Sustainable Construction Materials – The Singapore Experience

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ABSTRACT

Singapore the country having access to once most advanced technologies but has one major constrain of availability of natural resources of construction materials. The country were all the construction materials including sand, aggregates, cement, Ground Granulated Blast furnace Slag etc., is imported and therefore, is very concerned regarding sustainability of the construction materials.

Keywords: durability, concrete, construction, copper slag, sand

Innovative products from recycled materials were made and used as useful construction materials. For example, the natural sand is a scarce material in Singapore and was being imported from neighboring countries but became more difficult to obtain due to the restrictions put up by some of the neighboring countries.

Various alternatives were looked into and one of the alternative that was found was copper slag, which was being used for sand blasting in ship repair industry. After its use in sand blasting, about 500,000 tonne of this material was being dumped in dumping yards after paying huge cost for dumping and the availability of such dumping yards was is also scarce in Singapore. Now this 500,000 tonne is being used in construction industry and has become great sustainable construction material contributing substantially to environment friendly efforts. Holcim being the leader in sustainable construction materials globally as per the Dow Jones Sustainability Index for fourth year in succession, decided to work on this project & did the R&D work to convert this ship industry repair waste in to a sustainable construction material.

A large processing facility was installed, where the copper slag sand was screened, cleaned, washed and was made suitable for the replacement of natural sand in the concrete.

A case study

Holcim Group recognized as the "leader of the industry" in the Dow Jones Sustainability Index since last four years in succession it had achieved its target of reducing CO2 emissions by 14.7

percent since 1990 and has set a target of reduction of CO_2 by 20 percent by 2010. This concrete with washed copper slag is a Green Label Product, endorsed by Singapore Environment Council.

Figure 1. Holcim Singapore - Exclusive Range of Green Label Product

The greatest challenge before the concrete construction industry is to serve the two pressing needs of human society, namely the protection of the environment and meeting the infrastructure requirements of our growing population and consequential needs of industrialization and urbanization. In the past, the concrete industry has met these needs well. However, for a variety of reasons, the situation has changed now. Holcim is a responsible company and is doing its best to fulfill corporate social responsibility.

In this process, to conserve the natural resources for our future generations, Holcim in conjunction with BCA, has developed concrete from recycled materials having properties similar or better than normal concrete and being environment friendly, we have named it, Holcim Green.

Washed Copper Slag (WCS)

The new aggregate standard, SS EN 12620:2008 permits the use of WCS. It permits in addition to the use of natural aggregates, manufactured aggregates of mineral origin resulting from industrial process involving thermal or other modification and recycled aggregates.

Originally imported from Japan, WCS is a by-product of ship repair industry where it is used for sand blasting. After sand blasting, it is suitably washed to remove all deleterious materials.

WCS is cleared by the National Environment Agency (NEA) for “re-use” and is an inert material.

The performance of Holcim Green, both fresh and hardened, is expected to be better than normal concrete as the water demand for WCS is lower than natural sand or manufactured sand.

Why do we need Green

Figure 2. The High-Performance, Normal as well as High Strength Concrete?

- Is beneficial to society
- It conserves the natural resources for our future generations. It is available in all grades from G25 to G100
- Usage of Holcim Green for sunlight exposed pavements, keep the pavements and surroundings cooler
- Why do we need Holcim Green –
  The High-Performance, Normal as well as High Strength Concrete?

Putting the concrete into service at earlier age, for example, opening of pavement at 3 days Construction of high rise buildings by reducing column sizes and increasing available space Building the super-structures of long-span bridges and to enhance the durability of bridge decks, Wet bored pile construction, Post-tension structure satisfying the specific needs of special applications such as durability, modulus of elasticity and flexural strength

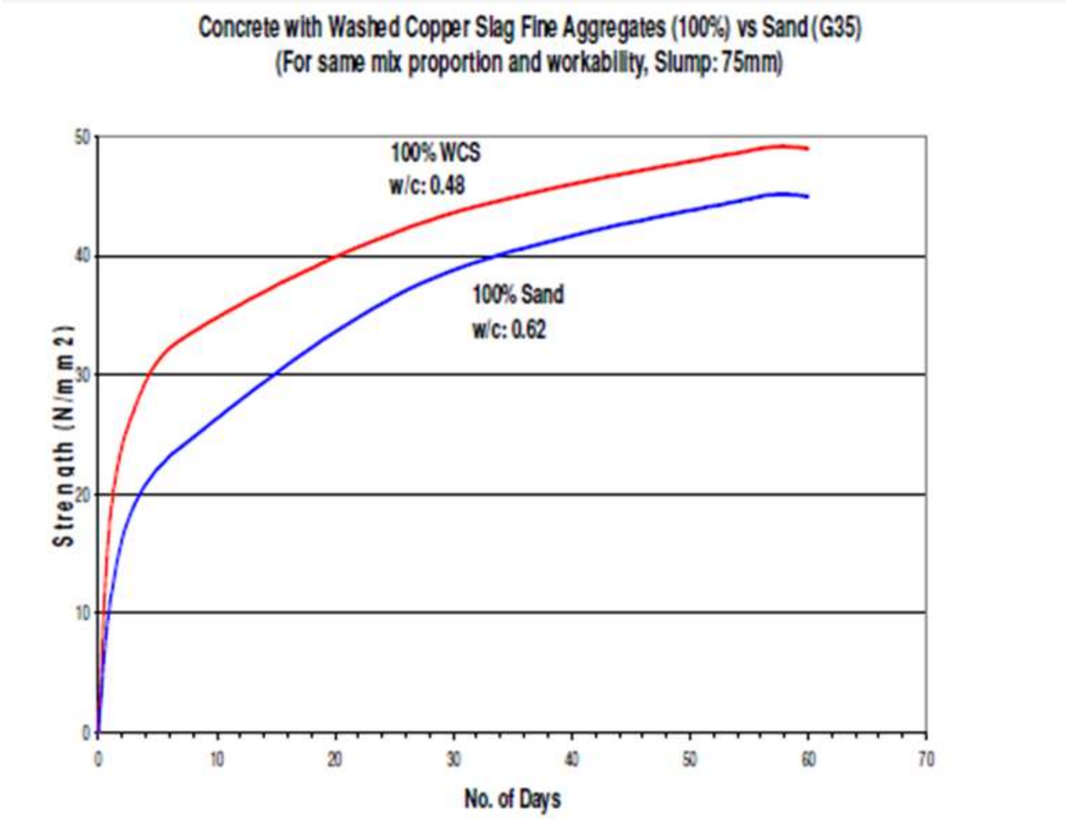
Grading of WCS (Fine Aggregate)

The following table show that the grading of the WCS conforms to the specifications.

Table 1. The grading of the WCS

B.S.410 Test Sieve (mm)	Wt Retained (g)	% Retained	Cumulative % Retained	% Passing
10	0	0.0	0.0	100.0
5	0	0.0	0.0	100.0
2.36	0	0.0	0.0	100.0
2.36	0	0.0	0.0	100.0
1.18	59	11.8	11.8	88.2
Microns				
600	198	39.6	51.4	48.6
300	168	33.0	84.4	15.6
150	67	13.4	97.8	2.2
75	0	0.0	0.0	0.0
Pan	11	2.2	2.2	97.8
Total	500	100.0		
Fineness Modulus			2.45	
Specific Gravity & SSD State	(1) Vol. Of Water in Cylinder = 100 ml (2) Weight of Sample = 200 g (3) Vol. Of sample + Water = ml $S.G. = \frac{(2)}{(3)-(1)}$			
F.S.T Silt Content	Amount of Silt x 100% Amount of Sand			
Organic Impurities	Colour of 3% Sodium Hydroxide Solution: 1☐ 2☐ 3☐ ☐4 ☐ 5 (Desired) (Standard)			
Remarks				

Comparison of WCS vs Sand



Grade 35 N			
Days	Holcim Green	Normal Concrete	% Variance
	100% WCS	100% Sand	
	W/C Ratio : 0.48	W/C Ratio : 0.62	23
	Strength (MPa)	Strength (MPa)	%Variance
1	18	11	39
3	27	19	30
7	33	24	27
28	43	38	12

Figure 3. Comparison of WCS vs Sand

Table 2. Compression Strength Test Results (MPa) Grade 35

Age	1	3	7	28
Av	9.37	20.30	28.99	38.32
SD	0.96	1.79	1.71	1.1

Age	1	3	7	28
Av	10.79	24.60	35.07	48.26
SD	1.54	2.12	1.38	1.24

Figure 4. Average Strength Gain for G35 Concrete

Figure 5. Average Strength Gain for G40 Concrete

Drying Shrinkage

- Drying shrinkage of concrete is dependent on two factors, namely w/c ratio and total aggregate content.
- Shrinkage is higher for higher w/c ratio.
- The size and magnitude of aggregate grading does not influence drying shrinkage.
- In our case, the total aggregate content for the 50% WCS mix and 100% sand mix were quite similar. However, the 50% WCS mix had a lower w/c ratio of 0.45
- (compared to w/c of 0.47 for 100% sand mix).
- This should directly conclude that drying shrinkage of 50% WCS mix is expected to be lower than the 100% sand mix.

Creep

- Creep of concrete is a slow time-dependent deformation of concrete subjected to sustained load and it is really the hydrated cement paste which undergoes creep, the role of aggregate (coarse aggregate) in concrete being primarily that of restraint. Creep is therefore a function of the volumetric content of cement paste in concrete.
- In our case, since the cement and coarse aggregates were kept the same and the grading, maximum size and shape of either the coarse aggregates or fine aggregates were not altered significantly, the creep characteristics of 50% WCS concrete and that of 100% sand concrete were expected to be similar. Also, there is no mention of any creep characteristic measurement required for concrete using copper slag in the Japanese Standards JIS A 5011-3:2003.

Green - The Beauty of WCS

WCS is cleared by the National Environment Agency (NEA) for "re-use" and is an inert material.
It has almost no silt contents.
It is not alkali silica reactive.
It has negligible water absorption as such it has lower water demand.
It provides higher workability due to its lesser angular particles
External appearance of concrete is similar to normal concrete
It has low paste porosity – making concrete durable It has low heat absorption
It has high density – high compressive strength

Water Absorption & Permeability

Table 3. Water Absorption & Permeability Test Results

Concrete Type	Vol. of Permeable Pore Space (Voids) (%)
Normal	12.63
Holcim Green	11.15

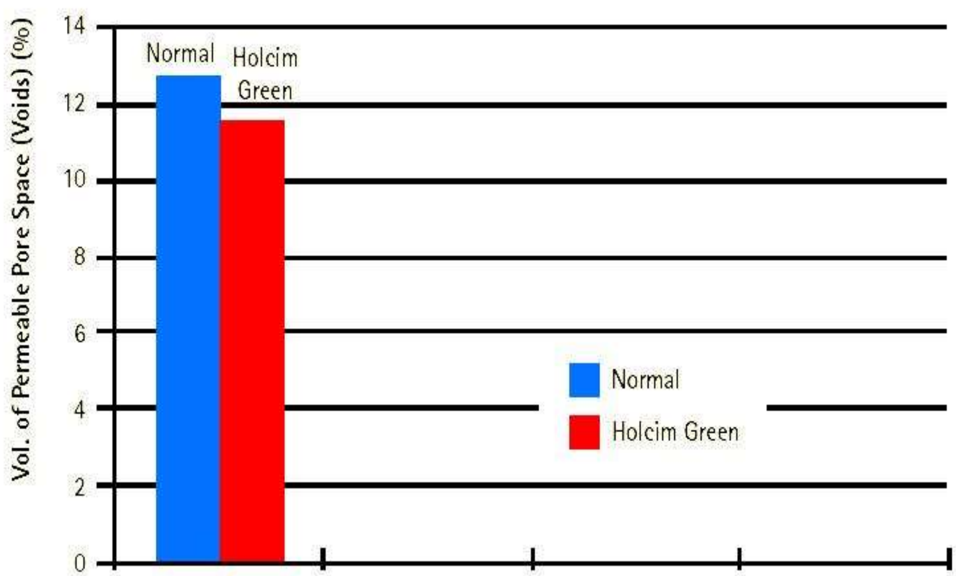


Figure 6. Water Absorption & Permeability Test Results (tested at Setsco)

The permeability test gives a measure of the resistance of concrete against the penetration of water and therefore the ingress of potential deleterious substances which affects the durability of concrete. From the above results, Holcim Green is less permeable than normal concrete.

Thermal Conductivity Test Results:

Table 4. Thermal Conductivity Test Results

Concrete Type	Vol. of Permeable Pore Space (Voids) (%)
Normal	2.501
Holcim Green	1.765

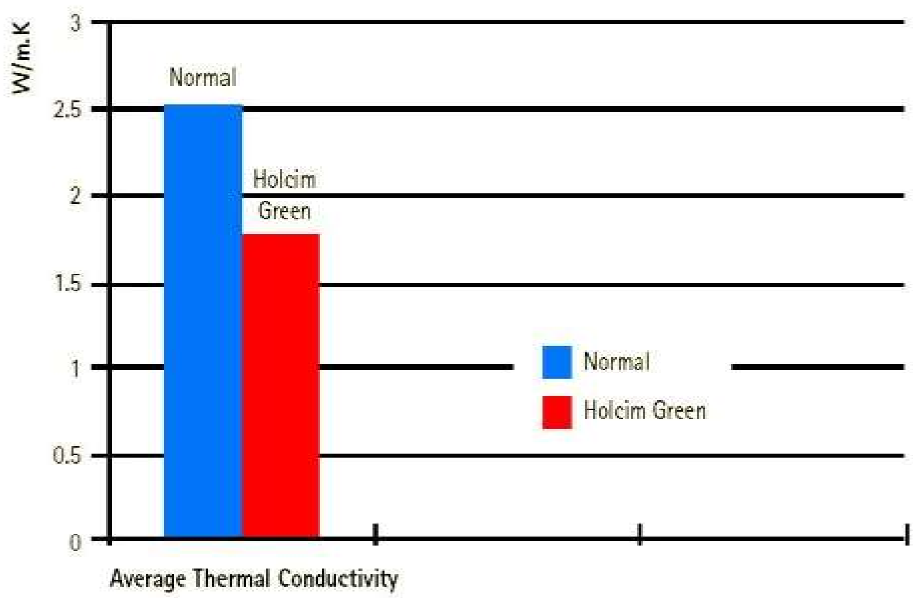


Figure 7. Thermal Conductivity Test Results

Thermal Conductivity, measuring the flow of heat or the ability to absorb heat, is lower in Holcim Green than in normal concrete. ***Holcim Green is thus "cooler" than normal concrete when exposed to direct sunlight.***

Compressive Strength Test Results (Tested at HDB Lab):

Table 5. Compressive Strength Test Results

Concrete Type	Grade	Average (MPa)		
		4 day	7 day	28 day
Normal	30P	31.9	35.8	41.2
Holcim Green	30P	32.3	38.2	45.2

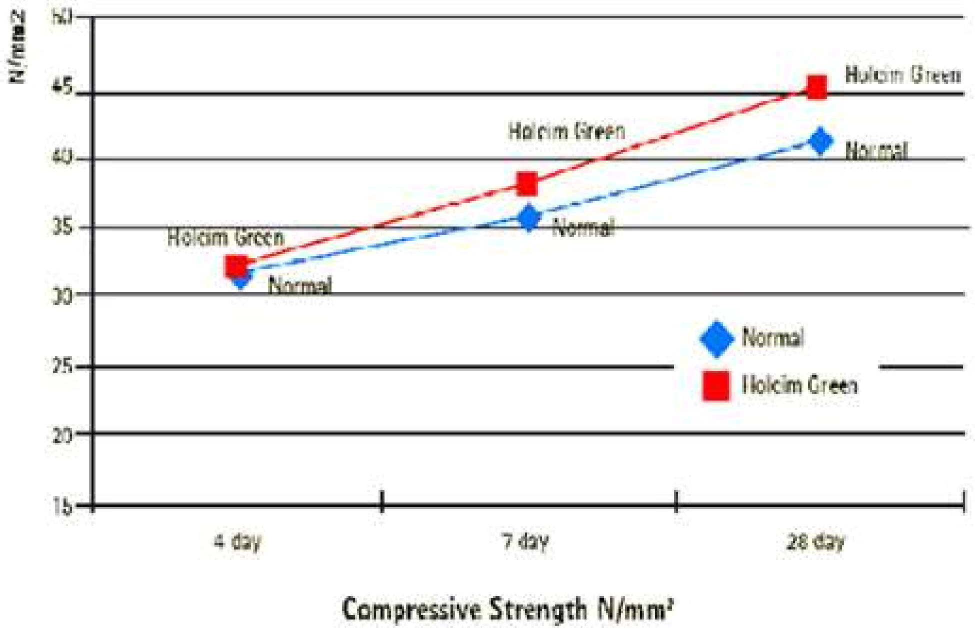


Figure 8. Compressive Strength Test Results

The above results show that the compressive strength of Holcim Green is higher than normal concrete at all ages. This is due to the lower water demand of WCS and hence lower water cement ratio in the mix design.