Tunnelling Asia' 2023
International Conference on
Climate Change Resilience and Sustainability
in Tunnelling and Underground Space

Elkem Microsilica in Tunnelling applications- Shotcrete

by

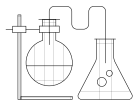
Ahmed Khalifa, PhD (Elkem)

Elkem ASA Silicon Products

Ahmed.khalifa@elkem.com

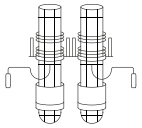
We are Elkem

Advanced silicon-based material shaping a better and more sustainable future



Silicones

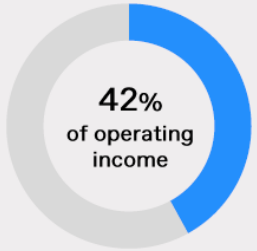
Silicon Products



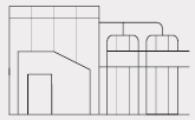
Carbon Solutions

Elkem operates through three divisions: All with global scale, leadership positions and global footprint

Silicones
Fully integrated silicones manufacturer with focus on specialities

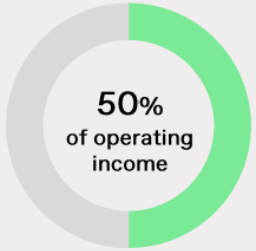


End markets
- Construction
- Automotive
- Chemical formulators
- Personal care
- Healthcare
- Paper & film release
- Silicone rubber
- Textile

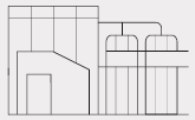


14 main worldwide

Silicon Products
Global producer and provider of silicon, ferrosilicon and specialties



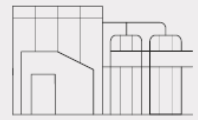
End markets
- Automotive
- Construction/industrial equipment
- Electronics
- Specialty steel
- Solar & wind turbines
- Refractories
- Oil & gas



10 main plants

Carbon Solutions
Leading producer of electrode paste and specialty products

End markets
- Ferroalloys
- Silicon
- Aluminium
- Iron foundries



6 main plants

Microsilica applications in tunneling

- Microsilica is A key component in landmark tunneling projects
- It serves as a vital additive in **shotcrete, precast and grouting applications**.

Precast linings

Grouting applications

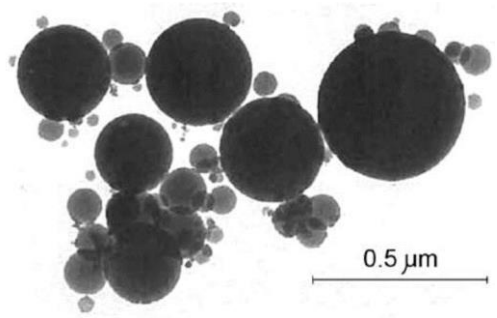
Shotcrete

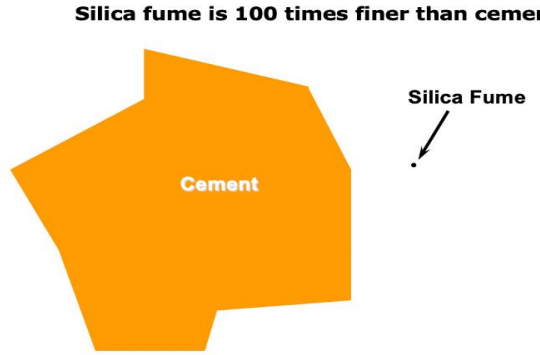
What is Microsilica?

Microsilica, Also known as **silica fume,** is a mineral composed of ultrafine non-crystalline silicon di-oxide (SiO_2). It is a highly reactive material that is used to enhance the properties of concrete. Depending on the application, its typically used between 2 and 20% by mass of the cementitious materials.

Microsilica has a very high content of amorphous silicon dioxide and consist of very fine spherical particles, typically averaging from 0.1 to 0.2 microns in diameter.

Each microsphere is on average 100 times smaller than an average cement grain.
At a typical dose of 10% by mass of cement, there will be 50,000-100,000 microsilica particles per cement grain.





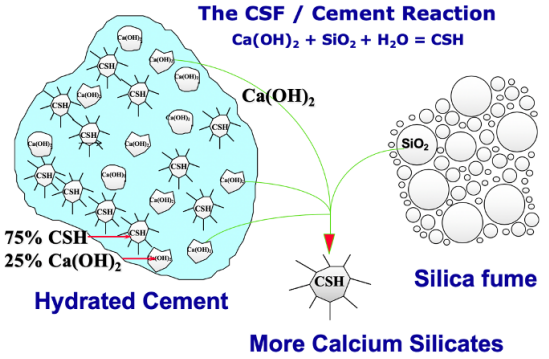
Microsilica reactions in **concrete**

<u>The chemical mechanisms include</u>:

As the Portland cement in concrete begins to react chemically with water, it forms calcium silicate hydrates (C-S-H) and releases calcium hydroxide (CH). Microsilica then will react with CH to form additional C-S-H, which is very similar to the C-S-H formed from Portland cement.

It is this essentially additional binder that gives microsilica concrete its improved hardened properties.

$$Ca(OH)_2 + SiO_2 = C - S - H$$



<u>The physical mechanisms include:</u>

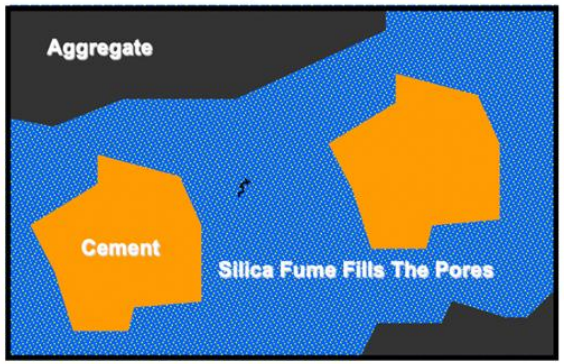
Reduced bleeding and greater cohesiveness

This benefits the hardened concrete structure in term of reduced segregation and bleed water pockets under reinforcing bars and coarse aggregates

The increased cohesion allows silica-fume concrete to be used in very high fluidity applications such shotcrete/sprayed concrete, as self-consolidating concrete (SCC) or ultra-high-performance concrete (UHPC) applications.

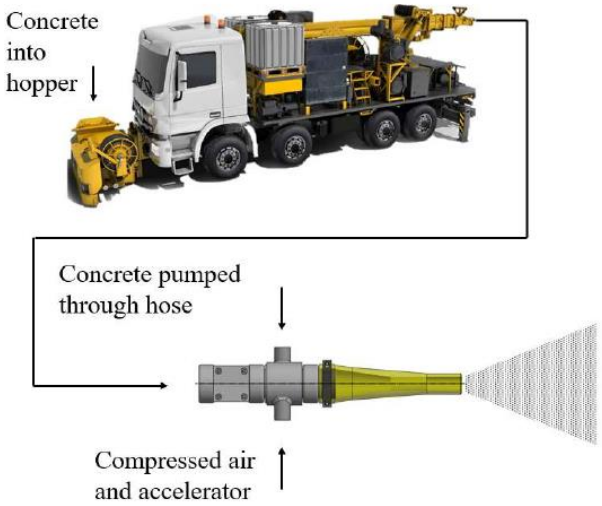
More efficient packing of the solid particles.

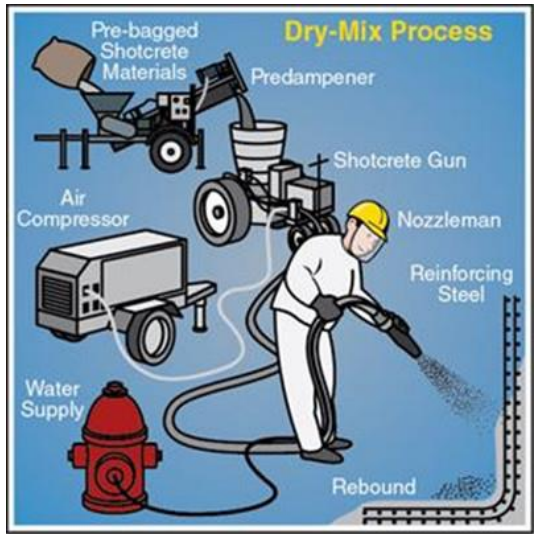
Silica fume fills the pores and control bleeding



Shotcrete/sprayed concrete

- Shotcrete is a cement/aggregate mortar or concrete mix that is shot at high velocity onto a surface by compressed air.
- There are two basic processes for shotcreting: wet mix and dry mix. Silica fume/microsilica additives can be introduced quite easily in either process.





The 'robotized' wet-mix process is dominating due to high productivity, high concrete quality and clean and safe working environment. Often steel fibres are replacing traditional mesh reinforcement. Alkali-free accelerator is replacing traditional accelerators.

Silica fume/Microsilica Shotcrete?

- Microsilica was first used in shotcrete in Norway in 1970s. Later, in the early 1980s, the use of microsilica shotcrete developed in the USA and Canada.
- Microsilica shotcrete is now widely used, in both the wet and dry processes, with and without steel fibers.
- The cohesive nature of this shotcrete allows for many applications that would have been difficult, uneconomical, or impossible to accomplish without the silica fume

Benefits of using Microsilica in shotcrete

1. Using silica fume in shotcrete allows for greater production, by improving the pumpability.

   This allows for **greater thickness of shotcrete layers**, particularly when shooting overhead, and a **significant reduction in rebound.** Thus, improving the materials **cost effectiveness**

- The proportion should be adapted to the purpose, typically from 3 to 15 % of the cement weight.
- The rebound consists mostly of larger aggregates. Loss of the larger aggregates increase the shrinkage. The loss of fibres results in poorer distribution of shrinkage cracks and decreased flexural strength. The overall quality, therefore, significantly improved by reduced rebound

Overhead application of silica-fume shotcrete. Because of its increased cohesion, silica fume shotcrete has much less rebound and allows for greater lift thickness when shooting overhead than shotcrete without silica fume.

Benefits of using Microsilica in shotcrete

2. Even though silica fume is **compatible** with all of the **accelerators** that are commonly used in shotcrete. Using silica fume in shotcrete can either eliminate or reduce the need for use of accelerators to achieve high early strength.

3. Silica-fume shotcrete frequently includes steel fibers to **provide increased flexural strength and improvements in the crack control**

4. An additional benefit is the **increased bond strength** of the silica-fume shotcrete to the underlying material and between lifts or layers in multi-pass applications.

5. Enhanced **resistance to chemical attack** from: Chlorides, sulfates, acids and alkali aggregate reactions

Microsilica shotcrete is 'sticky', has low rebound (around 5% can be achieved), and allows for thick layer build-up

No dust - clean working environment.

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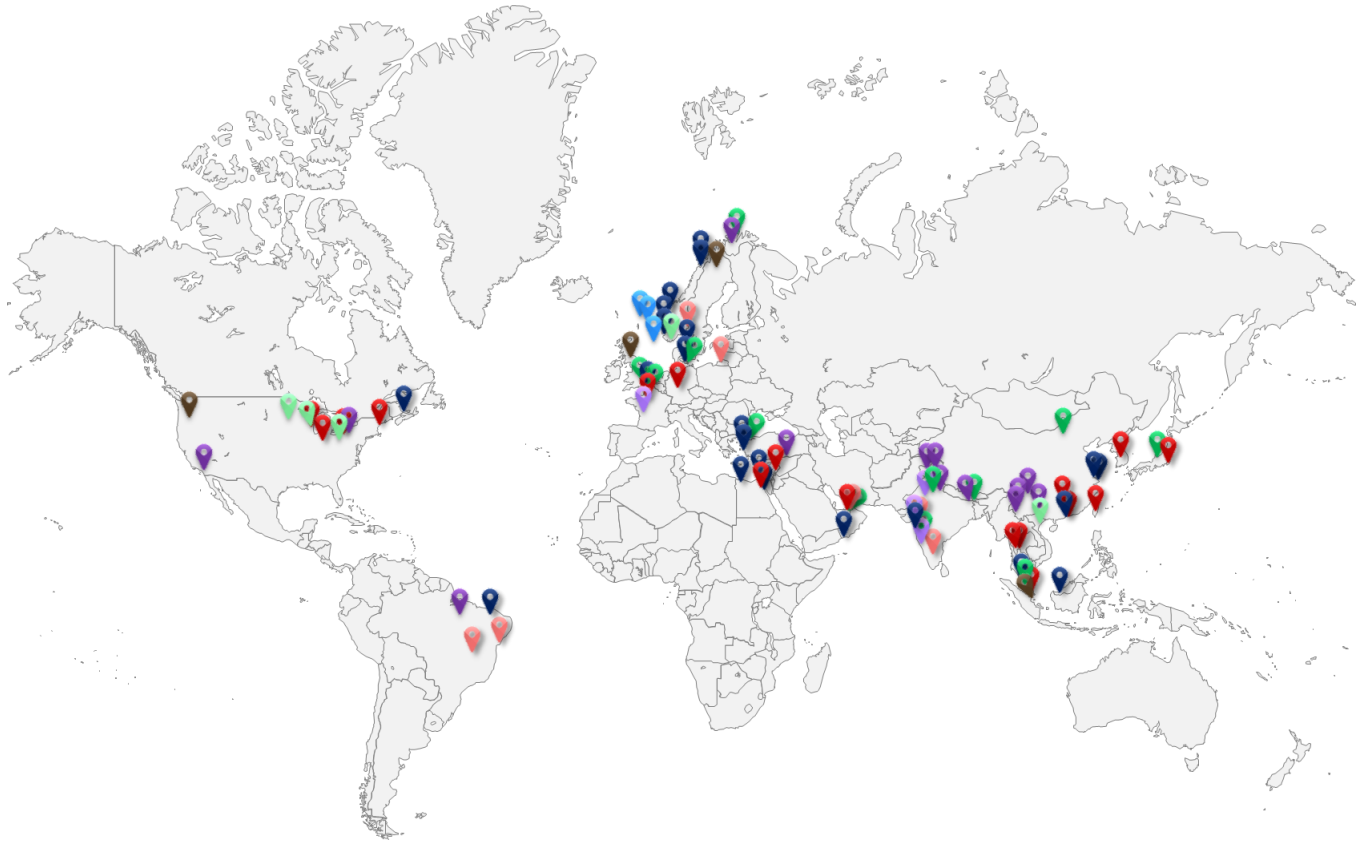
The world's most prestigious construction projects

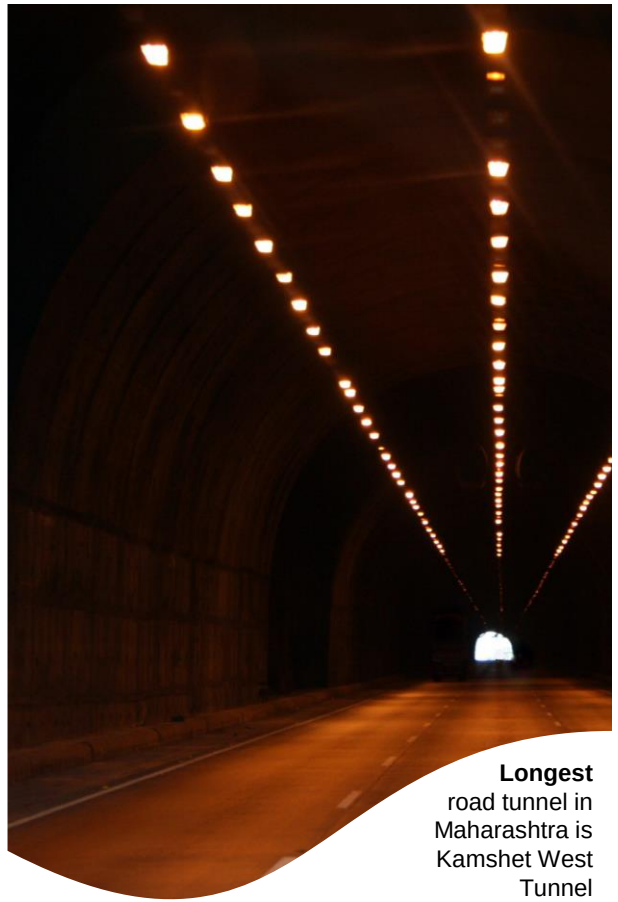
Legend:

- High-rise building
- Other building and structure
- Marine – bridge, seaports
- Marine – offshore wind farm and offshore platform
- Tunnelling
- Highway, bridge, pavement & parking structure
- Hydropower plant / Dam
- Nuclear power plant
- Industrial, Waste facility



Mumbai Pune Express Highway, India

- The Mumbai Pune Express Highway has 4 lanes wide tunnels at five locations with total length of 5.7 km. The five tunnels (Bhatan, Madap, Kamshet-I, Kamshet-II, Khandala and Aadoshi) built by Konkan Railway and were completed in 1997. The tunnels passes through the mountains of Western Ghats of Maharashtra
- High performance Elkem Microsilica® shotcrete in both wet and dry application methods. These five tunnels along the Mumbai to Pune Expressway were line with steel fibre reinforced Elkem Microsilica® shotcrete. Wet shotcrete included superplasticizers to aid with setting times, but the dry shotcrete mix used no chemical admixtures and still achieved very low rebound figures
- The wet mix included 50 kg of steel fibres, 475 kg of cement and 6.5% Elkem Microsilica®
- The dry mix was 500 kg of cement and 8% Elkem Microsilica®
- The use of the Elkem Microsilica® improved the concrete and reduce rebound that gave a much cleaner site and a more economical concrete



Longest road tunnel in Maharashtra is Kamshet West Tunnel

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Mumbai Pune Express Highway, India

Wet mix shotcrete with Elkem Microsilica®

Material	Quantity	Unit cost	Cost/m^3
Cement	460	3	1,380
Elkem Microsilica®	22	30	660
Aggregate	1,600	0.2	320
Steel fibre	50	60	3.00
Plasticizers	6	40	300
Accelerator	14	35	490

Dry mix shotcrete with Elkem Microsilica®

Material	Quantity	Unit cost	Cost/m^3
Cement	475	3	1,425
Elkem Microsilica®	40	30	1,200
Aggregate	1,600	0.2	320
Accelerator	15	35	424

Wet mix shotcrete - comparison

	Without Elkem Microsilica®	With Elkem Microsilica®
Total cost/m^3	5,995	**6,150**
Cost + Application	9,000	9,500
Cost + rebound	12,000 at 25%	**10,500 at 10%**
Cost/m^2 at 75 mm layer	900	**785**

Dry mix shotcrete - comparison

	Without Elkem Microsilica®	With Elkem Microsilica®
Total cost/m^3	2,870	**3,470**
Cost + Application	6,000	6,500
Cost + rebound	8,400 at 40%	**7,475 at 15%**
Cost/m^2 at 75 mm layer	630	**560**

"Higher total cost per cube but reduced losses from rebound. Shows savings for the finished work."

Norwegian road tunnels, Norway

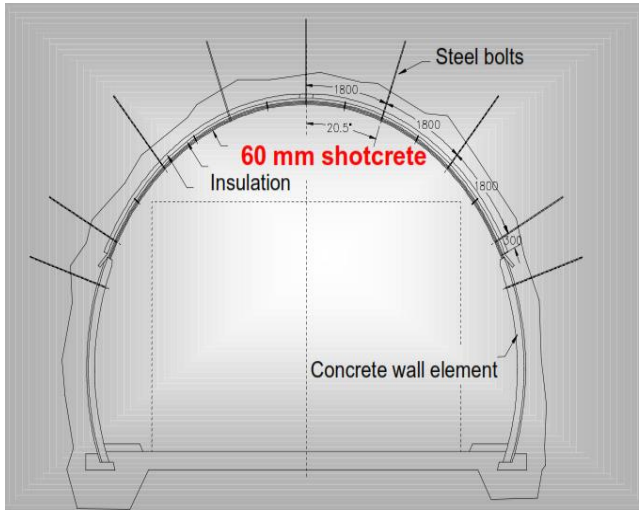
- In major road tunnels the rock support is supplemented with concrete wall segments combined with an in-situ produced arch of foam insulation, covered with shotcrete for water, frost and fire protection
- Most of the Norwegian shotcrete is steel fibre reinforced, and wet process shotcrete robots are standard. The strength level and thickness of the shotcrete lining depends on the local rock conditions. In reasonably good rock, a design strength level of 35 MPa and a thickness of 60 mm are often used

The Norwegian Public Roads Administration specifies the addition of microsilica to all concrete used for infrastructure applications.

Typical mix design, kg/m³	
Cement	425 – 500
Elkem Microsilica®	25-50
Aggregates (<8 mm)	1600-1700
Steel fibres	30-60
Chemical admixtures (P, SP and A)	As needed
Water/cement + Elkem Microsilica® ratio	0.40-0.45
Slump-value	200-250 mm

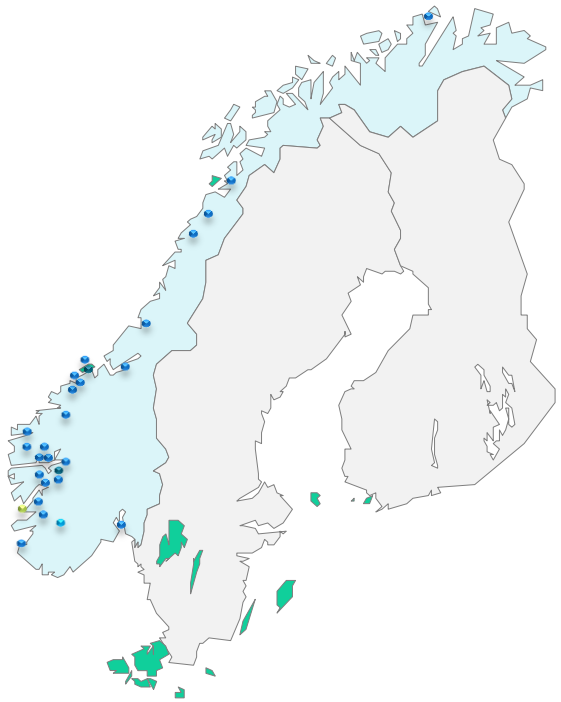
Norwegian road tunnels > 5000 metres	Length (m)	Opened
Laerdal road tunnel (World's longest)	24,510	2000
Gudvanga road tunnel	11,428	1991
Folgefonn road tunnel	11,130	2001
Korgfjell road tunnel	8,568	2005
Steigen road tunnel	8,079	1990
Bømlafjord road tunnel (subsea -262.5 m)	7,931	2000
Eiksund road tunnel (subsea -287 m)	7,765	2007
Svartisen road tunnel	7,615	1987
Hoyanger road tunnel	7,543	1982
Vallavik road tunnel	7,510	1985
Akrafjord road tunnel	7,400	2000
Oslofjord road tunnel	7,390	2000
Nordkapp road tunnel	6,875	1999
Frudal road tunnel	6,758	1995
Fodnes road tunnel	6,604	1995

Norwegian road tunnels > 5000 metres	Length (m)	Opened
Innfjord road tunnel	6,594	1991
Fjaerland road tunnel	6,397	1986
Averøy road tunnel (subsea -245 m)	5,955	2006
Byfjord road tunnel (subsea -223 m)	5,875	1992
Tosen road tunnel	5,857	1986
Haukeli road tunnel	5,682	1968
Hitra road tunnel (World's deepest, subsea -264 m)	5,645	1994
Frøya road tunnel (subsea -164 m)	5,305	2000
Heggur road tunnel	5,277	1984
Freifjord road tunnel (subsea tunnel -130 m)	5,086	1992
Flenja road tunnel	5,053	1986



Typical Norwegian tunnel design for main roads.

Norwegian road tunnels, Norway



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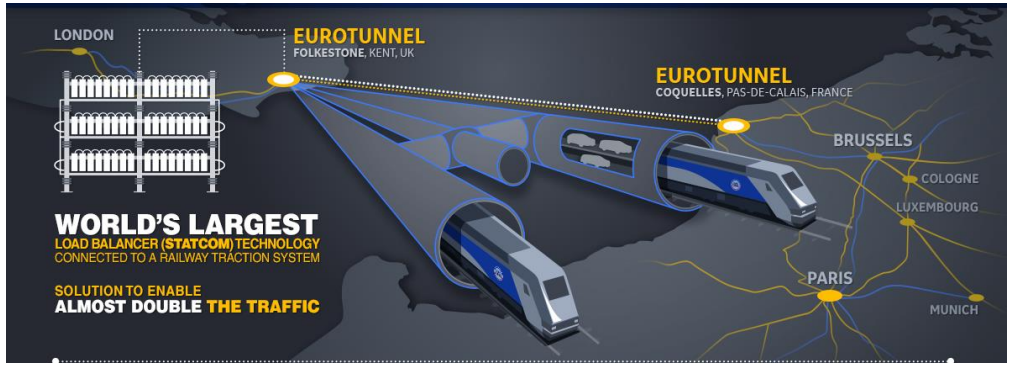
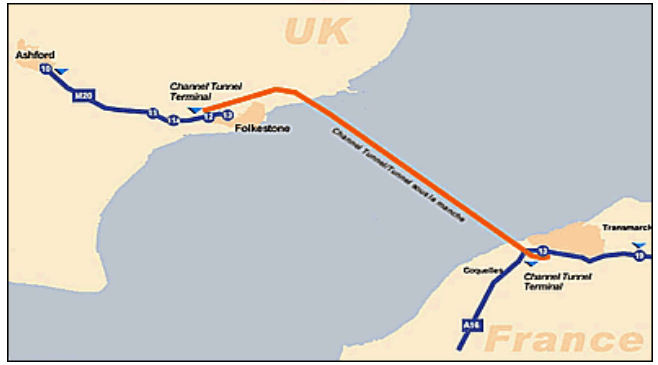
The Channel Tunnel, UK and France

- The Channel Tunnel (French: Tunnel sous la Manche), also known as the Channel, is a 50.46-kilometre (31.35 mi) underwater railway tunnel that connects England France beneath the English Channel at the Strait of Dover. It is the only fixed link between the island of Great Britain and the European mainland.
- About 30 000 m3 of microsilica dry shotcrete at 20 kg MS/m3. Mainly for caverns, cross-over points and emergency tunnels
- The longer the tunnels, the greater the threat to life in case of fire.
- Combination of MS concrete and PPE fibres provides an excellent fire resistance properties.





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