BENEFITS OF ELKEM MICROSILICA® IN CONCRETE

Draft in preparation for October 2017

Elkem
A Bluestar Company

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Founded in 1904

Owned by China National Bluestar since 2011

Headquarter in Oslo, Norway

Marine mega Structures – Durable microsilica concrete

Tsing Ma Bridge,
Hong Kong

Bandra-Worli Sealink,
Mumbai

Storebælt Bridge,
Denmark

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Tallest buildings – High strength microsilica concrete

Petronas Towers, KL

World One, Mumbai

Burj Khalifa, UAE

Tunnelling Examples – shotcrete, precast segments

Crossrail Railway Tunnel, London

- 21km twin-bore tunnels

Delhi Metro, shotcrete & segments

Avrasya Tunnel, Istanbul

- Under the Bosphorus strait

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Elkem Microsilica® - Global expertise in supply and use of microsilica for tunneling and shotcrete

- Trusted solution for shotcrete mix design, enabling optimum rheology, strength & durability
- Vast portfolio of major projects worldwide, including London's Crossrail underground railway
- ISO 9001:2008 – certified quality management system

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What is Elkem Microsilica® ?

- Microsilica (also termed ‘silica fume’) – highly reactive pozzolanic material

- International Standards
  - ASTM C1240
  - EN 13263

Mix Design

Application	Typical Dosage (% microsilica by mass of total cementitious binder)
Pumping aid	2 to 3
Self-compacting concrete	4 to 10
High strength concrete	6 to 10
Low permeability concrete	6 to 10
Underwater concrete	12 to 15
Sprayed concrete (Shotcrete)	8 to 12
Ultra-high performance concrete	15 to 25

Burj Khalifa, current worlds tallest building

Burj Khalifa

80 MPa superstructure concrete mix

- Elkem Microsilica® (10% of binder)
- Fly ash (13% of binder)
- Slump flow typically 600mm

Burj Khalifa

Piling concrete mix (SCC):

- Binder content 450kg/m^3 with 37% FA & 7% MS
- Max. aggregate size 10mm
- Self-compacting consistence
- Water/binder ratio 0.32
- Strength required 60 MPa

Piling Concrete: Mean Strength Results		
Age, days	Compressive, 150mm cubes	Tensile
7	40.5 MPa	-
14	51.5 MPa	3.75 MPa
28	64.5 MPa	4.35 MPa
56	75.5 MPa	-

Piling Concrete: Durability Specification & Test Results		
Requirement	Method	Test Result
Max water penetration, 10mm	BS EN 12390-8	Zero
Max water permeability, 5mm	Din 1048	Zero
Max water absorption, 1.5%	BS 1881: Part 122	0.7%
Rapid Chloride Permeability, <1200 C	ASTM C-1202	590 C (28 days)

Shanghai (Yangshan) Deep Water Port & Bridge

- Port linked to mainland by 32 km bridge

- Bridge: 13,000 tonnes of Microsilica
- Port: 10,000 tonnes of Microsilica

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Yangshan Deep Water Port, Phase III, 2008

Yangshan Deep Water Port – Mix Design

C45	kg/m^3
Cement (pre-blended with 15% fly ash + 5% microsilica)	**441**
Fine aggregate	**757**
Coarse aggregate	**1046**
Water	**150**
Super plasticiser	**6.17**
Target slump	**160 mm**
w/c ratio	**0.34**
Theoretical density	*2400*

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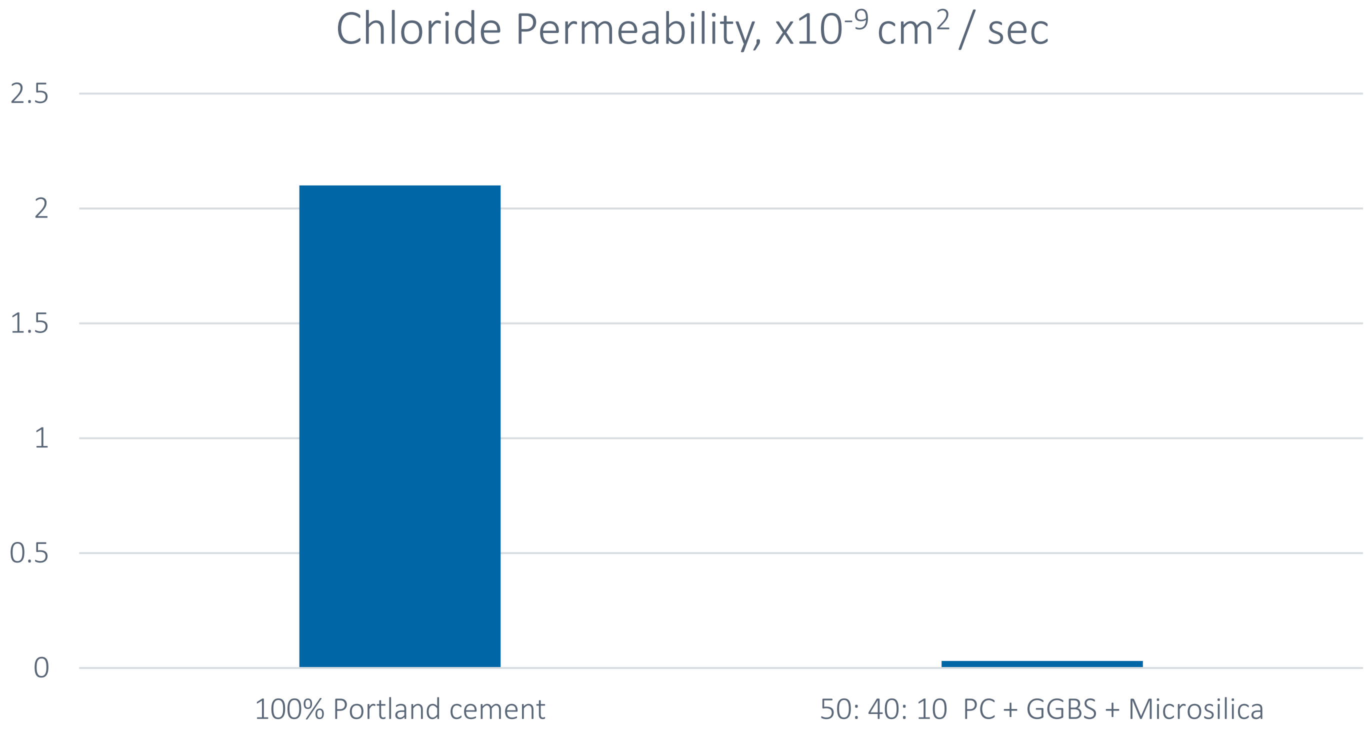
Reasons for selecting microsilica – improved resistance to corrosion

Structures at risk from chloride ion induced damage:

- Structures exposed to seawater
- Structures exposed to deicing salts

Sandberg report, uk, 1991 (testing: taywood engineering)



Oresund Link (Bridge & Tunnel) – Denmark to Sweden

- Triple blend, 100 year service life

Abrasion resistance – Industrial Floors

- Microsilica helps resist abrasion
  - High strength concrete
  - Absence of bleeding means no weak top layer is formed
  - Good bond between paste & aggregate
- Popular application in UK

- High performance concrete lasts longer – Saves money

Long-term study – 31 years

- Concrete blocks placed in situ in March 1983
- Installed at tidal zone at Trondheim, Norwegian coast

- Five concrete mixes – blocks size 0.5m x 1.5m x 1.5m

- Removed from site 31 years later

- Interim periodic reporting – for example:
  - Hammer, T & Havdahl, J (1986), SINTEF report STF65 A86003
  - Skjølsvold, O (2005), SINTEF report STF50 F05038

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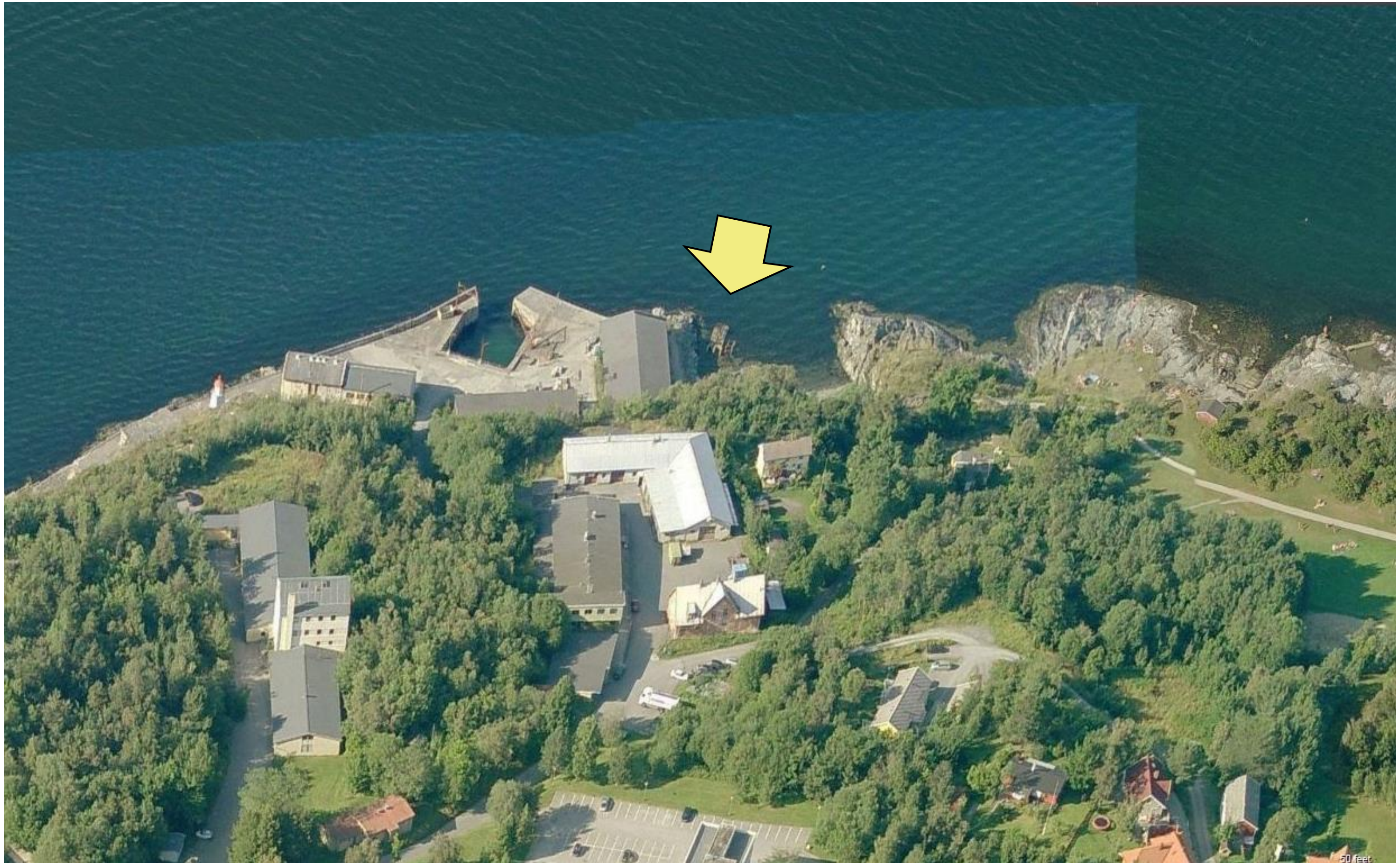
Long term test site location: Trondheim, Norway



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Location

- Splash zone condition
  - Low tide, blocks not immersed in seawater
  - High tide, approximately 0.2m of the blocks remained above water
- Wind and wave action
- Frost episodes during winter

Typical climate data at test site

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air temp, °C	-2.5	-1.8	0.8	4.0	9.6	12.8	14.0	13.6	9.8	6.2	1.3	-1.0
Sea temp, °C	4.3	3.3	4.3	5.6	9.1	12.1	13.9	13.8	11.6	9.2	6.7	5.3
Saline content, %	3.18	3.18	3.24	3.13	2.27	2.22	2.32	2.62	2.90	3.06	3.03	3.08

Ref: Skjølsvold et al (2007); Norwegian Meteorological Institute; SINTEF

5 concrete mix designs – Range of w/b ratios, 10% and 20% silica fume

	Control	Reduced cement + Silica fume		Increased cement + Silica fume	
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
CEM I, kg/m^3	370	275	234	457	394
w/c ratio	0.54	0.70	0.83	0.45	0.55
Silica fume dosage*	0 %	10 %	20 %	10 %	20 %
Silica fume, kg/m^3	0	27.5	46.8	45.7	78.8
Total binder, kg/m^3	370	302.5	280.8	502.7	472.8
w/(total binder) ratio	0.54	0.63	0.69	0.41	0.46

** calculated as percent of CEM I mass*

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Visual inspection of blocks after 31 years in tidal zone

Mix 1 – Control, w/b 0.54

Mix 4 – 10% Silica Fume, w/b 0.41

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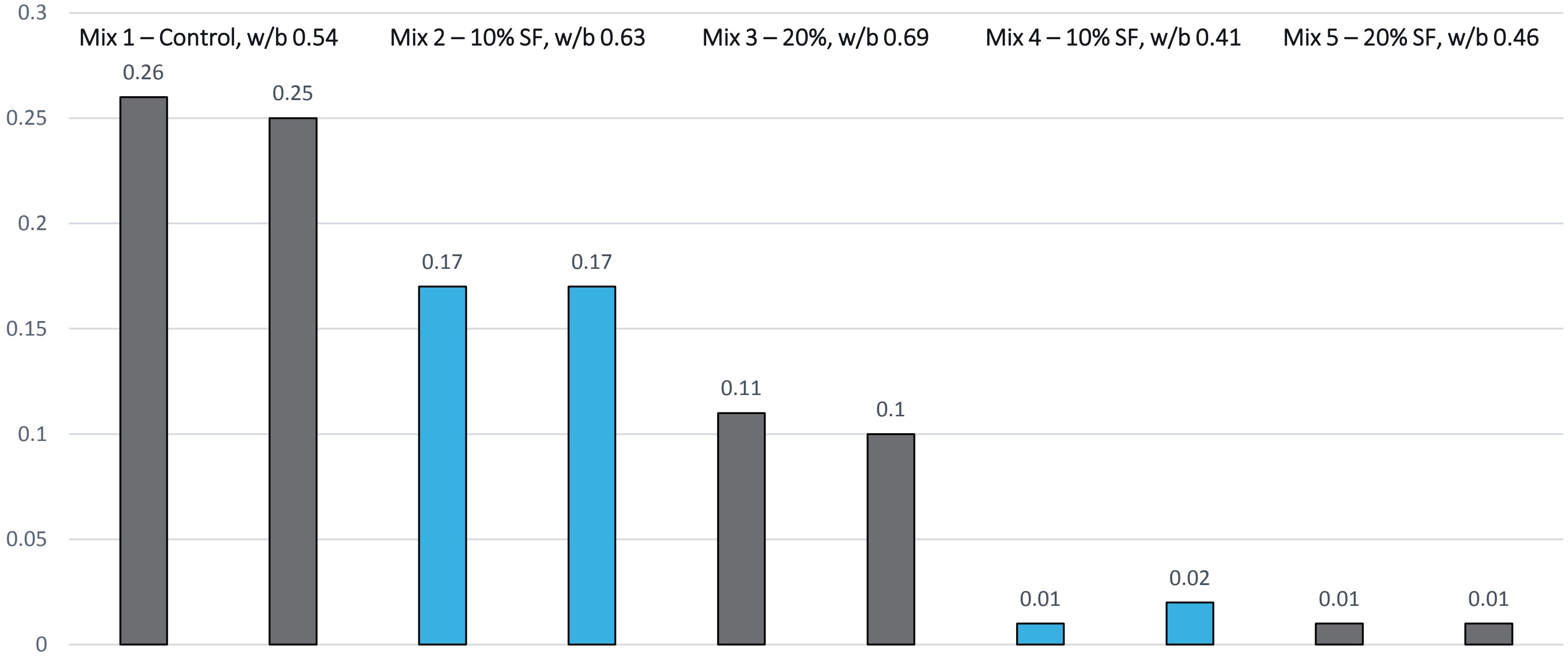
Chloride ingress – at layer 50mm - 65mm from surface, Cl^- % of dry concrete



Method: Two cores drilled from each concrete block; Layer ground from surface and chloride content determined by automatic potentiometric titration by Methrom titrator and silver electrode

Notes on long-term study

- Results are consistent with previous studies – Elkem Microsilica® concrete has more resistance to degradation caused by the ingress of aggressive ions – this has now been demonstrated empirically over a 31 year time span

- Structural integrity of the Elkem Microsilica® concrete with reduced water/binder ratio was maintained

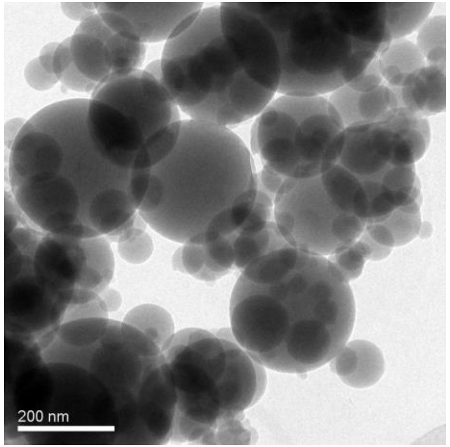
- Microsilica mixes showed significant reductions in chloride contents at typical reinforcement depths after 31 years in severe marine exposure

- The practical consequence of these factors is that Elkem Microsilica® significantly reduces the risk of chloride-initiated corrosion, especially in concrete exposed to severe marine environments

How Elkem Microsilica® works

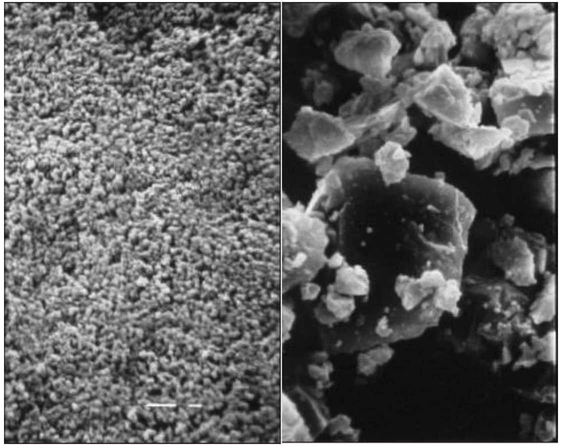
- Pozzolanic reaction of Elkem Microsilica® results in reductions to capillary porosity and densification of interfacial transition zones around aggregates

Elkem Microsilica® – Physical properties



Microsilica particles:
•Extremely small size; <1 µm
•Spherical shape

Particle size comparison:
•Each microsilica particle about 100 times smaller than Portland cement



Elkem Microsilica® – Chemical properties

SiO_2

Elkem Microsilica® is safe, pure & consistent:
•Typically >90% amorphous silicon dioxide

Elkem Microsilica® is Pozzolanic:
•When mixed with Portland cement it reacts with calcium hydroxide, forming calcium silicate hydrate

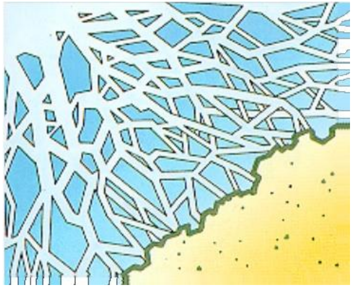
Reaction in Concrete

Plain concrete, no microsilica :

•permeable cement paste structure

•weak ‘transition zone’ between aggregate & cement paste

Cement particle

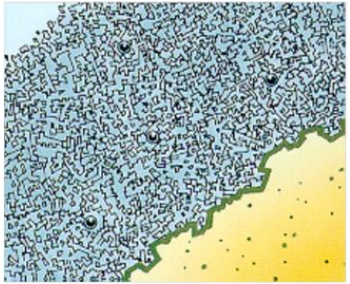


Aggregate

Reaction in Concrete

Concrete with Elkem Microsilica®:

- Extremely small particles; beneficial packing
- Pozzolanic reaction; SiO_2 reacts with $Ca(OH)_2$
- Impermeable paste structure with strong transition zone



Elkem

110 years of history as a technology provider

24 PLANTS WORLDWIDE
Headquarter in Norway

400 R&D PEOPLE
Global R&D centres in Norway and Lyon

3.600 EMPLOYEES
Worldwide

14,5 BNOK
Revenue in 2015

Founded in 1904 by Sam Eyde

Owned by China National Bluestar since 2011

Elkem – our **four business areas**

Silicon Materials
Global producer and provider of silicon, microsilica and specialty materials

Silicones
One of the foremost fully integrated silicones manufacturers in the world

Foundry Products
Leading producer of specialty-alloys for the foundry and steel industries

Carbon
Leading producer of electrode paste and other carbon products

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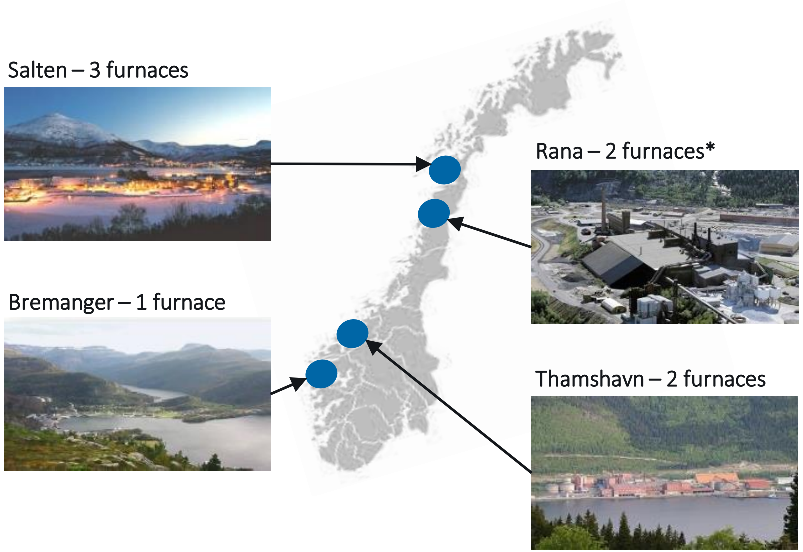
Elkem Silicon Materials: world leading supplier of microsilica

KEY FACTS

- One of the world's leading suppliers of silicon and Microsilica
- Four* smelting plants, two R&D centers, quartz mines, processing sites and an extensive global sourcing and sales network
- Strong customer relationships based on specialized products developed to improve customer's yield
- Solid energy recovery competence
- Secured access to high-grade raw materials

LOCATIONS



*Potential silicon capacity at Rana

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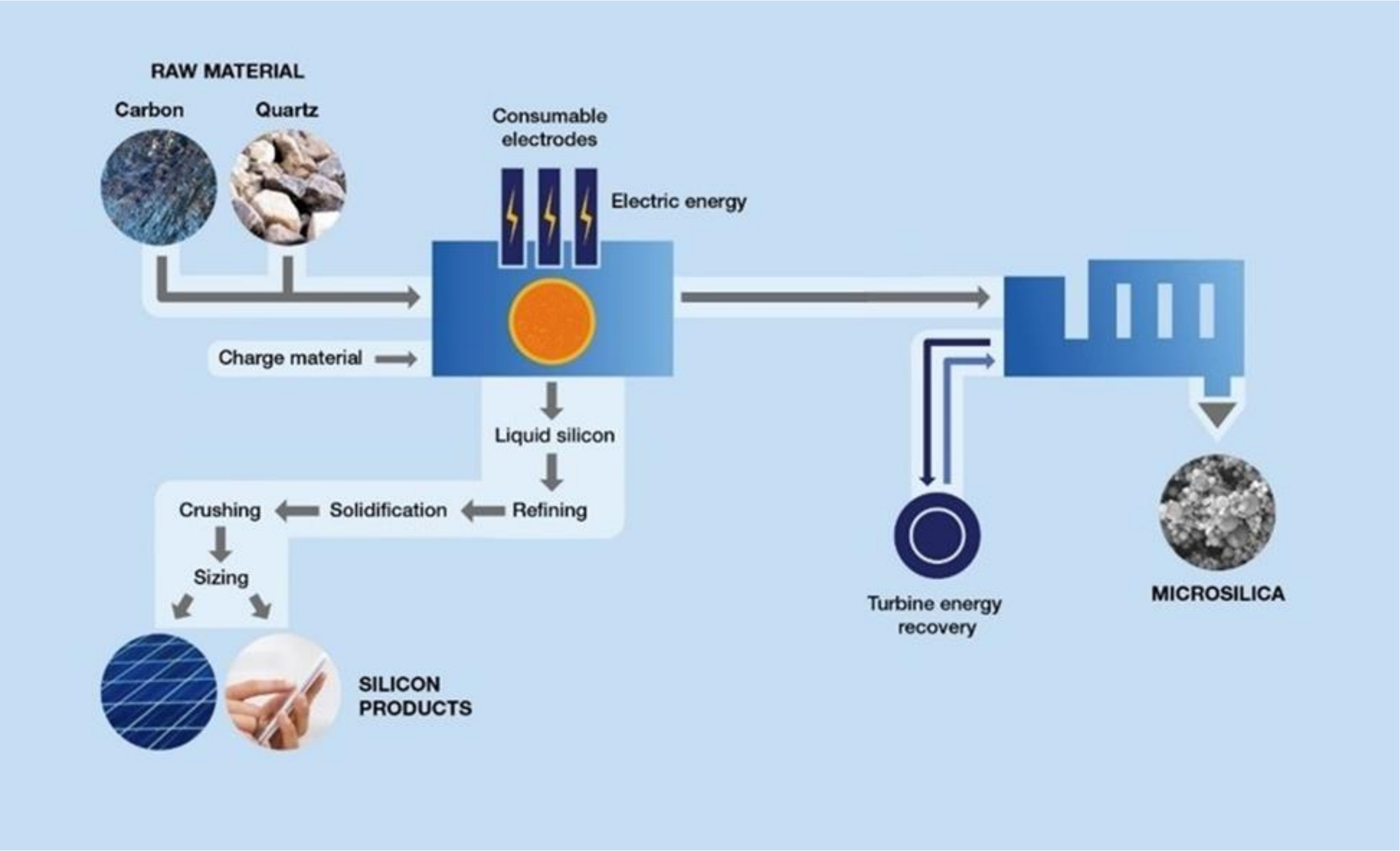

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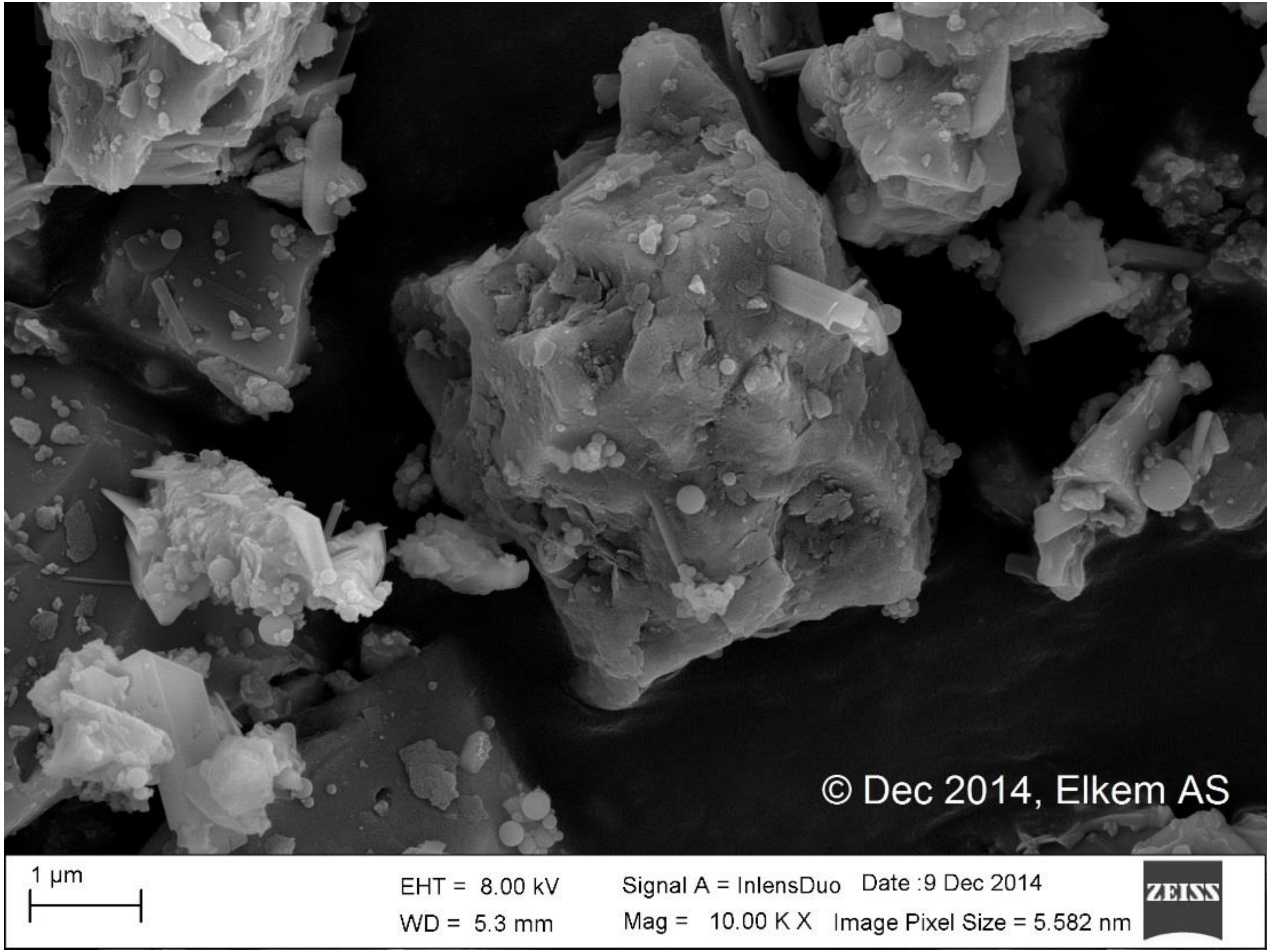

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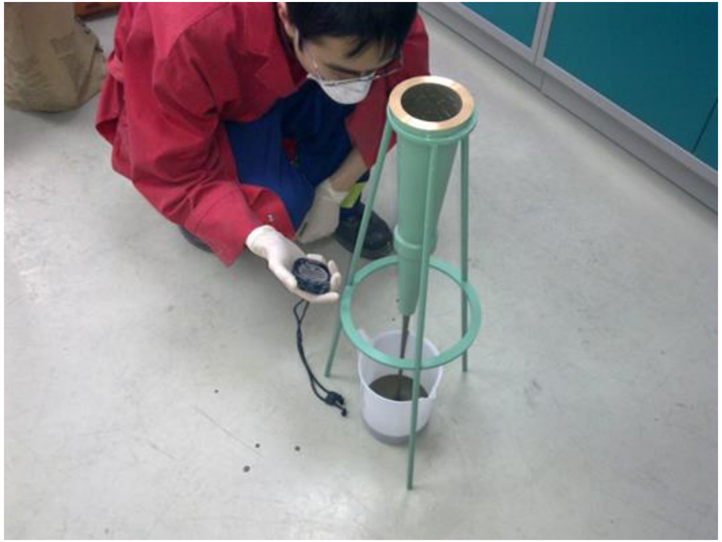
Choosing microsilica supplier – Viewpoints

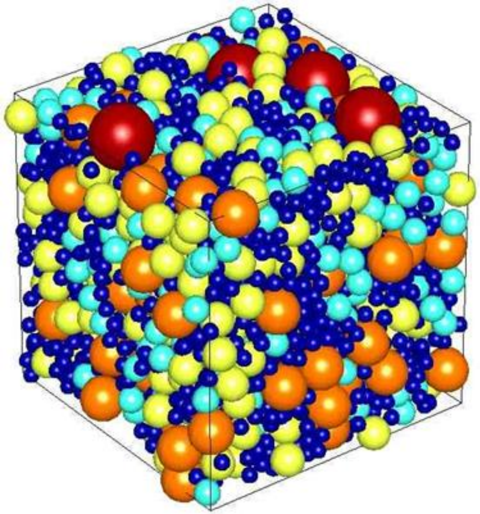
- Over the past 30 years, Elkem Microsilica® has established itself as a reliable material for producing HPC
- Microsilica contributes to optimised particle packing in concrete, enabling a dense structure with high strength and high durability
- High performance concrete mixtures are characterised by relatively low water content and high powder content, therefore HPC mixtures tend to more sensitive to the individual characteristics of microsilica from different furnaces/suppliers
- Effective dispersion of the microsilica particles is important, to ensure optimal performance
  - Dispersion can be achieved by thorough mixing combined with the use of a compatible superplasticiser
- Factors influencing the performance of a microsilica in a concrete mixture include physical factors such as particle size, shape and agglomeration. Also, chemical interaction between the silica fume, Portland cement and admixtures will influence performance

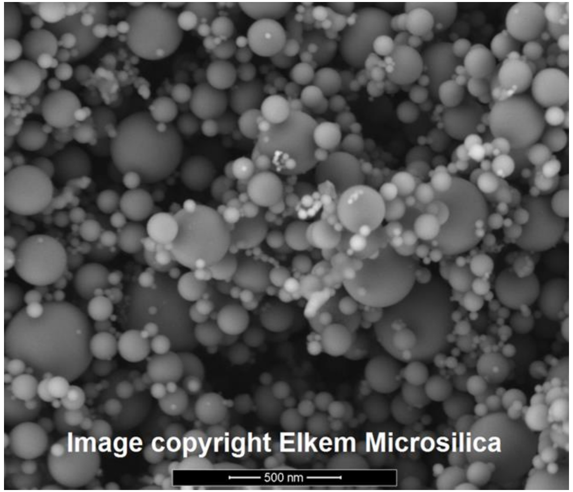
Chemical & physical attributes	USA ASTM C1240	European EN 13263	Japanese JIS A 6207	Chinese GB/T 18736	Brazilian NBR13956	Korean KS F 2567	Vietnamese TCXDVN 311	Indian IS 15388	Canadian CSA A3000
SiO_2 (%)	minimum 85	minimum 85	minimum 85	minimum 85	minimum 85	minimum 85	minimum 85	minimum 85	minimum 85
SO_3 (%)	-	maximum 2	maximum 3	-	-	maximum 3	-	-	maximum 1
Cl (%)	-	maximum 0.3	maximum 0.1	maximum 0.2	-	maximum 0.3	-	-	-
Free CaO (%)	-	maximum 1	maximum 1	-	-	-	-	-	-
MgO (%)	-	-	maximum 5	-	-	maximum 5	-	-	-
Free Si (%)	-	maximum 0.4	-	-	-	-	-	-	-
Alkalis (Na_2O eq.%)	Report	-	-	-	Report	-	-	maximum 1.5	Report
Moisture (%)	maximum 3	-	maximum 3	maximum 3	maximum 3	-	maximum 3	maximum 3	-
Loss on ignition (%)	maximum 6	maximum 4	maximum 5	maximum 6	maximum 6	maximum 5	maximum 6	maximum 4	maximum 6
Specific surface area, BET (m^2/g)	minimum 15	min 15 max 35	minimum 15	-	-	minimum 15	-	minimum 15	minimum 15

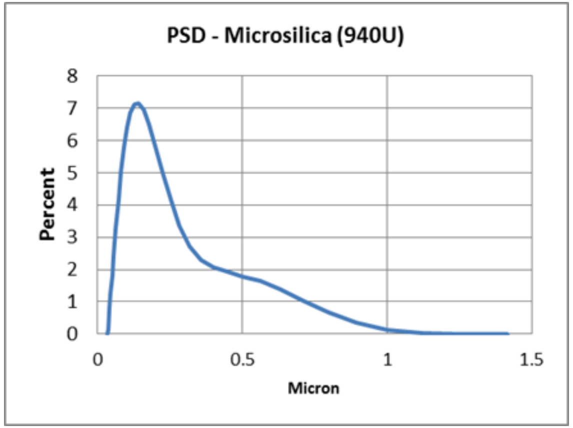
Choosing microsilica for high performance concrete



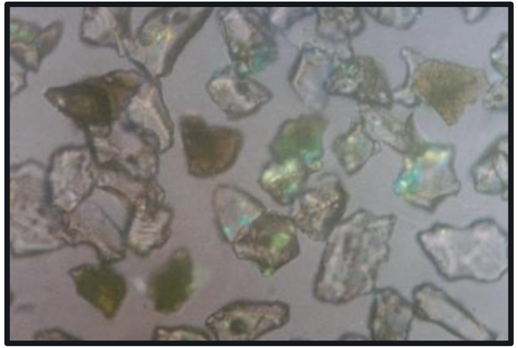
Particle packing



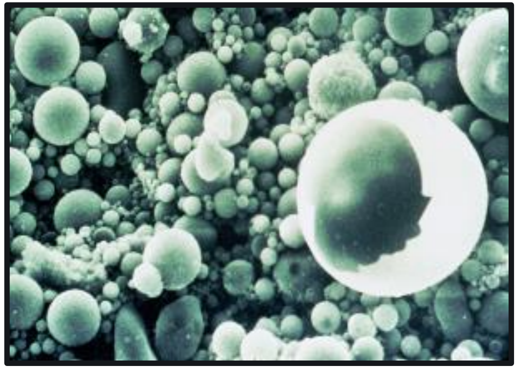




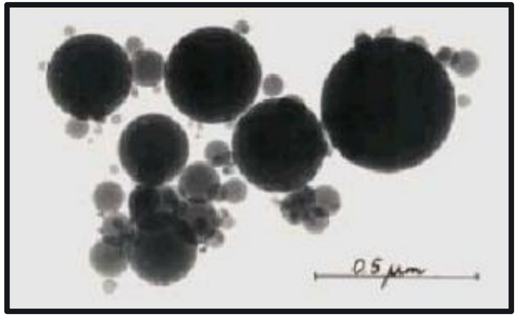
Comparison of particle size & shape



GGBS (~ 10 microns)

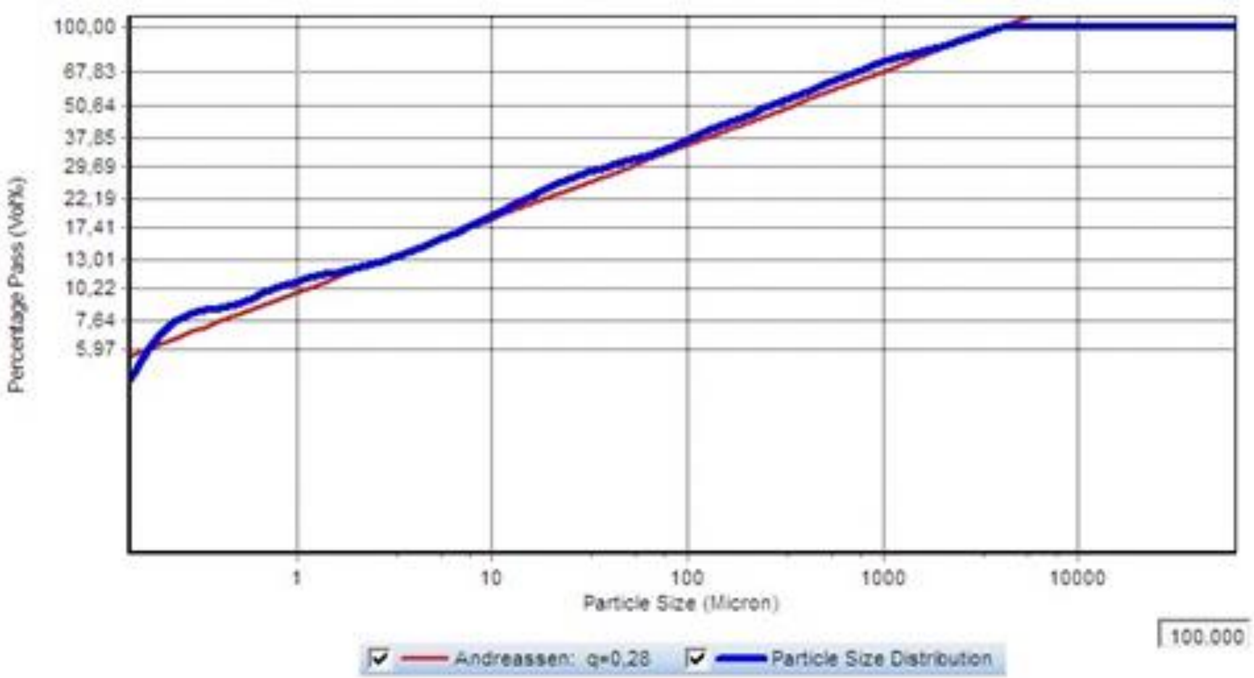


Fly Ash (~ 10 microns)



Microsilica (~ 0.1 microns)

EMMA program www.elkem.com
Ref. A.H.M. Andreassen and J.Andersen, *Kolloid Z.* (1930)



Sustainability

Material	Embodied CO_2 (kg / tonne)
Portland cement, CEM I	930
GGBS	52
Fly ash	4
Microsilica	28

Source: TR 74 – Embodied CO_2 of main constituents of reinforced concrete
Important note: UK data comparison, typical delivered product

Reasons for selecting Elkem Microsilica® – High Strength Benefits

Example: One Island East Building

308 metre tall building, Hong Kong

Comparison of design options, Grade 45 or Grade 100?	
Grade 45	Grade 100
45,440 m^3 concrete	32,000 m^3 concrete
14,768,000 $kgCO_2$	10,432,000 $kgCO_2$

Grade 100 = 15% less concrete

- Cost savings
- Environmental benefits

Grade 100 mix design

- PC 380 kg/m^3
- Fly ash 145 kg/m^3
- Microsilica 58 kg/m^3
- Superplasticiser
- w/c ratio 0.26

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Comparison of C45 vs C100 Concrete
(One Island East Building – Ref. F. Chan, MASTEC, HK, 2009)

	Carbon footprint of each ingredient ($kgCO_2/kg$)	Weight of each ingredient per unit volume of concrete (kg/m^3)	
		Grade 45 normal concrete	Grade 100 HPC
Cement	0.83	380	380
PFA	0.01	125	145
CSF	0.01	0	58
Aggregates	0.005	1,610	1,640
Water	0	200	150
Carbon footprint per unit volume ($kgCO_2/m^3$)	-	325	326

	Grade 45 normal concrete	Grade 100 HPC
Carbon footprint per unit volume ($kgCO_2/m^3$)	325	326
Concrete consumption (m^3)	45,440	32,000
Total carbon footprint ($kgCO_2$)	14,768,000	10,432,000
Gross floor area (m^2)	141,000	
Carbon footprint per unit floor area ($kgCO_2/m^2$)	105	74

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High performance concrete with Elkem Microsilica®

- Higher performance
  - Strength
  - Rheology
  - Durability
- Less permeable
  - Higher resistance to chloride ingress & damage
  - Longer service life
- Sustainable

ADVANCED MATERIALS
SHAPING THE FUTURE