



## FireBarrier 135 Tunnel Fire Protection Systems

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### Installation of FireBarrier 135 in the Bjørvika Tunnel Oslo, Norway 2009



The Norwegian Public Roads Administration (NPRA) is currently building the Bjørvika tunnel in the centre of Oslo with the aim of reducing traffic volumes from a large area along the Oslo fjord water front. The new tunnel links two existing tunnels; Festning in the west and Ekerberg in the east and will accommodate a traffic volume of 100,000 vehicles a day in a tunnel length of 6km overall, releasing the quays and previously traffic-laden areas in Oslo harbor to public and residential/commercial development. The Bjørvika road construction plan has two stages. The first stage is the construction of the tunnel. The second stage starts after the E18 motorway has been realigned through the new tunnel, thus releasing the area to new uses. This work will continue until 2012. The benefits to the city will be cleaner air and less noise.

The seabed of the inner Oslo fjord mainly consists of clay and in some places the bedrock is as deep as 50 meters below the top of the clay layer. This means that if a sub-sea rock tunnel were the adopted solution it would, even with very steep gradients, be several kilometres long. NPRA therefore chose to build an immersed tunnel. It is the first time that

the technique has been used for a tunnel with passenger traffic in Norway. The immersed tunnel is made up of six elements. Each element is 112.5 meters long, 28–43 meters wide and 10 meters high. The tunnel roof will lie eight to eleven meters below the average water level. The immersed tunnel will consist of two tubes, with three lanes in each direction.

The tunnel will be equipped with the latest surveillance and safety systems to ensure the road network is as safe as possible. Cameras with incident detection systems will be monitored from the Traffic Control Centre in Oslo which can remotely control lane signals and barriers and so close lanes and redirect traffic when maintenance is being carried out or in the event of an accident. For maximum safety, the NPRA have chosen also to install a fire protecting layer to the tunnel concrete structure to prevent collapse in the event of a fire. The material chosen for this is "FireBarrier 135" a product manufactured by Thermal Ceramics in Europe and already in use in a number of new and upgraded European tunnels such as the Mont Blanc Tunnel where it provided fire protection for the escape refuges built after the fire that occurred in 1999. What makes the use of this material interesting is that not only is it the first case of its use in an immersed tunnel but also the extensive testing and accreditation system that was required by NPRA to qualify it for use in the Bjørvika tunnel.

Following major tunnel fires such as those in the Mont Blanc and St Gotthard tunnels, much work has been done to ensure that the road tunnel infrastructure in Europe has appropriate levels of fire safety. The EU now has minimum levels for fire safety in tunnels and the EU-sponsored "UPTUN" (Upgrading of Tunnels) project has investigated both the potential fire loads generated and the performance of fire protection linings in a series of simulated fires in tunnels. The Mont Blanc tunnel fire demonstrated the potential severity of tunnel fires possible; both in terms of temperatures produced and duration. Real fire tests in the Runehamar Tunnel carried out within the UPTUN project produced peak temperatures of over 1300 °C when a 9.9 tonne lorry-load of wooden pallets was set on fire.

For tunnel operators, the impact of such severe fires can be more than the potential loss of life. The high temperatures generated can cause collapse of the tunnel due either to explosive spalling of the concrete lining or loss of strength of the steel reinforcing bars within the lining. Materials that can insulate the concrete in a fire can prevent this by maintaining its temperature below the critical level at which spalling will occur and also ensuring the reinforcing bars are maintained at a safe temperature. Additionally these fire insulation systems have to be able to cope with the normal operating conditions in the tunnel with respect to possible water leakage, fluctuating temperatures, vehicle emissions and cleaning regimes.

Qualification of fire insulation systems for use in tunnel is achieved by fire testing a representative specimen of the material installed on a concrete slab using a furnace heated to a prescribed temperature/time curve. The most established test method is the 2 hour-long "RWS" test from the Netherlands where the furnace temperature reaches 1200 °C within 10 minutes and is 1350 °C after 60 minutes. The fire insulation generally needs to ensure the surface of the concrete is less than 380 °C and the steel reinforcement bars do not exceed 250 °C for the entire test duration. However, as critical spalling temperature varies for different concrete grades, the surface temperature limit for the concrete may be set much lower than 380 °C; down to 200 °C in some cases. The various fire curves are compared in Figure 2.

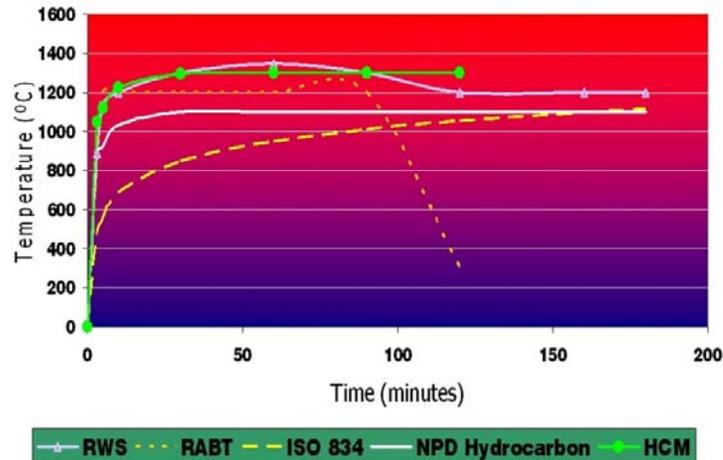


FIGURE 2 Above: Temperature Time curves used in tunnel fire tests. The RWS, RABT and HCM curves are widely used for fire testing tunnel materials and are much more severe than either the NPD hydrocarbon curve used in the offshore oil and gas industry or the ISO 834 curve used for fire testing for building

The design of tunnel linings is often based on thermal calculations to give expected load-bearing capacity. These calculations have restrictions. In prEN 1992-1-2, the Eurocode for concrete structures, the material models are only valid for heating rates between 2 and 50 °C per minute because creep effects are not explicitly considered. Hence erroneous results may be achieved if the models are used for tunnel linings designed for rapid heating such the RWS time-temperature curves where heating rates between 200 °C per minute and 240 °C per minute are encountered.

Calculations only work well as long as no spalling occurs. However, new types of denser concrete qualities introduced on the market during the last decades are much more probable to spall due to their lower permeability. These concretes have other advantages such as a better durability and higher strength, but unfortunately a lower fire resistance.

A joint fire test program of the NPRA and SP Fire Research in Sweden showed that severe spalling takes place if no precautions are taken to protect concrete exposed to high-rise fires. It also concluded that full scale fire-testing of any fire insulation solutions is necessary as some systems with existing successful fire test performance failed to stay in place when tested on concrete slabs that were pre-stressed to 5.5 MPa.

### Choosing the fire insulation system for the Bjørvika Tunnel

To qualify the fire insulation solution for the Bjørvika tunnel, the NPRA published a fire test standard through their Technology Report 2494. This requires that testing is done on large B45 grade concrete slabs 3.6m long, 1.2m wide and 600mm thick which are tensioned immediately before installation of the fire insulation to achieve a compressive stress of 11 MPa at the surface of the slab. This simulates the plastic moment due to the continuous load under rising temperature simulating as far as possible the bending moment of a hyperstatic immersed tunnel structure in a rapid rise fire. The fire curve chosen was the same as used in the RWS fire test method. The NPRA standard requires that no spalling occurs during the two hours test period.



Photograph: One of the 3.6m x 1.2m pre-stressed concrete slabs fire protected with 36mm of FireBarrier 135 being after the 2 hour fire test showing the surface to be intact with no spalling having occurred.

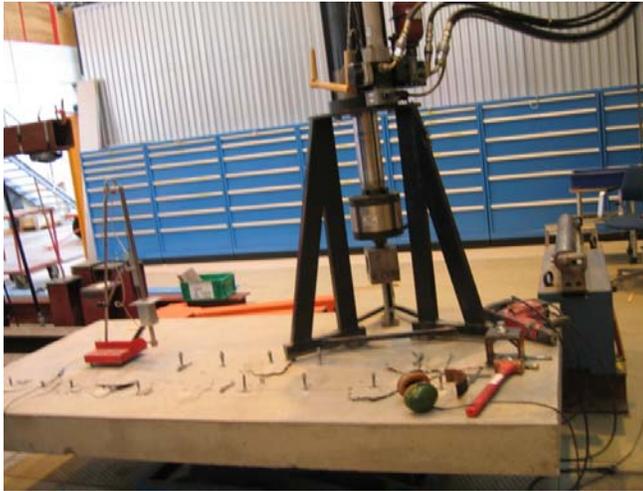
FireBarrier 135, part of the “FireMaster” fire protection product range supplied by Thermal Ceramics was selected as a potential fire insulation material for the tunnel due to a unique set of properties that provided the potential to fulfill the strict set of performance criteria set by the NPRA for the project. FireBarrier 135 already had extensive fire testing to the high-temperature fire tests used for tunnels, with 15 previous fire tests carried out at major fire test laboratories on concretes of 35 to 75 MPa compressive strength. Large slab fire testing (4.8m x 2m) had also been carried out in France for the Maurice Lemaire Tunnel where the product was used in a 7km length service tunnel as fire protection on the floor of a ventilation shaft formed by a false ceiling situated directly above the escape passage.

FireBarrier 135 had also been investigated by the TNO laboratory in Holland for various failure mode scenarios in exposure to tunnel operating environments and was found to be a chemically stable material. This was important as, in addition to the rigorous fire testing, NPRA also had set an extensive list of other tests for the fire protection material aimed at proving it could withstand the tunnel environment. These are summarized in TABLE 1.

TABLE 1: List of Testing Required by The NPRA for fire protection materials used in the Bjørvika Tunnel

<p><b>Fire Test</b> on 3.6 x 1.2 concrete slabs pre-stressed to 11 MPa. 2 hour duration test using RWS fire curve. NPRA standard 520.</p>
<p><b>Alkali resistance</b> testing NPRA specified method. Immersion in Sodium hydroxide for 2 days and then conditioned for 4 weeks at 23°C at 50% relative humidity. Comparison to non-exposed samples conditioned to the same regime.</p>
<p><b>Adhesion</b> test. Alkali exposed samples and non-alkali exposed samples tested to EN 1542:1999 to determine adhesion and effect of alkali exposure on adhesion.</p>

<b>Carbonisation</b> test in accordance with EN 13295:2004
<b>Dynamic Fatigue</b> – NPRA and SP method used for the FireBarrier 135, anchoring system tested to NS_EN 10088. 15 million cycles tear strength 1.97 KPa and compression 1.56 KPa. Simulation 100,000 vehicles per day traffic load.
<b>Frost Resistance</b> to EN 13687-1:2002 50 cycles 4 hours immersion (2 hours in saturated sodium chloride and 2 hours in water)
<b>High-Pressure cleaning.</b> Varying pressures from 50 to 150 bar for one minute duration over 1 m <sup>2</sup>



Photograph: The specially-designed equipment used by SP Sweden to carry out dynamic fatigue testing on the FireBarrier 135.

Having now established that FireBarrier 135 was a viable choice for fire protection of the tunnel, Thermal Ceramics set in motion the test program required by the NPRA.

Fire testing was carried out at SP Fire Sweden, one of the world's leading fire institutes. Material was installed during early 2008 and fire testing took place in autumn once the slabs had been conditioned in accordance with the NPRA fire test method. A thickness of 36mm of FireBarrier 135 was adequate to prevent spalling of the concrete on the pre-stressed slabs during the two hour fire test.

During the Spring to Autumn of 2008 work also took place to complete all the other tests required for the project to prove the in-service physical and chemical stability of the product.

As a result of the exhaustive test program FireBarrier 135 was chosen the fire protection system for the Bjørvika Tunnel in December 2008.

### **Installing FireBarrier 135 in the Bjørvika Tunnel**

Installation of the FireBarrier 135 lining commenced at the beginning of 2009. The standard application technique is to install a 50mm x 50mm wire mesh using anchors fixed into the concrete structure and then spray the FireBarrier 135 in one single layer into and over the

mesh. Wastage due to overspray is negligible due to the dense, "sticky" nature of the material. Installation was carried out by Innovative Fire Services Ltd (IFS), a French based specialist distributor of Thermal Ceramics providing tunnel fire protection solutions worldwide. To meet the tight project deadlines of completion by Autumn 2009, IFS used a team of 60 people to install the 35,000 m<sup>2</sup> of FireBarrier 135 required for the project. This includes all preparatory work, installation of expansion joints, mesh, fixing, lining thickness guide rails and the smoothing of the surface after spraying to produce the flat, high quality surface finish for which FireBarrier 135 is well-known. A strict quality plan was enforced as detailed in TABLE 2.

TABLE 2: Installation Quality Plan

Measurement of mesh attachment points
Tear strength of anchors
Thickness measurement
Support spacing
Density, fire loss, compressive strength of samples removed at periodic intervals throughout the installation
Adhesion tests in-situ performed once per week



Photograph: FireBarrier 135 being applied by Innovative Fire Services in the Bjørvika Tunnel. The material is supplied as a powder and then mixed with water and sprayed into place using a standard cement spraying machine. Alternate sections are sprayed. The sections are formed by metal rails which also act as the installation thickness guide. These rails are then removed before the adjacent sections are sprayed.

Of interest is the specific design of expansion joints made jointly by NPRA and IFS using a high-temperature felt manufactured by Thermal Ceramics to absorb the movement of the tunnel (350mm at the middle of the tunnel) and yet provide a fire safe solution for the water stops which have a maximum service temperature of 80 °C whilst also having a water 150 bar washing resistance at their surface.



Photograph: Expansion joint sealing system installed shown before installation of the FireBarrier 135

This latest installation adds one of the most exhaustively investigated projects carried out using FireBarrier 135 to approximately 20 tunnels currently in operation that have FireBarrier 135 fire protection installed.

