thick concrete members.

Since the modern cements are not capable of producing any significant improvement in strength after 28 days when compared with old cement, the durability of concrete may be affected. Therefore, the use of modern cement alone can be viewed as detrimental to the durable concrete construction. In order to achieve sustainable concrete construction, it can be said that "structural concrete should not be produced without SCMs and cement alone concrete mixes must be justified".

3.7 Supplementary cementitious materials in concrete and standard requirements Modern national specifications for concrete production are performance based. The responsibility of producing concrete mixes to satisfy the specification requirements is given to the concrete producers. By allowing SCMs as binder materials and recycled materials as aggregates, these specifications allow the concrete producers to design eco-friendly concrete mixes.

European standard specification for concrete EN 206-1:2009, places little restriction on the use of additions in concrete. It simply states that additions of Type I (inert filler) and Type II(cementitious) may be used in concrete in quantities as used in the „initial tests". Initial tests are defined as those required for demonstrating that a mix satisfies all the specified requirements for the fresh and hardened concrete. These initial tests may be from the laboratory investigation or from experience.

In order to include fly ash in concrete mixes, as Type II addition, EN206-1 assigns a cementing equivalence value to the fly ash, thereafter treating it as a simple addition partially taken into account within the specified minimum cement content and maximum water cement ratio. Up to a maximum of 25% fly ash by mass of the (cement plus fly ash) is allowed to be counted as cementitious. Any additional fly ash beyond this limit is effectively considered as an inert filler or Type I addition.

Rice husk, an agricultural waste, constitute one fifth of 300 million tonnes of rice produced annually in the world. By burning the rice husk under a control temperature and environment, a highly reactive rice husk ash is obtained (Zhang and Malhotra, 1996). The ash is non-crystalline and similar to silica fume and has great potential to be used as an effective SCM in concrete production. The rice husk ash is considered as a carbon-neutral material, since the growth of paddy absorbs carbon dioxide from the atmosphere. Unfortunately, this potential has not yet utilized by the rice-producing countries and most of the rice husk is burnt openly without any temperature control, adding carbon dioxide to the atmosphere.

4. IMPROVING CONCRETE SUSTAINABILITY THROUGH ADMIXTURES

4.1 Cement saving using water reducers and superplasticizers

For many decades, chemical admixtures were used to achieve modifications in fresh and hardened concrete properties. They can be used to accelerate or retard the concrete setting, to improve workability of concrete and to improve the freeze-thaw resistance of concrete, through air entrainment. Continuous developments in admixture technology had resulted in new generation admixtures with improved performance and many of these admixtures are now considered as essential component materials in producing special types of concrete.

The production of high and ultra-high strength workable concrete mixes, with very low water to cement ratio, cannot be produced with the addition of superplasticiser. The use of high strength concrete reduces the size of the columns in high-rise buildings and improves the construction speed due to early high strength. The combined benefits of reduced concrete volume and improved productivity contribute to the sustainability of concrete construction.

With the use of water reducers, concrete mixes of any required strength grade can be produced with reduced cement content without affecting their workability, strength and permeability. With the addition of water reducers and superplasticizers the water reductions of 8% and 20%, respectively, can be achieved. These water reductions lead to similar reductions in the cement contents, at a given water to cement ratio. On the other hand, if the same cement content is maintained than the reduced water to cement ratio improves the strength and impermeability of concrete, thus increasing the cement efficiency.

Aitcin (2008) estimated that at a conservative water reduction of 8 per cent, the worldwide requirement of cement can be reduced by 12 to 16 per cent. As more than half of the concrete produced currently does not contain water-reducer, the cement reduction should be applied to 800 million tonnes of cement. At a 13 per cent water reduction, 100 million tonnes of cement were wasted and equal amount of carbon dioxide emission could have been eliminated.

Alternatively, this amount of cement together with SCMs could have used to produce 400 million cubic meters of concrete without any increase on the environmental impact of the cement industry.

The use of water-reducer and superplasticiser in concrete production should be considered as a first step in the overall objective of reducing the environmental impact of concrete. With the reduction of 20 per cent of water requirement, the strength can be increased from 25MPa to 75MPa, by the use of the same amount of cement. This allows the concrete volume in columns to reduce by one-third of the original amount. The low water to cement ratio improves the impermeability of concrete and enhance its durability performance.

4.2 Self-compacting concrete to improved construction productivity Self-compacting concrete is viewed as a major breakthrough in concrete construction. It
was developed in Japan in late 1980s. Since then, it has been widely accepted around the world. It is distinguished from conventional concrete by its extreme deformability without any mechanical intervention. High deformability and stability enables self-compacting concrete to pass through the congested reinforcement and to fill in the entire formwork under its own weight, without vibration or segregation. Its key benefits to the construction industry include an improved working environment, reduced noise, faster construction, improved quality of finished product, less remedial work, and increased overall productivity.

Three main characteristics of self-compacting concrete are filling ability, passing ability and resistance to segregation. The self-compacting concrete mixes are designed carefully with conventional concrete making materials and superplasticizers. Viscosity modifying agent may help to improve the cohesiveness of the concrete. The properties of fresh concrete are evaluated using a number of accepted tests including slump flow, U-flow and V-Funnel.

With the growing shortage of construction workers due to ageing population in developed countries and increasing labour demand by the construction industry, the self-compacting concrete will be a useful material in achieving quality concrete construction. The effective use of manpower, energy and materials with improved productivity contributes to the economic sustainability of concrete construction when self-compacting concrete is used.

4.3 Permeability-reducing admixture to improve service life of concrete structures Improved sustainable concrete construction requires the use of durable concrete,
particularly in marine environment. Although the reduced water to cement ratio can improve the impermeability of concrete addition measures to be taken to achieve further improvements in impermeability. Dao et. al. (2010) investigated the effectiveness of permeability-reducing admixture on chloride diffusion in concrete. The results showed that the incorporation of the permeability reducing admixture, characterized by hydrophobic and pore-blocking effects, enhanced the concrete durability with respect to chloride-induced corrosion, as shown by the reduced diffusion coefficient and longer estimated time to corrosion initiation.

5. SUSTAINABLE RECYCLED AGGREGATE CONCRETE

Aggregates for concrete mixes are traditionally from natural sources and strict materials specification requirements had virtually eliminated the use of aggregates from other sources in producing normal weight structural concrete. However, with the desire to produce eco-concrete for sustainable concrete construction with limited used of natural aggregates, the current concrete performance-based specifications for concrete allow the use of aggregates from alternative sources, provided the specification requirements for concrete are met. EN206 allows carrying out initial tests in developing suitable concrete mixes, independent of the sources of its component materials.

The recycled concrete aggregate produced from waste concrete is a natural candidate to be considered as one of the alternative resources for aggregates for new concrete. If the recycled concrete aggregates can be used in concrete production, then the waste concrete generated from demolition activities can be considered as a „new" resource. The usage of recycled concrete aggregates in concrete production will help to minimize the demand of natural materials reduces the consumption of depleting natural resources. In addition, it provides an engineering solution to the disposal of concrete from demolition waste. Singapore Standard Specification for Aggregates for Concrete (SS EN 12620:2008) allows the use of aggregates, resulting from the processing of inorganic materials previously used in construction.

The recycled concrete aggregate particles are composed of two different materials: natural aggregate and variable amount of attached cement mortar. With the decrease in the aggregate particle size, the volume of attached mortar is increased. It has high water absorption, low density, strength and stiffness when compared with those for the natural aggregate. Considerable research had been reported on the properties of recycled concrete aggregates and the properties of concrete with these aggregates.

Sriravindrarajah and Tam (1983) conducted pioneering research using laboratory produced clean recycled concrete aggregate to produce recycled aggregate concrete. The results showed that partial or full replacement of natural coarse aggregate with recycled concrete aggregate affected the strengths, modulus of elasticity and shrinkage of concrete. With the combined replacement of both coarse and fine aggregates with recycled concrete coarse aggregate and crushed concrete fines further reductions in the engineering properties had occurred (Sriravindrarajah and Tam, 1985). With the addition of pozzolanic materials and lowering the water to cement ratio, Sriravindrarajah and Tam (1988) reported that it is possible to recover the strength loss. However, the detrimental effects of using recycled coarse concrete are the reduction in the modulus of elasticity and increase in the drying shrinkage and creep.

Domingo et. al. (2010) reported that the drying shrinkage and creep after 6 months is found to increase by 71% and 50%, respectively with the use of recycled concrete aggregates over the natural aggregate concrete. Sagoe-Crentsil et. al. (2001), reported the properties of concretes made with commercially produced coarse recycled concrete aggregate and natural sand. The difference between the properties of recycled aggregate concrete is relatively narrower than reported for laboratory-produced recycled aggregate concrete.

Sriravindrarajah et. al. (2001), investigated the variability of the properties of commercially produced recycled coarse aggregate over a six-month period and used them in new concrete mixes. The interesting finding of this research is that the variability in the properties of recycled concrete aggregate had insignificant influence on the properties of concrete mixes produced from these aggregates. Therefore, it can be stated that material specification for recycled concrete aggregate should not be overemphasized from the point of its suitability in producing structural concrete. Since the current concrete specifications are performance based and a reasonable quality variation for recycled concrete aggregates can be accommodated without any reservation.

Although the recycled concrete aggregate can be used as alternative aggregate source for concrete, it is important to evaluate the deformational properties and permeability of recycled aggregate concrete for their compliance with the specification requirements. It is no longer acceptable to evaluate strength alone for concrete mixes and permeability of concrete need to undertaken when recycled concrete aggregate is used. The environmentally friendly concrete need not be the suitable concrete for sustainable construction if its durability performance is decreased.

Due to the uncertainty of recycled concrete aggregate and to make it acceptable for structural application, several aggregate beneficiation methods have been researched to reduce the attached mortar content in the concrete coarse aggregate particles. They include acid pre-soaking, conventional heating, microwave heating, mechanical rubbing and grinding, combination of conventional heating and mechanical rubbing. Some of these methods are time consuming and energy intensive and hence their application is questionable. Until these methods become cost effective the use of recycled concrete aggregate should be used in low to medium strength concrete. For low grade concrete such as pervious concrete, natural aggregate should not be used instead it can be fully replaced with recycled concrete aggregates.

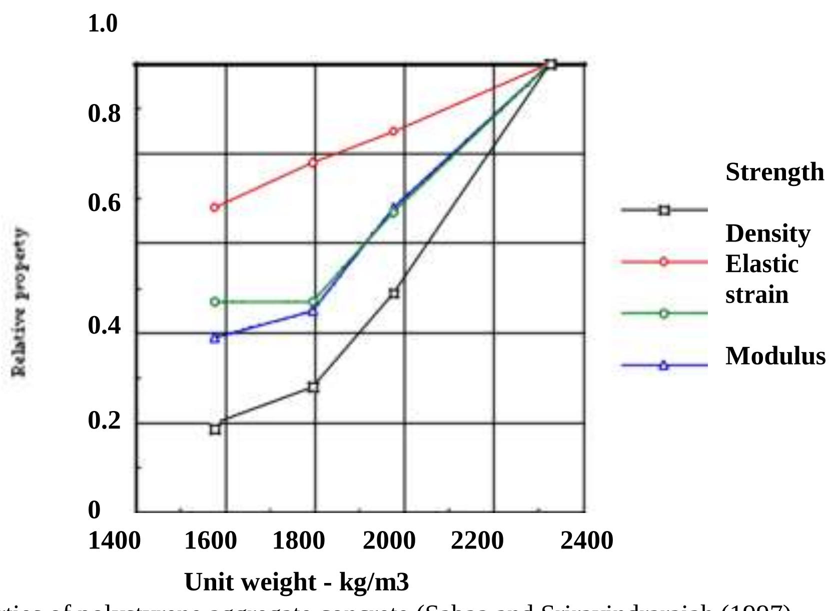

Figure 3: Properties of polystyrene aggregate concrete (Sabaa and Sriravindrarajah (1997)

6. SINGAPORE INITIATIVES FOR SUSTAINABLE CONSTRUCTION

Singapore, an island state with no natural resources, is densely populated with the current population just over 5 million. The construction industry of Singapore has played a key role in the country"s socio-economic development, creating the physical facilities and infrastructure which have made possible the nation"s remarkable progress. Increasingly, the industry will have to play a greater role in shaping a sustainable environment for Singaporeans, now and the future.

Concrete had played an important role through its usage in the construction of residential and commercial buildings, hospitals and educational institutions and transportation structures. It was used mainly for economic and technical reasons. Until recently Singapore was able to obtain good quality natural aggregates needed for concrete production from its neighbouring countries. In addition, the availability of low-cost foreign workers made the concrete construction most cost effective. The export restriction of sand and granite ban from Indonesia had increased the concrete price from S$70 to up to $200 per cubic meter (Ong et. al. 2009).

To achieve economical sustainability, Singapore recognized the need to improve the ways to use the available resources, and to expand our renewable resources. In 2008, the Building and Construction Authority (BCA) launched a Sustainable Construction Master Plan which targets to reduce the sand requirements by the building projects from current 95% to 50%. Several building elements used in Housing Development Board houses are modified to limit the usage of sand, through design alternations or change of materials used.

From October 2010, all Ready-Mix Concrete manufacturers supplying concrete for structural use in Singapore will have to be certified based on standards developed by BCA and the Singapore Accreditation Council. This accreditation process is aimed to enhance the quality control on concrete produced, including concrete made from recycled aggregates. This in turn will facilitate greater demand and higher adoption of sustainable materials for construction.

To stress the importance of sustainable construction, BCA expects Green Mark Goldplus and Platinum projects to meet a minimum level of sustainable construction. Developments aiming for the higher Green Mark ratings will need to achieve a higher level of efficiency in the use of natural materials or to use recycled materials such as Recycled Concrete Aggregates. It has also developed the Concrete Usage Index (CUI), a benchmark indicator to encourage more efficient concrete usage. The use of eco-cement and lesser natural aggregates content, for example, will result in a significant reduction in the Concrete Usage Index in BCA‟s Green Mark Incentive Scheme by earning up to 4 points.

Design for 100 years service life: Motorway concrete structures in Sydney

In Australia, the design and construction briefs quoted Australian Standards as a minimum requirement while specifying design life to be achieved. There are currently five Australian Standards for design of concrete structures: Concrete structures AS3600, Piling –design and installation AS2159, Concrete structures for retaining structures AS3735, Guidelines for the design of maritime structures AS4997, Bridge design - Concrete AS51005.5. Reliance on design codes to provide required service life requires that these codes are adequate. The lack of consistency and inadequacy in some areas are major concern Issues of concern are the lack of consistency in the classification of the environment, the first step in durability assessment. In addition, it is possible that due to changing climatic conditions the current exposure classification may not be applicable in the future.

When designing concrete structures in a recently completed motorway, the concrete work specification required the designer to use one class higher than the current exposure classification to accommodate the changing carbon dioxide concentration over the design 100 years service life. This requires that the nominal cover of 45mm for 50MPa concrete with standard formwork and compaction, or 55mm for 40MPa concrete.

7. CONCLUDING REMARKS

Concrete is the essential material for infrastructure construction, due to its versatility, adoptability and economy. Both cement and concrete industries are successfully adopting measures to minimize the environmental impacts of concrete and to improve the sustainability of concrete construction. Modern specifications for cement and concrete are performance-based and they allows the concrete producers to chose appropriate concrete making materials and mix compositions to produce concrete mixes to meet the specification requirements.

The concrete industry is helping the environment by using wastes and by-products in concrete mixes and considering these materials as resource materials. This approach is helping the authorities to find useful solution to waste disposal in a positive way.

Developments in admixture technology have resulted in producing self-compacting concrete to improve the productivity of concrete construction and to minimize the manpower needs and noise pollution. In addition, the water reducers and superplasticizers are used to produce concrete mixes with low cement content concrete and high proportions of SCMs, without affecting the engineering properties of concrete.

In order to improve the service life of concrete structures, modern specifications give priority to durability-based design over the strength-based design. Although the modern specifications produce over-design concrete structures, this may be accommodated when we consider the workmanship related construction defects such as inadequate compaction, curing and reinforcement placement.

In order to improve the durability of concrete, researchers are concentrating their efforts to produce impermeable concrete, namely, nano-modification with of paste matrices with carbon nano-particles (Shah, 2010), addition of super absorbent polymers to promote curing and minimize autogenous shrinkage in ultra-high strength concrete (Dukziak and Mechtcheerine, 2010), addition of permeability-reducing admixtures (Dao et. al. 2010); addition of poly-vinyl-alcohol microfibers to develop strain hardening cementitious composites (Li, 2010); and he application of bacteria to repair the concrete cracks (Narayanasamy et. al,, 2010).

At a low level the use of pervious concrete is proving a successful environmentally friendly material useful in helping to solve flooding related problems in urban environment. This concrete also acts as an effective filter-material to improve the quality of the stormwater runoff.

In concluding, it can be said that the current knowledge on concrete technology is adequate to produce concrete for sustainable construction and its application needs to be considered and initiatives and awards schemes like in Singapore may be helpful to realize its importance.

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