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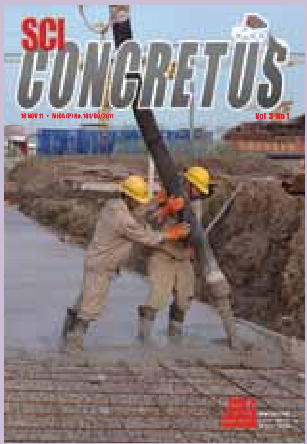


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**For Advertising enquiries, contact**
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SINGAPORE CONCRETE INSTITUTE

SINGAPORE CONCRETE INSTITUTE
Blk 342 Ang Mo Kio Ave 1
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Fax: (65)-65520417
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# President's Message

As we celebrate our 33rd Anniversary of the Singapore Concrete Institute, we would like to remind ourselves and everyone in the construction industry on the need of our nation's drive towards higher productivity. It is even more relevant than ever before as the demand for more foreign workers in our industry continues unabated.

It is with this concern in mind that SCI has decided to set the theme "The Path Towards Productivity" for this year's 33rd Anniversary Gala Dinner together with the fourth issue of the SCI Concretus.

The Board has also decided that, starting from this year, SCI shall give recognition to those outstanding organizations who have contributed towards the productivity movement in the construction industry by awarding them the SCI Excellence Awards annually. This is to serve as a constant reminder for all stakeholders of the industry on the need for higher productivity and efficiency.

This fourth issue of SCI Concretus, also sets in the productivity theme, will provide our readers and supporters with the latest information on concrete technology and issues related to productivity improvement in the concrete industry.

In heeding the global call for environmental protection and sustainability, SCI, in partnership with Professor Ravindra K Dhir of Applying Concrete Knowledge (Consultant) and with funding from the Building and Construction Authority and a group of industry sponsors, has embarked on a project entitled "Recycled and Secondary Aggregates for use in Construction: A State of the Art Review". Our readers will be able to read more about this important milestone project in the next few issues of the magazine. Through this project, SCI is doing its part in promoting sustainable construction by taking affirmative action in saving our environment.

On behalf of the SCI Board of Directors, I would like to thank all our sponsors, friends and supporters for their continuing support of this publication. We look forward to all your future contributions for SCI Concretus in creating a well recognized platform in environmental sustainability and construction excellence.

Thank you.
Oh Lock Soon
President
Singapore Concrete Institute
16 November 2011

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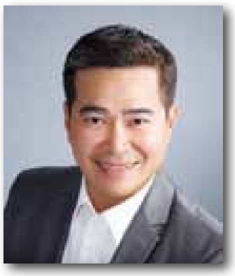

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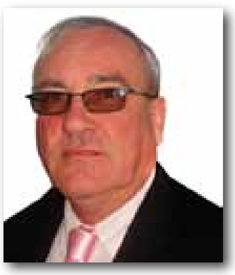

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# THE USE OF LOW FINES SELF CONSOLIDATING CONCRETE (SCC) IN EVERYDAY APPLICATIONS TO IMPROVE PRODUCTIVITY

***Seow Kiat Huat, Nilotpol Kar, Dr Feng Qiuling,*** *BASF Construction Chemicals*

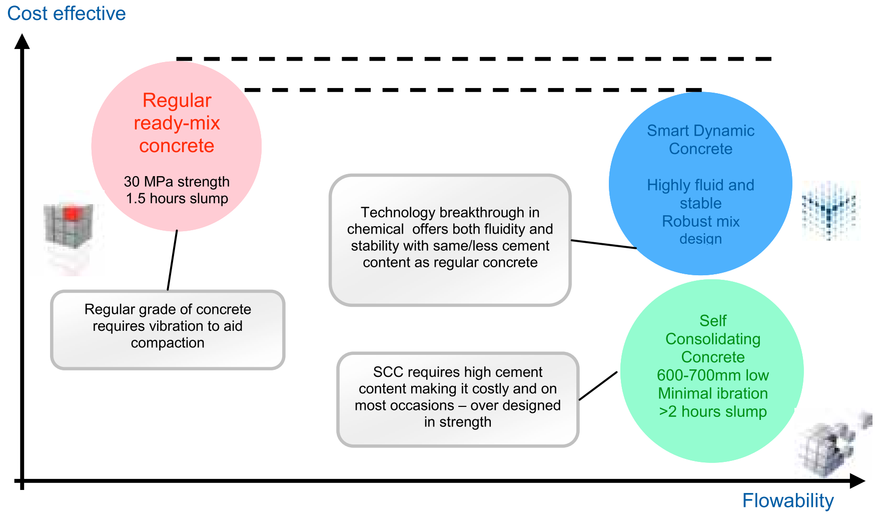


*Fig.1: Smart Dynamic Concrete (SDC), a low-fines self consolidating concrete incorporates the ideal properties of cost effectiveness of regular ready mix concrete and the flowability of conventional SCC.*

## 1. INTRODUCTION

The use of high flow concrete mixes has been around for a long time since the mid 80's. However, there are several hurdles in the use of SCC. First SCC is designed for its rheological property. In order to achieve high flowability and to be cohesive (to avoid segregation and bleeding), it is necessary to increase the powder content of the mix. It requires about 500 to 580 kg of total fines to ensure that that mix will not segregate or bleed while achieving high flowability thus self consolidating property. In this 500 to 580 kg of total fines, no less than 450kg is made up of cementitious content. The resultant mix is that the compressive strength is very high in the order to 60 to 75MPa.

Another major aspect in Asia is that the majority of concrete class required is less than 35 MPa. The most widely used grade of concrete in construction is between 20 – 40 MPa almost 85% in usual construction projects. This would result in "overkill" in the concrete mix design – this is probably one of the biggest reasons why such a concrete, in spite of the immense benefits never grew popular across Asia Pacific. The additional gap of 25 to 40MPa needs to be paid for resulting in high cost of the SCC mixes.

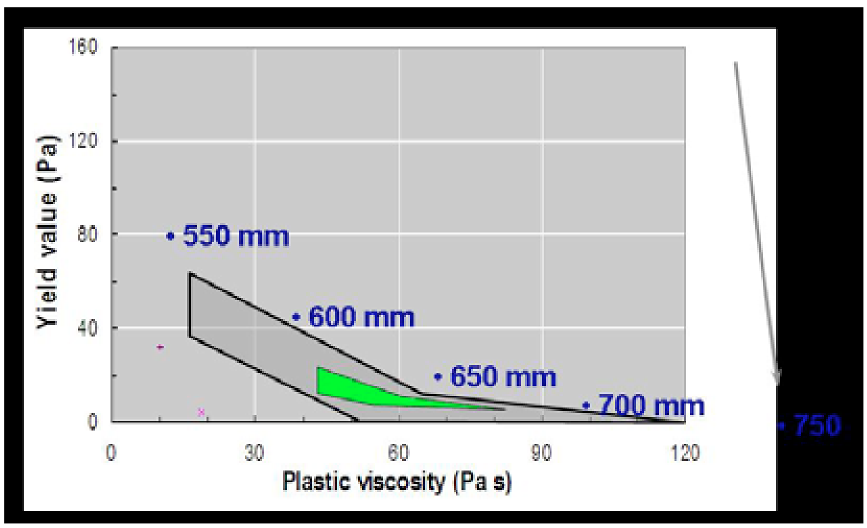


*Fig 3 :Yield value against plastic viscosity*

## 2. INTRODUCTION OF SDC (SMART DYNAMIC CONCRETE)

It is a quite a challenge to produce everyday concrete – strength classes of 20 – 40 MPa – to be of flowable nature, especially with low cementitious content. With a revolutionary viscosity modifying agent (VMA) integrated with a hyperplasticizer (PCE), this addresses the conflicting issues of flow and cohesiveness and the result is a reality of a normal concrete with self consolidating properties. Such a low fines self consolidating concrete (refer to as Smart Dynamic Concrete concept) in Asia Pacific has found good use across China, India, Indonesia, Malaysia and Singapore. It brought in a store of benefits for various players in the construction value chain (Fig 1) [1].

It has been observed in quite a number of instances – ASEAN countries, India, China that low fines self consolidating concrete prepared with the special VMA integrated within the superplasticizer has much better robustness in terms of cement compatibility and /or slight changes in water content. The hyperplasticizer and VMA in combination offer a perfect balance and stability against bleeding and segregation as shown in Fig 3 as is measured for yield values vs. plastic viscosity 2.

With regards to the cost low fines self consolidating concrete in strength classes 25 -40 MPa have shown marginal cost increase compared to conventional concrete (referred to as conventional vibratable / pumpable concrete), but with a huge reservoir of benefits as conventional Self Compacting Concrete.


*Fig 4: Field demonstration of the savings in labour and in time for placement of conventional vibratable concrete vs. low fines self consolidating concrete (Smart Dynamic Concrete)*

# 3. CASE STUDIES ACROSS ASIA PACIFIC

## 3.1 ASEAN

The SDC technology has been successfully tested at lab scale and plant scale prior to undertaking some significant projects in ASEAN countries. Similar comparison between conventional pumpable concrete (vibrated for compaction) and Smart Dynamic Concrete at similar cementitious contents have shown reduction in manpower and vibration with higher productivity.

As an example of a site demonstration carried out ( Fig 4), two panels were cast with conventional pumpable concrete (or traditional vibratable concrete) and Smart Dynamic Concrete respectively – these panels were 12' x 8 ' and approx 250 mm thick. The panel cast with SDC using a PCE based superplasticizer integrated with the special VMA was completed in 1'40" by a single worker with no vibrator against the other panel cast with traditional vibratable concrete of slump approx 14 cm by three workers with the help of a vibrator.

## 3.2 COMPLETED AND CURRENT PROJECTS IN ASEAN

### 3.2.1 Malaysia

SDC is currently in use for the construction of a factory to produce PV cell technology in Penang with an estimated total quantity of about 8,000 m3. The readymix company producing the SDC is marketing this concept as 'Green Concrete' due to its lower cementitious content and ease of placing the concrete. The main reason for its use compared to the conventional concrete is the tight schedule of the project and the requirement for better surface off form finish.

There is a growing interest in SDC across Malaysia and there are quite a few major projects opting for such a concrete in the near future.

### 3.2.2 Singapore

**Wharf Residences**

This was a test case and demonstration for SDC. A small slab of about 100m3 was first cast. After seeing the benefits of less manpower and the highly flowable mix, the contractor proceeded to cast nine number of 9m high columns. Through this exercise, it was found that the concrete has better finish, noise reduction as there was no need for vibration and faster placing time. Various other concrete elements of the projects were also cast using SDC. The total SDC quantity was about 1000m3.

**Other projects using SDC in Singapore**

The other projects that have used or currently using SDC are:
a. JEC – Jurong Entertainment Centre (estimated about 800m3)
b. Alba Condominium at Cairnhill Rise (about 8000m3)
c. Lush @ Holland Hill Condominium (about 10,000m3)

With the Singapore government's push towards higher productivity for the construction industry and the tight labour market, SDC will definitely be a growing trend in the coming years.

### 3.2.3 Indonesia

Since the launch of SDC in early April 2010, the following projects were done:

| Date | Project Description |
|---|---|
| 30 April 2010 | Slabs for residential construction |
| 3 May 2010 | Access road for warehouse |
| 5 May 2010 | Foundation/slabs for housing |
| 6 May 2010 | Showroom and commercial estate |
| 9 May 2010 | Building and commercial estate |
| 10 May 2010 | Slabs/access road for warehouse |

Although the quantity of SDC concrete was small (about 1000m3) in each of the project, it has shown that SDC can be applied successfully using the Indonesian raw materials.

### 3.3 China

The concept of Smart Dynamic Concrete (low fines self consolidating concrete) was first started in China in 2009 for Asia Pacific. The first biggest pour using the Smart Dynamic Concrete technology incorporating the unique and versatile viscosity modifying agent in PCE technology was executed in a single pour of 60,000 cubic metres of concrete for the raft foundation of proposed 632 metre high rise tower, early this year. The raft foundation is 121 m in diameter and 6 m thick.

*Fig 5.: Aerial view of the raft foundation placement of a major high rise in China*

## 4. CONCLUSIONS

Low fines SCC addresses the needs of the ready mix concrete industry and projects where more than 80% of the concrete produced is between strength classes 25 – 40 MPa. This type of concrete goes into structures that are not heavily reinforced (everyday RC structures). This eliminates the extra costs related to fines (material, silos, handling, logistics, etc.) and reduces the binder content for the required strength class. This means less cement or more supplementary cement materials (SCM). The innovative viscosity modifying admixture is now available in most Asia Pacific markets and is poised to be a break through for increasing the use of self-compacting concrete in the construction industry as it offers multiple benefits to the various stake holders.

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# ULTRA LIGHTWEIGHT CEMENT COMPOSITE

*Kok-Seng Chia, Min-Hong Zhang and Richard J.Y. Liew*
*Department of Civil and Environmental Engineering, National University of Singapore, Singapore*

## 1. INTRODUCTION

An ultra lightweight cement composite (ULCC) with density 0.6 times that of conventional concrete and strength exceeding 60 MPa was developed. This paper presents experimental results from material characterisation of the novel ULCC as a potential structural material. The ULCC was produced with porous filler obtained as by-product from ash ponds of coal-fired thermal power plants [1]. Particles of the filler have spherical shape consisting of a hollow interior that is covered by a thin shell with typical thickness 5-10% of its diameter. Due to its hollow structure, the filler has low particle density typically ranging from 600 to 900 kg/m$^3$. Particle size is usually between 100 – 300 µm with top size at ~600 µm. In this paper, properties of the ULCC is benchmarked with two control concretes – a normal weight and a lightweight concrete, which are designed to possess similar 28-day cube compressive strength.

## 2. EXPERIMENTAL PROGRAM

### 2.1 Materials

The ULCC was produced with water, binder, and lightweight filler. Cementitious binder included ordinary Portland cement and silica fume. Water-to-binder ratio (w/b) was 0.35. The ULCC was fibre-reinforced with 6-mm polyvinyl alcohol (PVA) fibres (aspect ratio = 220). Chemical compositions of the main ingredients in the ULCC are given in Table 1. Particle density of the filler was found to be about 850 kg/m$^3$ determined by a helium pycnometer. Particle size distribution of the filler was obtained by dry sieving (ASTM C136) and is shown in Fig. 1 in comparison to that of Portland cement (by laser diffraction) used.

A normal weight aggregate concrete (NWAC) and a lightweight aggregate concrete (LWAC) with 28-day cube compressive strength similar to that of the ULCC were included for comparison. Ingredients of the NWAC (w/b = 0.45) were water, Portland cement, quartz sand as fine aggregate and granite of 20 mm as coarse aggregate. The LWAC (w/b = 0.35) consisted of similar ingredients as the NWAC, except that the coarse aggregate was 4-8 mm expanded clay type lightweight aggregate, and silica fume was used to achieve required strength.

Table 1: Chemical composition of cement, silica fume, and lightweight filler

| Elements (wt.%) | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $SO_3$ | LOI |
|---|---|---|---|---|---|---|---|---|---|
| Portland cement | 4.2 | 20.5 | 3.2 | 65.3 | 4.1 | 0.17 | 0.50 | 2.1 | 2.2 |
| Silica fume | | 95.5 | | | | | | | 2.4 |
| Lightweight filler | 29.5 | 59.7 | 4.3 | 0.8 | 1.5 | 0.85 | 3.32 | 0.02 | - |

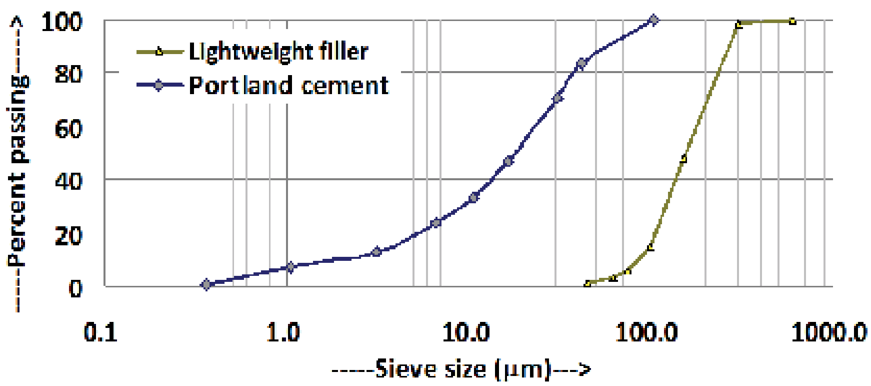


*Fig. 1: Particle size distribution of Portland cement and lightweight filler*

### 2.2 Test methods

Table 2: List of material properties evaluated and relevant test methods

| Property | Test standard | Specimen type & size |
|---|---|---|
| Flow consistency | BS EN 1015-3:1999 | -- |
| Density of hardened specimens | BS EN 12390-7:2009 | All specimens |
| Compressive strength | BS EN 12390-3:2009 | 100-mm cube and Ø100 x 200 mm cylinder |
| Splitting tensile strength | BS EN 12390-6:2009 | Ø100 x 200 mm cylinder |
| Static Young's modulus & Poisson's ratio | BS 1881-121:1983 | Ø100 x 200 mm cylinder |
| Resistance to chloride-ion penetration | ASTM C1202-05 | Ø100 x 50 mm cylinder |

## 3. RESULTS AND DISCUSSION

Properties of the ULCC are presented and discussed in this section in comparison to those of the control NWAC and LWAC (Table 3).

Table 3: Comparison of ULCC with control mixtures at 7 and 28 days

| Material property | ULCC | | LWAC | | NWAC | |
|---|---|---|---|---|---|---|
| Slump (mm) | --* | | 100 | | 100 | |
| Density after de-mould (kg/m$^3$) | 1450 | | 1860 | | 2350 | |
| | 7d | 28d | 7d | 28d | 7d | 28d |
| Compressive strength, cube $f_{cu}$ (MPa) | 55.7 | 64.0 | 54.2 | 57.8 | 55.4 | 68.0 |
| Compressive strength, cylinder $f_c$' (MPa) | 51.1 | 64.6 | 51.2 | 63.4 | 43.2 | 55.7 |
| Ratio $f_c'/f_{cu}$ | 0.92 | 1.01 | 0.94 | 1.10 | 0.78 | 0.82 |
| Splitting tensile strength (MPa) | 3.9 | 4.4 | -- | -- | -- | -- |
| Static modulus of elasticity (GPa) | 16.0 | 16.8 | -- | 23.4 | -- | 28.2 |
| Static Poisson's ratio | 0.24 | 0.26 | -- | 0.20 | -- | 0.16 |
| Electrical charge passed (C) | -- | 153 | -- | 242 | -- | 2890 |

*Flow consistency =180 mm

### 3.1 Density and compressive strength

Density of the hardened ULCC was 1,450 kg/m$^3$, about 60 and 80% that of the controls NWAC and LWAC, respectively. Average 100-mm cube compressive strengths ($f_{cu}$) for the 3 mixtures were similar both at the 7 and 28 days, except for the LWAC which was 10% lower at 28 days. Cylinder compressive strength ($f_c$') of the ULCC shows, in general, similar trend in strength development as the cubical specimens. For normal weight concrete, $f_c$' is about 80% that of fcu. Ratio ($f_c$'/$f_{cu}$) of the NWAC in this study (Table 3) was in agreement with concrete strength classes defined in Table 7 of BS EN 206-1:2000. However, no obvious trend could be observed for the ratio ($f_c$'/$f_{cu}$) of the ULCC. Similar observation was noted for the LWAC where the ratio ($f_c$'/$f_{cu}$) was 0.94 and 1.10 at ages of 7 and 28 days, respectively (Table 3). A study by Hammer et al. [2] also reported this with the ratio ranging from 0.84 to 1.05 for LWAC with $f_{cu, 28d}$ = 50 MPa. However, others [3-4] reported consistently lower $f_c$' than $f_{cu}$ with the ratio ranging from 0.90 to 0.93 (LWAC $f_{cu, 28d}$ = 80 MPa). Despite of the disagreement of data, a ratio of 0.91 was used in Table 8 of BS EN 206-1:2000 for lightweight concrete.

### 3.2 Splitting tensile strength

Splitting tensile strength of the ULCC was 3.9 MPa at 7 days, and 4.4 MPa at 28 days. On average, ratio of splitting tensile to compressive strength ($f_{st}$ / $f_c$') of the ULCC was about 0.07 at the different ages. From Fig. 2, it is estimated that $f_{st}$ / $f_c$' for normal weight concrete also has similar value within 0.07 to 0.08, based on the similar strength of 60 MPa as the ULCC in this study.

### 3.3 Modulus of elasticity and Poisson's ratio

Modulus of elasticity of lightweight concrete is affected by its strength and density, and is generally lower than that of normalweight concrete of the same strength. At 28 days, the ULCC had a $E_c$ of 16.8 GPa, whereas $E_c$ of the controls LWAC and NWAC were 23.4 and 28.2 GPa, respectively. It is noted that $E_c$ of the NWAC in this study is lower than that calculated from Formula (1) (~36 GPa). This indicates that the normal weight aggregate used in the NWAC probably has low elastic modulus.

The formula (1) is used to predict static modulus of concrete $E_c$, based on density $\rho_c$ (1440 to 2560 kg/m$^3$) in ACI Code 318 [6]:

$$E_c = 0.043\rho_c^{1.5}\sqrt{f_c'}$$

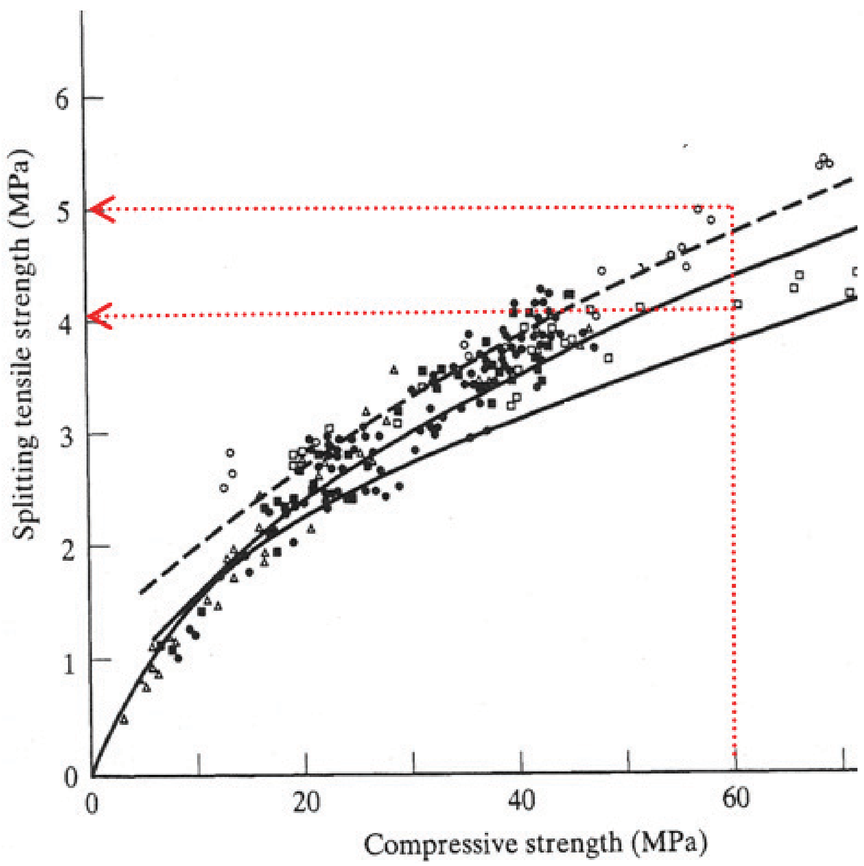


*Fig. 2: Splitting tensile strengths versus compressive strength for NWAC, adapted from [5]*

The 28-day static Poisson's ratio of the ULCC was 0.26 which seems to be higher than that of the LWAC and NWAC (Table 3). Static Poisson's ratio of the NWAC and LWAC in this study agrees with that of typical LWAC and NWAC reported which is between 0.15 and 0.25 with an averaging of 0.20 [7]. Limited experimental results seem to indicate that the static Poisson's ratio was increased with the reduction in the density of the material. However, it should be noted that the ULCC was fibre-reinforced with no coarse aggregate.

### 3.4 Resistance to chloride-ion penetration

Total charge passed through the ULCC according to ASTM C 1202 test was 153 coulombs (Table 3), which was comparable to that of the control LWAC, but much lower than that of the control NWAC. Both the ULCC and LWAC were classified as "very low" chloride penetrability, whereas the NWAC was classified as 'moderate' chloride penetrability. The lower charges passed in the ULCC and the LWAC may be attributed to the dense matrices due to incorporation of silica fume and lower w/b in these two materials. This also indicates that high resistance to chloride-ion penetration can still be achieved in the more porous ULCC and LWAC. A more detailed discussion on the effect of pore structure on chloride penetrability is found in [8].

### 3.5 Potential applications

In practice, high performance LWAC is used where applications require high structural efficiency with reduction in dead weight such as high-rise buildings, floating structures, and bridges. Material with high structural efficiency has high specific strength (strength-to-density ratio). An example is the Heidrun tension leg platform, constructed using high-strength LWAC having specific strength about 40 kPa/(kg/m$^3$), with density of 1,940 kg/m3 and 28-day cube compressive strength of 80 MPa [3-4]. In this study, specific strength of the ULCC was above 40 kPa/(kg/m$^3$), based on the 28-day cube strength. This is equivalent to specific strength of high-strength normal weight concrete with compressive strength of about 100 MPa.

Many offshore and marine structures are floating structures at some point of their life as they are often constructed in shipyards or graving docks and must be towed to sites. Thus, there is a need to reduce the mass and improve the structural efficiency of these structures, especially where part of the voyage includes shallow water conditions that will mandate lower draft requirement for the structures. Structural efficiency is increased for material with similar strength but lower density since it is directly related to specific strength. Improvement in structural efficiency is most pronounced for lightweight structures in submerged conditions. This can be illustrated using density ratio, defined as ratio of apparent density of normalweight concrete to lightweight concrete or the ULCC in this case. Structural efficiency is increased with higher density ratio when comparing materials of similar strength grade.

For example, density ratio (in air) for NWAC / ULCC is 1.6 (2.35/1.45), and is further increased to 3.0 [(2.35-1.00)/(1.45-1.00)] for submerged structures. On the other hand, density ratio (in air) for NWAC / LWAC is lower at 1.3 (2.35/1.86), or 1.6 [(2.35-1.00)/(1.86-1.00)] for submerged structures. Hence, structural efficiency for ULCC is about twice that of the LWAC and thrice that of the NWAC in submerged condition.

With high structural efficiency, the ULCC is suitable for shipbuilding and marine structures based on sandwich design concept. Typical lightweight sandwich design consists of a lightweight core structure sandwiched between two surface steel plates. Such design has been identified as feasible in shipbuilding [9].

## 4. SUMMARY

Distinct advantages of the ULCC include a low density of 1450 kg/m$^3$ (0.6 times of normal weight concrete) and a high 28-day compressive strength above 60 MPa. Ratio of splitting tensile-to-compressive strength of the ULCC was similar to that of normal weight concrete. However, the ULCC had lower Young's modulus and higher Poisson's ratio than typical concretes used in practice. Despite of its low unit weight, the ULCC had very low chloride penetrability according to ASTM rapid chloride penetration test. For structural applications, drying shrinkage and creep behavior of the ULCC are currently under investigation.

## ACKNOWLEDGEMENTS

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# AN ECO-FRIENDLY APPROACH FOR AIRCRAFT PAVEMENT CONSTRUCTION AT SINGAPORE CHANGI AIRPORT

*By*
*Dr Ho Nyok Yong, Dr Kelvin Lee Yang Pin, Dr Tan Jun Yew, Mr Hon Lip Yung & Mr Lim Wee Fong*
*Samwoh Corporation Pte Ltd (Contact: wflim@samwoh.com.sg)*

*Professor Fwa Tien Fang*
*National University of Singapore (Department of Civil Engineering)*

*Mr How Choon Onn, Ms Koh Sim Yi & Ms Meryl Lan*
*Changi Airport Group Pte Ltd (Engineering & Development Group)*


*Demolition of aircraft stand rigid pavement*

## Introduction

In recent years, the Singapore government has been actively promoting the use of recycled waste materials in construction applications to alleviate waste disposal problems in land-scarce Singapore, as well as to reduce our strong reliance on the import of natural aggregates from overseas. To support the government's directive towards sustainable development, Samwoh Corporation Pte Ltd, a leading infrastructure construction and material supply conglomerate, has undertaken an ambitious and forward-thinking pilot project by Changi Airport Group Pte Ltd (CAG) to reconstruct the existing aircraft stand rigid pavement at Singapore Changi Airport using concrete made of recycled concrete aggregate (RCA). The existing aircraft stand rigid pavement has been used for over 20 years and is due for rehabilitation. The aim of the project is to recycle the concrete waste derived from the demolition of the existing rigid pavement for the construction of new aircraft stand rigid pavement. The project also involved a pavement consultant from the National University of Singapore (NUS). It is the first of its kind in the region and has opened a new frontier in civil engineering construction and sustainable development in Singapore.

| Property | Test Method | Requirements | | | | | |
|---|---|---|---|---|---|---|---|
| Gradation | ASTM C136 | Sieve Size (mm) | 2.36 | 5 | 10 | 20 | 25 |
| | | % by Weight Passing | 0-5 | 0-10 | 20-55 | 90-100 | 100 |
| Flakiness/Elongation | ASTM D4791 | Max 8% | | | | | |
| Los Angeles abrasion | ASTM C131 | Max 40% | | | | | |
| Acid-soluble sulfate ($SO_3$) content | BS EN 1744-1 | Max 1.0% | | | | | |
| Chloride content | BS 1881-124 | Max 0.01% | | | | | |

## 1.Production of Recycled Concrete Aggregate

The existing aircraft stand rigid pavement was broken up using hydraulic breakers and the concrete waste was transported to a nearby recycling facility for processing. The waste contains mainly crushed concrete, ferrous metals and very small amount of other foreign materials. The waste was processed via a few key processes which include crushing, sorting and sieving of the end product (RCA) into the required sizes to meet the CAG requirements as shown in the above table.

## 2. Mix Design for RCA Concrete

The mix design for the concrete with RCA (hereinafter known as RCA concrete) was determined with respect to CAG specification requirements which specified a minimum flexural strength of 4.2N/mm$^2$ at 28-day. The workability was designed based on a slump value of 38-65mm in accordance with the requirements for side-form paving method of construction.

The RCA concrete was designed using 20% of RCA (by mass of coarse aggregate). Laboratory tests results have shown that RCA exhibited much higher water absorption (about 5%) as compared to granite aggregate (typically less than 1%) which is normally used for concreting in Singapore. This would drastically reduce the workability of the concrete mix. Many researchers attempt to address this issue by increasing water and cement contents in order to achieve the required workability at a constant water to cement ratio. However, the increase in cement content can affect the properties of the hardened concrete such as shrinkage. To overcome this problem, a rational mix design approach developed by Ho et al. was used without the need to increase the cement and water contents. The method involves adjustments in the coarse aggregate to fine aggregate ratio and addition of some admixtures to achieve the required workability. The findings of the study have been shown that RCA concrete provides comparable strength as compared to normal concrete without RCA using this method of mix design.

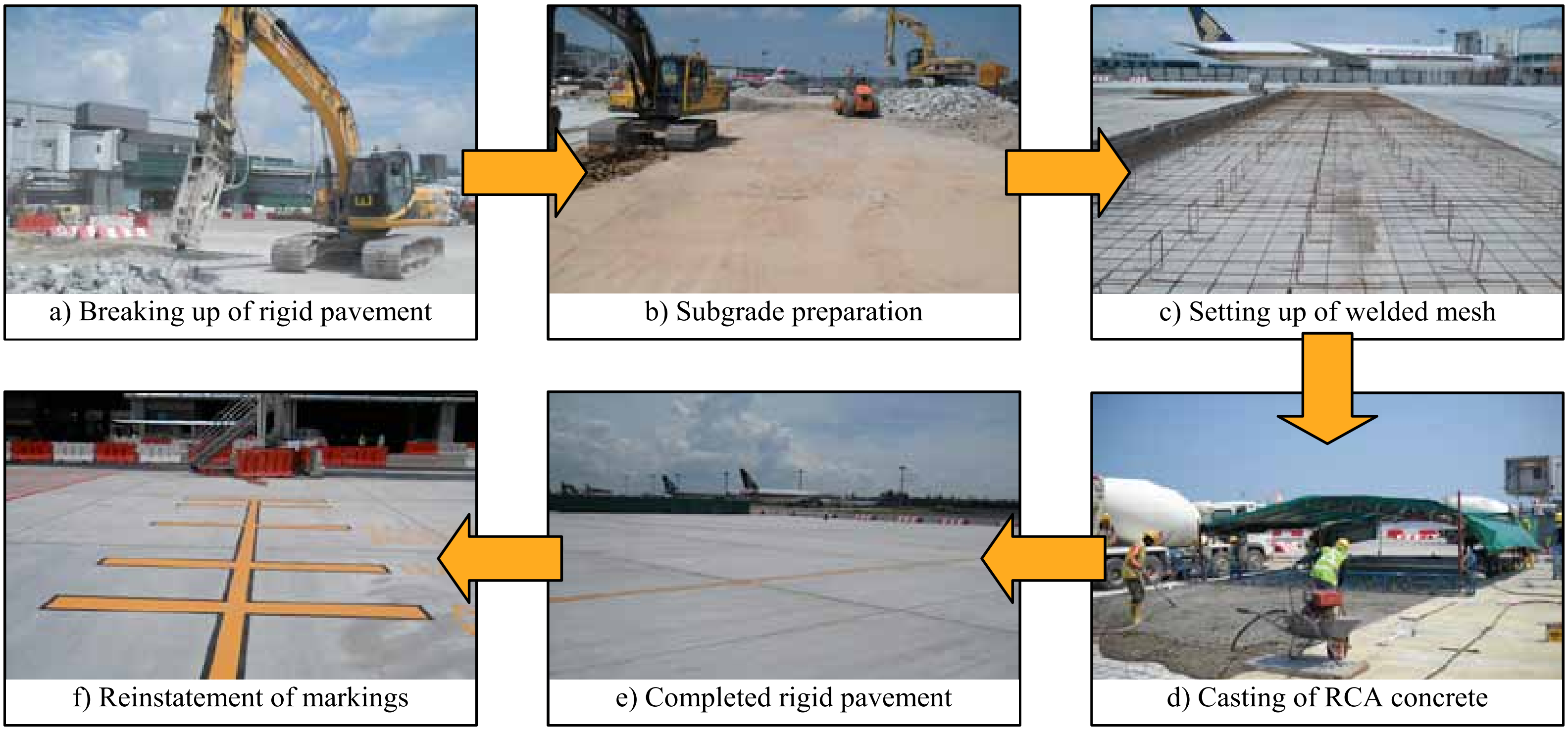
## 3. Construction

The aircraft stand rigid pavement comprises 435mm thick of the RCA concrete and 75mm thick of lean concrete. A key challenge in the construction of the rigid pavement is that RCA concrete tends to exhibit higher shrinkage than normal concrete which may lead to shrinkage cracks. Special curing measures were undertaken during the casting of RCA concrete. Immediately after casting, the concrete surface was applied with a concrete curing compound and then covered with a curing shelter and polyethylene sheets. Based on site observations, the method was found to be effective even when the construction was conducted in the afternoon. With this curing method, it allows casting in the day which eases casting work, improves visibility and increases productivity.

Stringent quality control was carried out to monitor the workability of the fresh concrete and the flexural strength. The workability of fresh concrete was monitored for every batch of concrete delivered to the site to ensure it meets the slump requirement of 38-65mm. Samples of the RCA concrete were also obtained and tested for 7- and 28-day flexural strength for every concrete mix produced per day or per pavement construction operation. The following observations can be drawn from the test results.

a) 7-day flexural strength – All the test results meet the required strength of 4.2N/mm$^2$. This implied that the completed aircraft stand can be opened to traffic earlier

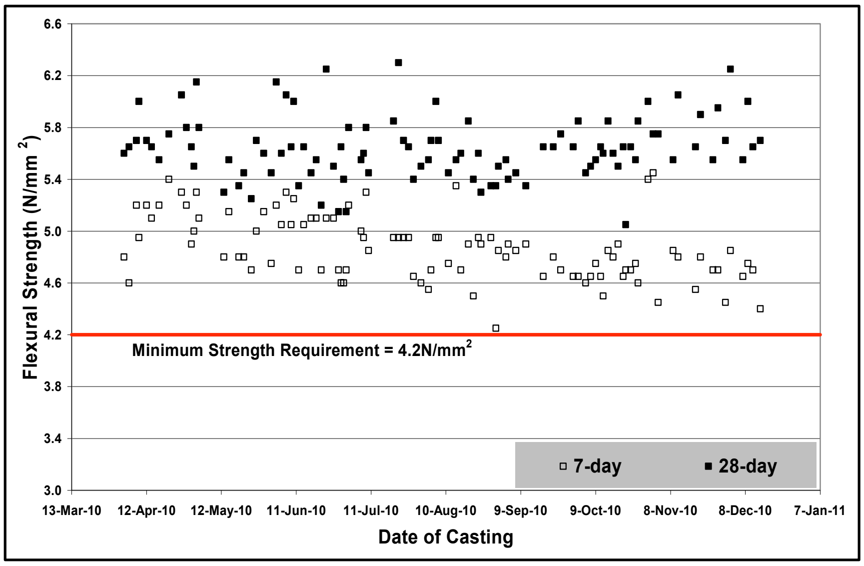
*Samples of RCA*




Construction process of aircraft stand rigid pavement using RCA concrete

than the stipulated period of 14 days after placement of concrete as specified according to CAG specification.

b) 28-day flexural strength – The average flexural strength is in the range of 5.1-6.3N/mm$^2$. This implied that that RCA concrete can be designed to achieve or perform even better than the required flexural strength.




Quality control test results of RCA concrete

## 4. Conclusions and Further Study

This project has demonstrated the feasibility of using RCA derived from the demolition of the existing aircraft stand rigid pavement for the reconstruction of the aircraft stand rigid pavement at Singapore Changi Airport. To date, the project has been carried out successfully since March 2010 and the first phase, comprising 8 aircraft stands, will be completed in December 2011. The remaining aircraft stands will be progressively rehabilitated using the RCA concrete over the next few years. To further optimize the use of RCA, Samwoh has carried out extensive research to evaluate the feasibility of using higher dosage of RCA. The laboratory tests have shown that it is possible to use up to 40% of RCA in concrete for the aircraft stand rigid pavement and field trials are being carried out to validate the performance. In addition, carbon footprint analysis was also carried out to evaluate the carbon footprint of RCA versus natural granite aggregate. The study showed the RCA produces less carbon emissions than natural granite aggregate. In other words, the use of RCA not only provides a substitute for natural aggregate, it is also a greener alternative to granite aggregate. It is envisaged that the project will put Singapore in the forefront of sustainable development in the region.

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# If Concrete Can Speak

*By Dr. Tam Chat Tim, Associate Professorial Fellow*
*Department of Civil & Environmental Engineering*
*National University of Singapore*

Productivity is the current catchword in all endeavours, with concrete construction still far from catching up in the race to the top. In fact, the current level of productivity in the local concrete construction sector is a long way from that in more industrialised regions. Why am I so far behind my overseas cousins? What should I do to catch up?

There are at least three areas that I need to improve. The first is in adopting more advanced technologies in construction. The second is in worker's training as such technologies tend to demand better skill and basic knowledge in their implementation. Finally, it is the attitude towards quality assurance so that all things are done right the first time.

I do not need to go far in shopping for the new technologies in concrete construction that enable higher productivity. The shopping list is easy to find but in order to acquire any such new ways there is always the first cost to bring them into the local construction industry. (BCA has introduced an S$250-million Construction Productivity and Capability Fund (CPCF).

I also need the support of far sighted management that has recognised the poor return of employing unskilled labour on long term productivity increase – remember how dedicated were our "samsui" women with their broad red head dress and blue-dark samfoo dress, in carrying their work at the level of skill available then! Pride of work is the best driving force.

Why do my present day handlers in the concrete construction have to return to their home countries after a few years in the industry when they have just about gained enough experience to do a better job? They have to learn how to handle me on the job, from others often of limited training themselves. When I am not given the right treatment, I cannot be expected to perform as intended. However, I am capable of better performance.

For example, let me talk about members of my concrete family with self-compacting capability, or self-consolidating, if you prefer, by their initials, SCC. Why don't I see them around more often? It is only in the few cases where my contractor friend cannot find other suitable members of my concrete family to perform the task that my cousin, SCC has to be selected to do the job. Why not in more cases where SCC is considered as the alternative? I am the material in precast concrete elements commonly adopted in housing projects, transportation infrastructures and tunnel segments. In nearly all cases, I am designed with a low slump and heavily compacted by means of external and at times also internal vibrators. In order for me to accept such high level of vibration, I have to be confined within very strong moulds which are not only costly but heavy to handle. The opposite situation is the norm when you adopt my SCC cousin for the same products, lighter moulds and minimal vibration. In addition, the rate of casting will also be increased – productivity! Yes, my SCC cousin may well be a bit more costly, but the overall savings will more than compensate for this. The experience with post tensioned precast girders in North American in the past decade demonstrates the classic case of a higher materials cost often ending with a lower overall product cost. The fact that the issue of defects in the anchorage zones being reduced to near non-existence has been sufficient to promote changing over to SCC. This is the case of getting it right the first time, and most of the time, even though may not be all the time. Of course, there is the need to train my producer and handlers in working with my new cousin, initially.

In conclusion, not only productivity is improved, my carbon footprint is also reduced through the use of lighter moulds, less time, labour and energy in handling the new type of moulds and much less energy needed to achieve full compaction at a short time. I look forward to the day when my SCC cousin will dominate the precast concrete sector bringing not only better productivity but also the other concomitant benefits to the construction industry.

# Ultra Durable Concrete for Everyday Application

*Bahador Sabet Divsholi (bsabet@ntu.edu.sg)*
*Tze Yang Darren Lim (dtylim@ntu.edu.sg)*
*Associate Professor Susanto Teng (csteng@ntu.edu.sg)*
*School of Civil and Environmental Engineering, Nanyang Technological University*

## Introduction

With the rapid consumption of natural resources, there is a growing concern about sustainable development. More than 6 billion tons of concrete are produced annually for various construction purposes with limited life expectancy. In addition, fast rising cost of construction and demolition of concrete structures in densely populated areas is a great concern for the future. One of the best solutions to tackle these challenges is to increase the life expectancy of the structures. Residential and important civil structures are typically designed for a life span of 50 and 100 years respectively. However, the life expectancy of structures can be increased to several hundred years with careful planning and proper design. The increase in material cost for concrete is not a considerable amount compared to the total construction cost of the reinforced concrete structures. Doubling the concrete materials cost may only increase the total construction cost by a few percent but it can increase the life expectancy of the structure significantly, resulting in extra savings.

The two most common causes of deterioration in concrete structures are carbonation and chloride penetration promoting the corrosion of steel bar in reinforced concrete. However, the addition of supplementary cementitious materials such as Granulated Ground Blast-furnace Slag (GGBS) and silica fume, combined with low water/cementitious (w/c) ratio will produce Ultra Durable Concrete (UDC) with high internal degree of saturation, very fine pore structure and low degree of porosity [1]. This high degree of saturation will restrict the gas diffusion of CO2, allowing the effect of carbonation to be neglected [2]. Also, the low permeability of the UDC will reduce the chloride penetration rate, inhibiting steel reinforcement corrosion [3]. In addition, the electrical resistivity of the UDC will be increased. This increase in electrical resistivity is a result of reduced permeability from the inclusion of GGBS and silica fume [4].

A comparison between UDC mixes with one normal High Strength Concrete (HSC) in terms of cost, mechanical and durability aspects is done in this work showing UDC have superior qualities which makes it a favourable construction material for future structures [1].

## Experimental work

A total of four mixes were designed, two concrete mixes with w/c ratio of 0.28 and the other two mixes with a w/c ratio of 0.25. Mix A is the reference mix with 100 % Ordinary Portland Cement (OPC), Mix B has 30 % UFGGBS replacement. Mix C and D are higher grades of concrete due to lower w/c ratio and 10 % Undensified Silica Fume (USF) replacement. Differentiating Mix C and D is the 30 % UFGGBS replacement in Mix D. The mix proportions are presented in Table 1, and the material properties of OPC, UFGGBS and USF are listed in Table 2.

## Results and discussions

**Compressive strength:** Compression test results of cube specimens tested on 3, 7, 28, 56 and 90 days were compiled and plotted in Fig. 1. The inclusion of UFGGBS and USF leads to a higher rate of hydration and pozzolanic reaction. It also has better filling effects of the interfacial transition zone pores with subsequent improvement in the strength of the concrete.

Table 1: Mix proportion details

| Mix | A | B | C | D |
|---|---|---|---|---|
| Water / cementitious | 0.28 | | 0.25 | |
| Aggregate / cementitious | 3.35 | | 2.85 | |
| UFGGBS replacement (%) | 0 | 30 | 0 | 30 |
| USF replacement (%) | 0 | 0 | 10 | 10 |
| Total cementitious (kg/m$^3$) | 523 | 518 | 585 | 580 |
| Coarse / fine aggregate | 1 | | | |
| HRWRA / cementitious (%) | 1 | 1 | 1.5 | 1.5 |
| Aggregate by weight ratio | 0.722 | 0.722 | 0.69 | 0.69 |

Table 2: Physical and chemical characteristic of cement (I), UFGGBS and USF

| | Cement (I) | UFGGBS | USF |
|---|---|---|---|
| *Physical properties* | | | |
| Blaine Surface Area ($m^2$/kg) | 360 | 870 | - |
| BET Surface Area (m2/kg) | 1466 | 4968 | 20340 |
| Particle Mean Diameter (µm) | 14.7 | 4.09 | < 0.1 |
| Density(kg/$m^3$) | 3150 | 2720 | 2200 |
| *Oxide compositions (%)* | | | |
| $SiO_2$ | 21.5 | 31.2 | 93 |
| $Al_2O_3$ | 5.5 | 9 | 2 |
| $Fe_2O_3$ | 4.5 | 1 | 1 |
| CaO | 63 | 35.1 | 1 |
| $SO_3$ | 2.5 | 0.1 | 0.3 |
| MgO | 2 | 11.8 | 1 |

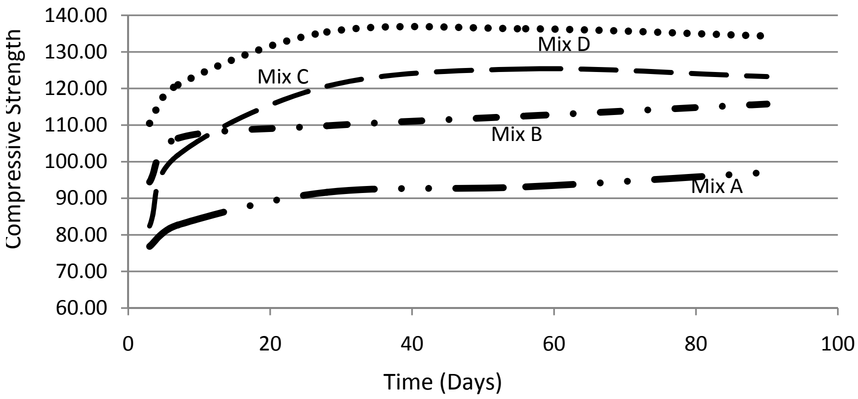


Fig. 1: Concrete strength (MPa)

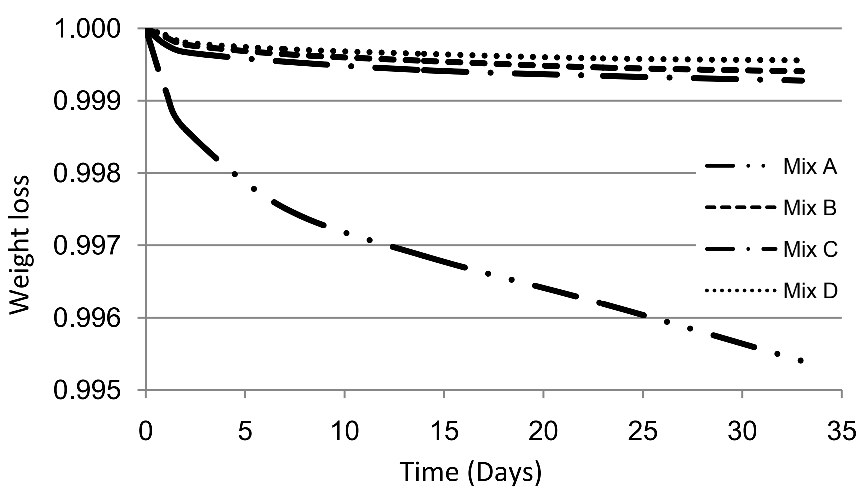


Fig 2: Weight loss ratio under normal drying condition

**Drying test:** Fig 2 shows the gravimetric weight loss of the four mixes of concrete samples under indoor drying condition with relative humidity at 75 %. After the indoor drying, the same samples were subjected to prolonged oven drying at 105°C to measure the total evaporable water content. The degree of saturation for the four mixes was 89, 98.1, 98.7 and 98.6 % for Mix A, B, C and D respectively. Mix B, C and D have very high degree of saturation, therefore allowing us to neglect the effect of carbonation.

**Chloride penetration:** The chloride penetration is modelled by chloride binding capacity through adsorption isotherm and chloride diffusivity [5]. For Mix B, C and D, considering diffusion alone will allow us to yield good prediction of the chloride penetration. By using the law of diffusion [6], a time-dependent chloride diffusion coefficient [7] and a Monte Carlo Simulation, the probability of failure of the concrete can be calculated through analysis [8]. In addition to the empirical age factor (α-values) of the concrete, the diffusivity coefficients for 28 day water cured samples experimentally measured based on NT BUILD 492 are to be provided for the analysis. Details of the input parameters are presented in Table 3 and the prediction results are shown in Fig. 3.

In locations with harsh weather conditions, the probability of failure should be limited to 10 percent in the serviceability limit state [9]. From the results presented in Fig 3, Mix C and D obtained 5.1 and 1.1% probability of failure respectively for a service period of 500 years, showing the superior qualities of these concrete mixes. Using commercially available Wenner probe method the electrical resistivities of these four mixes were measured at 90 days of curing in saturated conditions. The measurements were 30, 137, 460 and 1740 KΩ cm for Mix A, B, C and D respectively. Significantly higher electrical resistivity values for Mix C and D and their ratios support the prediction presented in Fig 3. The material cost of Mix C and D are 45 and 50 % higher than Mix A respectively. However, this increase is only a small percentage of the overall construction cost yet extending the life span of the structures.

Table 3: Input parameters in probability of failure calculation

| Mix design | A | B | C | D |
|---|---|---|---|---|
| Design life | 500 years | | | |
| Cover depth | 50 (2) mm | | | |
| Temperature | 30ºC | | | |
| Dcoef | 7.91 (1.22) | 0.95 (0.07) | 0.16 (0.04) | 0.11 (0.01) |
| t0 (age when tested) | 28 days | | | |
| te (age when exposed) | 28 days | | | |
| α (age factor) | 0.4 (0.08) | | | |
| Ccr (critical chloride content) | 0.4 (0.08) | | | |
| Cs (surface chloride content) | 3.8 (0.9) | | | |

*standard deviation is presented in bracket

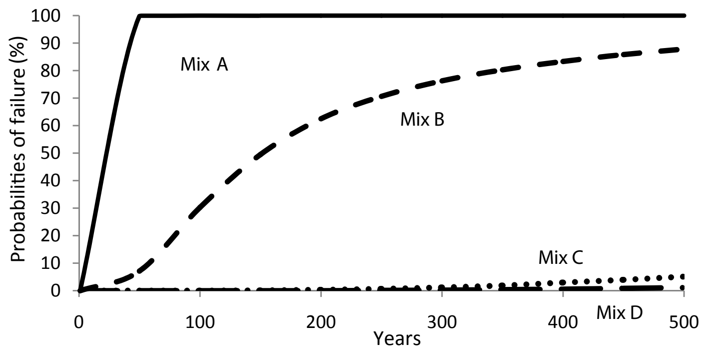


Fig. 3: Probability of failure for 500 years

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