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Tunnel Ventilation Dampers: Experiences, Durability and Corrosion Resistance, Testing Against High Temperatures

This paper aims to provide an insight on the durability of tunnel ventilation dampers in road and rail tunnel application. It is mostly based on the experience as a tunnel damper manufacturer for over 40 years. The main aspect of this paper discusses the different forms of corrosion on the dampers due to the tunnel environment and other factors from installation, which affects the dampers durability, in particular those that are manufactured from stainless steel. It also discusses some of the testing that was done in order to extend the durability of the damper by different methods of improvement, e.g. using sealant or construction changes and subjecting them to salt spray tests. The findings are then reviewed and some of the changes are adopted into the design and manufacturing processes of the tunnel ventilation dampers.

Rauchabsaugklappen für Tunnel: Erfahrungen, Dauerhaftigkeit, Korrosionsbeständigkeit, Temperaturprüfungen

Dieser Beitrag gibt einen Einblick in die Dauerhaftigkeit von Belüftungsklappen für Anwendungen in Straßen- und Eisenbahntunneln. Er stützt sich zum überwiegenden Teil auf mehr als 40 Jahre Erfahrung als Hersteller von Tunnelklappen. Hauptgegenstand des Vortrags sind die verschiedenen Formen von Korrosion, die aufgrund der Tunnelumgebung und anderer einbaubedingter Faktoren an den Klappen auftreten und sich nachteilig auf deren Dauerhaftigkeit auswirken, insbesondere bei Klappen aus Edelstahl. Außerdem wird auf die Prüfungen eingegangen, mit denen getestet wird, wie durch verschiedene Verbesserungsmöglichkeiten die Dauerhaftigkeit der Klappen verlängert werden kann, z. B. Verwendung von Dichtmitteln oder konstruktive Änderungen oder Durchführung von Salzsprühnebeltests. Die Erkenntnisse werden anschließend ausgewertet und manche der Änderungen werden in den Entwurfs- und Herstellungsprozessen für Tunnelbelüftungsklappen übernommen.

1 Tunnel environment and corrosion

The usage of tunnel ventilation dampers varies according to the type of application, which can be designed for road tunnels, metro/subway systems and high speed rails. In general, the dampers act as a control device for airflow or smoke and in some instances as a fire barrier to maintain the fire compartmentalization of the wall or ceiling. The usage of these dampers would vary depending on the type of tunnel ventilation system used, i. e. longitudinal, semi-transverse or transverse systems. Whether it is for smoke extraction, shut off or modulation control to allow for portal balance or pollution control, dampers are used to provide these controls. The installation and working condition of tunnel ventilation dampers are subjected to very harsh and demanding environments.

Even in normal use, road tunnels are subjected to varying temperatures and high levels of corrosive chemicals from emissions and deicing salts, which are strewn in the tunnel or carried into the tunnel by vehicle tires.

The environment inside a road tunnel is especially onerous as it typically contains chemicals such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and hydrogen sulphide (H_2S) from exhaust emissions (Table 1).

Other contaminants found in rail or road tunnels include abraded tire particles, heavy mineral dust deposits, particles of iron from vehicle braking system, soot, and water soluble chlorides. This concoction of elements results in a very arduous environment for the tunnel ventilation dampers to operate safely.

Tunnel	Relative humidity	Temperature range	Atmosphere		
			SO_2	NO_2	H_2S
Gotthard (CH)	25–81 %	3–27 °C	81 ppm	3 ppm	27 ppm
Mont Blanc (F-I)	41–85 %	6–25 °C	95 ppm	6 ppm	25 ppm
San Bernadina (CH)	Average: 73 %	–20–17 °C	–	73 ppm	20 ppm
Seelisberg (CH)	7–72 %	14–18 °C	72 ppm	14 ppm	28 ppm

Table 1 *Example of some of the European road tunnels showing variations in temperature, humidity and toxicity levels [1]*

Figure 1 *Stainless steel damper installed on to an opening in the wall with clamp plates*

This normally requires the tunnel ventilation dampers to be manufactured from very durable material like SS316L or higher grade of stainless steel, otherwise resulting in corrosion problems, which can be devastating in the worst possible case. Another argument for high quality material would be the reducing of maintenance and the extended durability and reliability of the tunnel ventilation system.

The tunnel ventilation dampers are generally installed onto concrete walls, ceiling slabs or directly to steel ducts. Dampers can be installed in various ways depending on the request of the customer. Typically, dampers are installed with an extended rear flange or with clamp plates (Figure 1).

Dampers manufactured from stainless steel material are susceptible to a few types of corrosion:

- Pitting corrosion: The passive layer of stainless steel can be attacked by certain chemicals. The chloride ion Cl^- is the most common and is found in salt which is present in tunnel nearby coasts and also in tunnels affected by deicing salts. Pitting corrosion is avoided by making sure that stainless steel does not come into prolonged contact with harmful chemicals or by choosing a grade of steel which is more resistant to attack. The pitting corrosion resistance can be assessed using the Pitting Resistance Equivalent Number calculated from the alloy content.
- Crevice corrosion: Stainless steel requires a supply of oxygen to make sure that the passive layer can form on the surface. In very tight crevices it is not always possible for the oxygen to gain access to the stainless steel surface thereby causing it to be vulnerable to attack. Crevice corrosion is avoided by sealing crevices with a flexible sealant or by using a more corrosion resistant grade.
- Intergranular corrosion: This is now quite a rare form of corrosion. If the carbon level in the steel is too high, chromium in combination with carbon can form chromium carbide. This occurs at temperatures between 450–850 °C. This process is also called sensitization and typically occurs during welding. The chromium available to form the passive layer is effectively reduced and corrosion can occur. It is avoided by choosing a low carbon grade, the so-called 'L' grades, or by using steel with titanium or niobium which preferentially combines with carbon.
- Galvanic corrosion: If two dissimilar metals are in contact with each other and with an electrolyte, e.g. water or other solution, it is possible for a galvanic cell to be set up. This is rather like a battery and can accelerate corrosion of the less noble metal. It can be avoided by separating the metals with a non-metallic insulator [2].

Another concern during manufacturing is the corrosion arising due to foreign material/iron particle cross contamination on stainless steel. The manufacturing processes for dampers manufactured from stainless steel and galvanized steel must be completely separated to avoid this form of corrosion. Normally, tools used to manufacture products from other types of steel should not be used for manufacturing stainless steel products. These steps must be documented in the quality system. Figure 2 shows corrosion on dampers due to sharing the same grinding tool between stainless and non stainless steel products.

The manufacturer Trox has created a white factory area, which is used only for stainless steel product manufacturing. This ensures that no cross contamination can occur during the handling, machining, welding, cleaning and packaging processes.

Another factor, which results in corrosion after installation of the dampers, is groundwater seepage. Groundwater contains minerals and salts which are highly corrosive to metal and accelerate corrosion. Occasionally very poor installation conditions can also lead to accelerated corrosion of the damper. Figure 3 shows an installation in India, which was done very poorly and the damper is left exposed to foreign elements, resulting in bad operability of the damper and also the onset of corrosion. The damper, once installed, must be kept clean and free from debris, shotcrete, paint and any other type of contaminants that can lead to corrosion.

Figure 2 *Cross contamination on stitch welds leading to corrosion*

Figure 3 Very poor installation and lack of maintenance on the dampers

Figure 5 Results obtained on a specimen, which was treated. Almost no corrosion on the material and on the bolt is observed

2 Salt spray testing

In a particular road tunnel project in Europe, crevice or gap corrosion was observed on the dampers which are mounted on the roadside of the tunnel. The tunnel is approx. 3.1 km long and is located close to the coast and crosses under a river. It is important to also state that during cold months road salts are used for gritting the road also inside the tunnel. The dampers were completely manufactured from stainless steel grade 316Ti or 1.4571. Pitting in the stainless steel material resulting from the chlorides and ferritic particles is shown in Figure 4.

These corrosion signs were observed approx. 1.5 years into the operation of the tunnel. The dampers were cleaned once every three months, periodically as part of the maintenance plan put in place for equipments directly exposed to the roadway.

The tunnel operator asked to investigate the cause and to propose a solution which would help to minimize the corrosion while extending the durability of the damper. As part of the dampers had been supplied and installed, a solution had to be found that could be applied to the existing dampers, i.e. without construction changes to the damper.

After discussing alternatives with numerous suppliers as well as with steel suppliers, a couple of solutions were narrowed down. The preferred solution was to use a corrosion protector called Dinitrol. Dinitrol does not only protect the base element from corrosion but also preserves it. It is quite easily applied to the dampers by spraying it on, and letting it dry out. To test the effectiveness of Dinitrol, salt spray tests were conducted to understand how this solution could improve the durability of the dampers.

Figure 4 Close-up of the corrosion caused by gap corrosion

A salt spray test was carried out per the EN ISO 9227:2006 norms. The salt spray method was used as it is suitable for checking that the comparative quality of a metallic material, with or without corrosion protection, is maintained. They are not intended to be used for comparative testing as a means of ranking different materials relative to each other with respect to corrosion resistance [3].

Numerous samples were tested to understand how long it takes for corrosion to start and what effects Dinitrol coating systems will offer against corrosion (Figure 5).

Due to the positive results obtained from the salt spray test a suitable solution could be proposed to the tunnel operator for the next batches. The Dinitrol coating must be sprayed on to the damper material including the nuts, bolts and washers which are used for assembly and let to be naturally dried (Figure 6).

3 High temp – 400 °C and fire integrity / UL555s

Tunnel ventilation dampers are required to extract smoke in case of fire in the tunnel. Generally, the type of tunnel and the design fire size determines the overall ventilation system and its capacity, as this is required to prevent back layering and a good tenable condition upstream of the fire.

The requirement of the ventilation system is detailed in the local/regional standards for tunnels. Normally on tunnel projects, the National Fire Protection Association (NFPA) or the Eurocode directive are referred to and each of this standard/directive has different approaches to safety and in particular ventilation system during a fire or emergency.

The EU Directive 2004/54/EC and the RABT (*Richtlinie für die Ausstattung und den Betrieb von Straßentunneln*) stipulates that the tunnel ventilation dampers must be able to operate at 400 °C for up to a period of 2 h.

The NFPA 130 on the other hand requires an emergency ventilation system (for smoke extraction) to be rated at 150 °C for

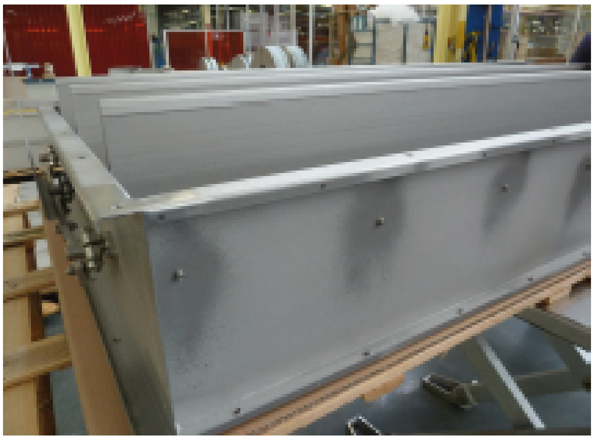

Figure 6 Damper casing where the bolts are attached is sprayed with Dinitrol and left to air dry

a minimum of 1 h, but not less than the required safe egress time. Therefore, the smoke extract dampers and fans must be able to operate at 150 °C for 1 h minimum as per the Underwriters Laboratories (UL) standard for damper and fan testing. The UL555s testing for dampers used for emergency ventilation must be subjected to a temperature degradation test which is done at 250 °F for a minimum of 1 h, in which after a 30 min exposure and while at an elevated temperature the dampers are operated by cycling them three times. At the end of the test, operation of the damper is checked again to ensure successful completion of the test.

However, there is no particular test standard of the European Union (EU) available for testing tunnel ventilation dampers at high temperature.

The testing of dampers at high temperature per the requirements of UL555s requires the dampers to be tested completely as a system, i.e. with actuator, thermal enclosure (if necessary), external limit switches, cable glands etc. This is due to the increase in damper torque from thermal expansion of the material and due to the degradation of the performance provided by the actuator at high temperature. Damper and actuator sizing for a project must be based on torque value used during the high temperature test; otherwise there is a very high risk of the damper not being operable at higher temperature i.e. during a fire.

Figure 7 Damper assembly after the 250 °C for 2 hours fire test. The furnace is at the background on the left

Figure 7 provides further understanding of the high temperature test conducted on the tunnel ventilation dampers.

The tunnel ventilation dampers are also sometimes required to retain the fire compartmentalization of the concrete opening. To meet the criterion the tunnel ventilation dampers are fire integrity tested to the BS 476 Part 20 requirement for a period of 4 h. This test is performed to verify that there are no collapse of the damper, no sustained flaming on the unexposed surface and no loss of impermeability.

On 17th March 2011, the new smoke control damper requirement was approved for use in the EU. This standard is "*EN 12101-8 Smoke and heat control systems – Part 8: Smoke control dampers*" which defines the use and functions of a smoke control damper. The standard requires the testing of these dampers according to the EN 1366-10 and also the EN 1366-2, amongst others. Whilst this standard is not clearly defined only for building smoke extraction applications it is believed that it could be adopted for tunnel ventilation application as well.

To qualify a damper to the EN 12101-8 is very challenging and the flow chart shows the process flow of the damper test to meet the requirements of the standard (Figure 8). The requirements of this test are very stringent as before any fire test is conducted, each damper must be tested for closed blade leakage for endurance with weights on every blade (20.000 cycles of open and closing the damper), followed by another closed blade leakage test.

The requirements of the EN 12101-8 for testing a smoke control damper is very demanding. The excerpt from the standard gives an overview of the different criteria, which are tested and classified by the standard [4]:

a) Integrity: This shall be tested in accordance with test method in 5.2 and the integrity classification (E) declared;
b) Insulation: This shall be tested in accordance with the test method in 5.2 and the insulation classification (I);
c) Leakage: This shall be tested in accordance with test method in 5.2 and the leakage classifications (S) declared;
d) Mechanical stability: This shall be tested in accordance with test method in 5.2 and forms part of the integrity classification (E) declared;
e) Maintenance of cross-section: This shall be tested in accordance with test method in 5.2 and forms part of the integrity classification (E) declared;
f) High operational temperature: This shall be tested in accordance with test method in 5.2 and the classification (HOT400/30) declared.

There are few major requirements, which distinguish the European Standard (EN) requirement to the British Standards or the UL requirement in terms of fire testing and rating. The EN standard requires smoke leakage to be measured across the damper during the fire test while being subjected to an under pressure of 500 Pa. If the smoke leakage exceeds a predetermined value of 200 $m^3/h/m^2$ the results of the test are considered to be negative.

The other important criteria is the insulation properties of the damper. Thermocouples are fitted to the connecting ducts and to predetermined positions on the damper both on the exposed and unexposed side of the fire. If the temperature rise on the unexposed side exceeds 180 K on any thermocouple or exceeds 140 K as an average value, then the damper is deemed

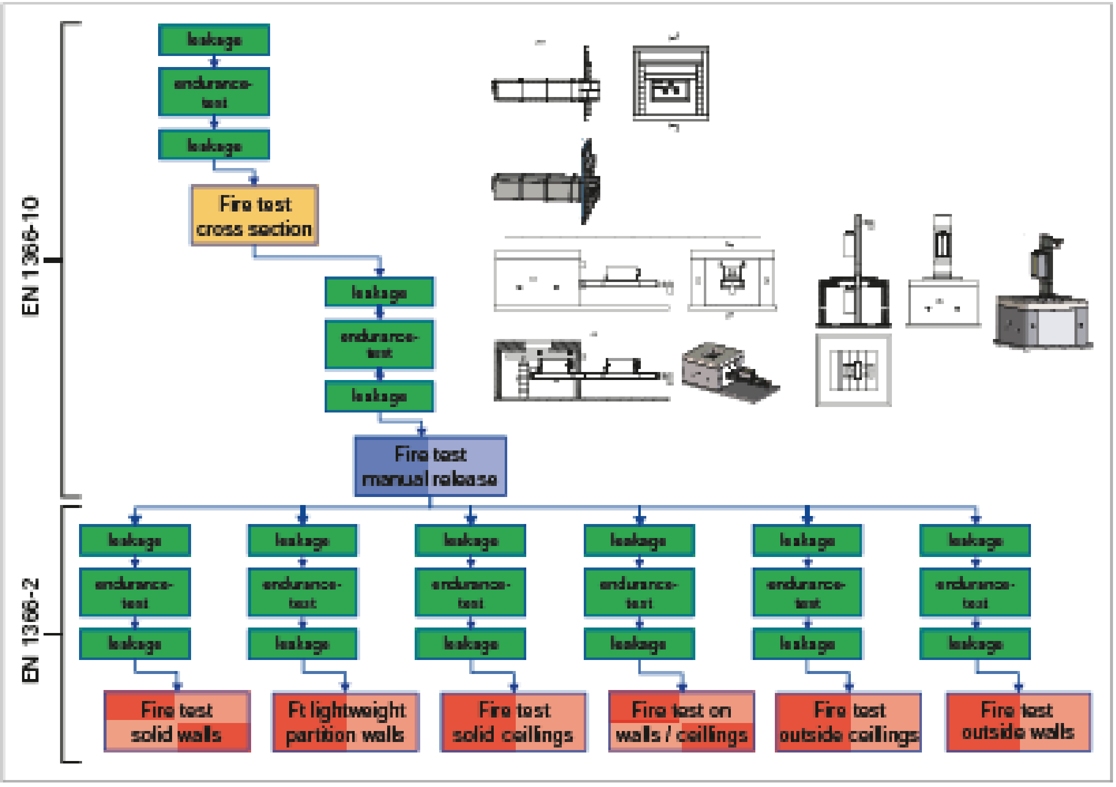

Figure 8 Testing processes in accordance to the requirement of the EN 12101-8 standard

to have failed on insulation criteria. Ratings for insulation and leakage are normally given in periods of 60, 90 or 120 min.

4 Conclusion

Whilst the damper test in accordance to the EN 12101-8 seems to be very demanding, this was cause to find a material which is able to conform to this strict test requirements. Successful testing has led to the development of a product, which is manufactured entirely from calcium silicate. This material has excellent thermal resistance properties and is relatively easy to work on, from a manufacturing perspective. The boards do not need to be welded, and can be fixed by screws. As the thermal expansion rate of calcium silicate is far more superior than stainless steel, the expansion of material is far lower, and therefore there is almost no increase in damper torque due to high temperature. This results in smaller actuators to be used, which saves space and power consumption of the motors.

There are specifications for tunnel ventilation dampers for some of the new road tunnel projects in Europe which are stating compliance to EN 12101-8. In many tunnels, the tunnel linings are now made from calcium silicate as well in order to protect the segmental lining or shotcrete layer. This allows for an easy interface between smoke control dampers and tunnel lining. As there is no metallic compound on the damper frame and blades, they will also be free from any corrosion related issues.

References

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