
Characterisation of the Behaviour of Containment Equipments under Mechanical and Thermal Stresses in STARMANIA Facility

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ABSTRACT: Most of the containment equipments used in the French nuclear facilities could be considered as construction products, like fire dampers or fire doors. So, to assess their behaviour under thermal stresses, these equipments are concerned by fire resistance regulations as French regulations on construction products or European standards. However, the realisation of experimental tests on fire and numerical simulations, especially at the IRSN, have shown that the development of a fire in a contained facility is not only characterised by an increasing temperature but also by pressure stresses strong enough to become mechanical stresses. Because of a lack of experimental facilities, no data was available on the behaviour of containment equipments under pressure stresses representative of facility accidental working conditions. According to this observation, a new experimental facility, called STARMANIA, was built at the nuclear research centre of Saclay. The main objective of the STARMANIA facility is to determine the mechanical strength which is the differential pressure value corresponding to the equipment failure but also to determine the aeraulic resistance evolution especially on the unknown working range of the equipment.

Descriptions of the STARMANIA experimental facility and the presentation of typical results obtained during fire dampers and fire doors tests are given.

1 INTRODUCTION

Among the accidental situations, the fire, because of the level of risk, is the phenomenon for which the regulation to assess the strength level of the construction products is the best defined one. Most of the containment equipments used in the French nuclear facilities could be considered as construction products, like fire dampers or fire doors and they are concerned by the fire resistance regulations as French regulations on construction products or European standards. All these regulations are based on the same plan. Fire resistance tests have been developed to simulate the thermal stresses of a fire, using a specific furnace with a standard curve of temperature increase. Using data from fire resistance tests, the regulation specifies the procedure for fire classification of construction products.

However, the realisation of experimental tests on fire and numerical simulations, particularly at the IRSN, has shown that the development of a fire in a contained facility is characterised by pressure stresses. These stresses are due to a competition between the quantity of energy released by the fire and the ability of the fire room and the ventilation network to evacuate this energy. Pressure stresses characterise fire unsteady states especially during the fire inflammation (over pressure in the fire room) or extinguishment (under pressure in the fire room). The pressure range of the fire room depends on the fire characteristics and on the size and the thermal characteristics of the fire room but also on the aerodynamic and mechanical behaviour of the containment equipments used. So, the integrity of the containment could be challenged by the behaviour of these equipments and it is necessary to know the resistance of these equipments under pressure stresses (mechanical strength and aerodynamic resistance). Nevertheless, until now, no or few data were available on the behaviour of containment equipments under pressure stresses representative of facility accidental working conditions. Actually, such experimental investigations have been essentially performed on air cleaning systems using HEPA filters. Los Alamos National Laboratory investigated air cleaning system response to the stress of accident conditions, especially tornado effects [1]. Later, Forschungszentrum Karlsruhe designed the test facility BORA for the experimental study of air cleaning components and phenomena under simulated nuclear facility accident conditions [2]. These facilities have essentially permitted to assess the mechanical strength of HEPA filters. In our understanding, the mechanical strength of others containment equipments (like fire dampers or fire doors) was not investigated in this kind of experimental facilities.

Moreover the mechanical strength which characterises the equipment failure, it is also necessary to determine the aerodynamic behaviour of the equipment, which characterises the level of tightness. The aerodynamic behaviour, conditioning the integrity of the containment, is determined by the measure of the airflow across the equipment (leak airflow) under specific conditions of differential pressure. Some of the containment equipments have tests procedures to measure the leak flow. For instance, the European standard EN 1366-2 [3] sets a value of 300 Pa for the differential pressure applied to determine the leak airflow of fire dampers. Moreover, European standard is also available to determine the tightness of fire doors under 10, 25 or 50 Pa (EN 1634-3 [4]). Nevertheless, the level of the differential pressure to investigate the tightness of the containment equipment is not representative of accident conditions.

Because of this lack of data, the IRSN decided to start on 1999 a research program to characterise the aerodynamic and mechanical behaviour of containment equipments under pressure stresses representative of accident conditions, especially fires. First of all, the experimental facility STARMANIA was designed and put into operation on January 2002 at the nuclear research centre of Saclay.

2 OBJECTIVES

The main objective of this research program is to characterise the aerodynamic and mechanical behaviour of different containment equipments under pressure stresses representative of fires. First of all, this research program is defined to determine the mechanical strength which is the differential pressure value corresponding to the equipment failure (opening, significant cracks or breakdown), but also to determine the aerodynamic resistance evolution especially on the unknown working range of the equipment. The knowledge of the aerodynamic resistance evolution of the containment equipment during accident conditions is necessary to properly assess the integrity of the facility containment. Actually, the aerodynamic resistance characterises the level of tightness of the containment equipment.

Moreover, the aeraulic resistance is a basic data for a ventilation code as SIMEVENT [5] to predict the consequences of fires on the facility ventilation network. Until now, such ventilation code is based on constant aeraulic resistance hypothesis, except for the ventilation network components with action (fire damper closing for instance). However, the pressure stresses observed during contained fire tests or simulations may be strong enough to become mechanical stresses for the containment equipments. In such a case, the level of tightness of the containment equipments could be modified due to a modification of their structure. So, the aim of the tests on STARMANIA facility is also to determine the differential pressure values characteristic of the change of aeraulic resistance. These transition values define the influence of the pressure stresses on the equipment structure and define the evolution of the tightness level of the equipment. The aeraulic resistance determination uses the flow law ($\Delta P=f(F_{leak})$) and needs the measurement of the leak airflow of the equipment (F_{leak}) during the pressure stresses.

The experimental facility STARMANIA was put into operation on January 2002. Since this date, four experimental studies have been led, two on fire dampers and two on fire doors. In the following text, descriptions of the STARMANIA facility and the presentation of typical results obtained during fire dampers and fire doors tests are given.

3 STARMANIA FACILITY

STARMANIA facility is an aeraulic test bench specially designed to simulate on equipments the development of an accidental or disturbed situation. The main purpose is to realise analytical tests using all the performances of the experiment in order to determine the equipment behaviour on all the range of use (until the failure). The facility was designed to be able to characterise any kind of containment equipment.

Three parameters have been chosen to simulate the accidental or disturbed conditions: the pressure, the temperature and the relative humidity. The maximal range of these parameters has been evaluated in order to be representative of the situation to be simulated. So, the STARMANIA facility is able to generate:

- a differential pressure value on the equipment between - 500 and 900 hPa;
- a maximal airflow of 20 000 m³.h⁻¹;
- a maximal air temperature of 400 °C;
- a relative humidity up to saturation at 50 °C, 50 hPa and 3 400 m³.h⁻¹.

To be able to generate all these different stresses, the experimental facility is an aeraulic test bench with modular parts. The Figure 1 gives a map of the facility.

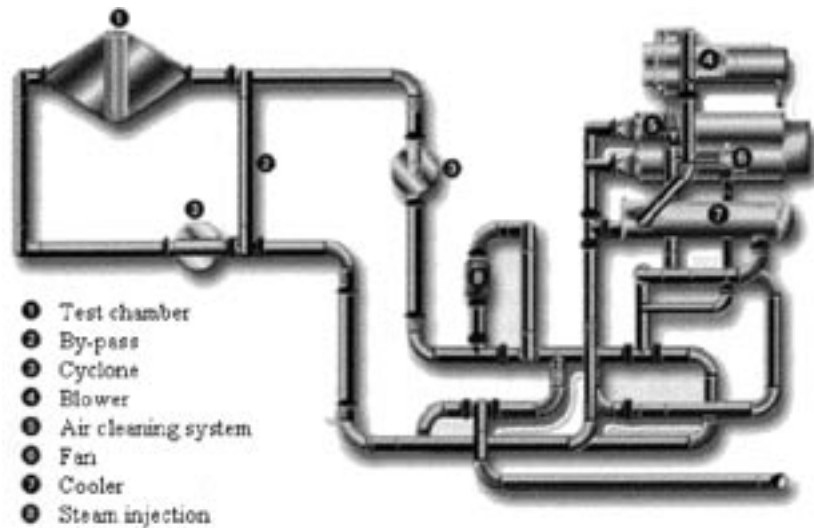


Figure 1: Map of the STARMANIA facility

Two different areas could be distinguished on the experiment: a test area (on the left on Figure 1) with the test chamber and an area to condition the airflow (on the right on Figure 1). A by-pass is used to separate the two different areas and to regulate the stresses applied on the test equipment.

The test area was designed to respect the constraints for aerologic measurements. So, straight ducts allow established airflow conditions and the well mixing of several tracers used for the leak flow measurement. The airflow measurement is realised by gas tracer flowmeter and also by ultrasound flowmeter.

The test area is principally composed by a cyclone and by a test chamber specific of the equipment. The cyclone was designed to collect equipment fragments, which could be broken during a test. The cyclone position in the facility depends on the functioning mode. A differential pressure measurement between the upstream and the downstream of the test chamber allows to control the pressure stresses applied on the equipment. Two valves on the by-pass and on the test duct regulate the airflow on the equipment. According to the working mode and the characteristics of the test equipment, the differential pressure increase on the equipment could reach $15 \text{ hPa}\cdot\text{s}^{-1}$.

The airflow preparation area is composed of all the components necessary to the facility functioning. Two different working modes are available: the first one allows the study of disturbed conditions and the second one allows the study of accidental conditions.

The disturbed mode is operating only in opened configuration using outside air (Figure 2). A standard high-pressure fan generates pressure and airflow conditions representative of nominal conditions. At the fan inlet, an air cleaning system with heater allows the filtration and the heating of the air (maximal air temperature: 50 °C). At the fan outlet, a steam injector allows the relative humidity increase of the airflow. A steam boiler produces the vapour necessary to the steam injector and to the heater. The main purpose of this working mode is to investigate the consequences of relative humidity on HEPA filters (filtration efficiency, clogging and mechanical strength) but also the behaviour of equipment with hygroscopic components as fire dampers.

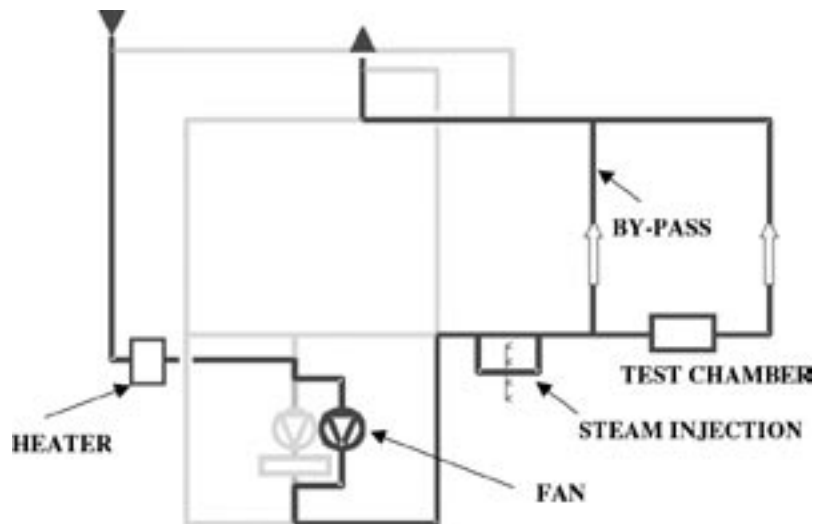


Figure 2: Functioning principle to simulate disturbed conditions

The accidental mode allows to simulate the development of accident conditions in contained facility, like a fire. In order to be representative of the contained fire development, the experimental facility is able to generate over pressure stresses of a fire inflammation and under pressure stresses of a fire extinguishment. These two pressure transitions of a contained fire are generated by two different test bench configurations (Figure 3 and Figure 4). However, the functioning principle is the same for this kind of pressure stresses. A two-stage blower is necessary to reach the stresses range representative of accident conditions (differential pressure between - 500 and 900 hPa ; maximal airflow 20 000 m³.h⁻¹). Moreover, increases of the air temperature are only due to compression in the two-stage blower, which is sufficient to reach the maximum air temperature level of the test bench (400 °C). With a concept of re-circulating flow, it is then possible to eliminate the air heater. A cooler, which is an air-water exchanger, is used to control the outlet air temperature. The test area is the same as the previous working mode, with a regulated by-pass and a specific test chamber. To generate an over pressure stress on the test equipment, the airflow circulating is set to put on the test equipment at the blower outlet. To generate an under pressure stress on the test equipment, the airflow circulating is reversed to put on the test equipment at the blower inlet.

Figure 3: Functioning principle to simulate over pressure accidental conditions

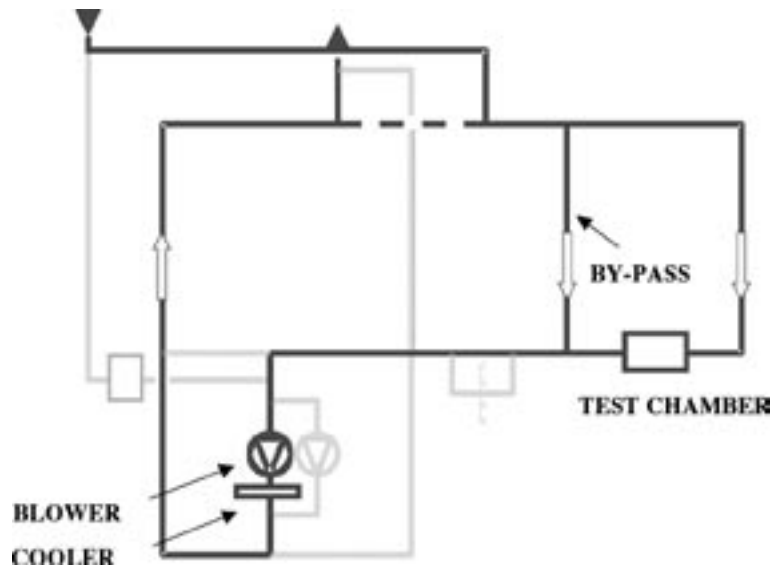
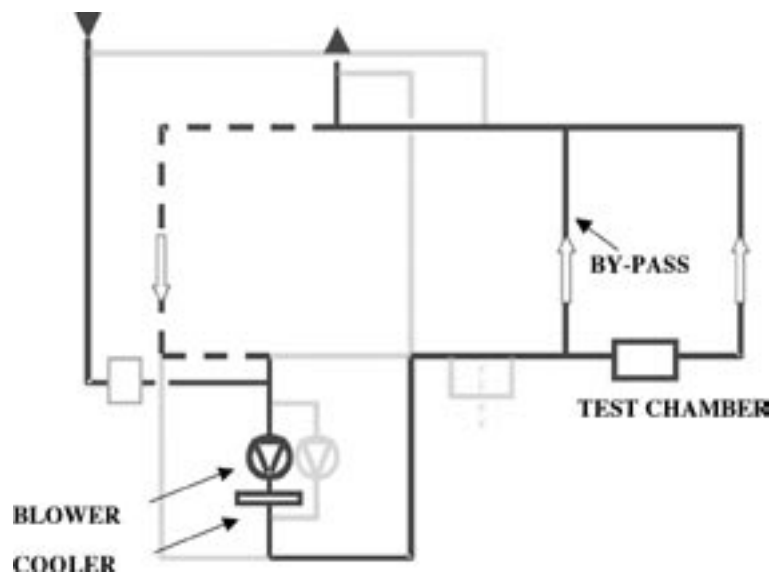


Figure 4: Functioning principle to simulate under pressure accidental conditions

The main purpose of the accidental mode of STARMANIA facility is to investigate the behaviour on containment equipments especially on the unknown working range. Because of their important contribution to the integrity of the containment, the two first experimental studies, realised on 2002 and 2003, have concerned the behaviour of fire dampers and fire doors under over or under pressure stresses representative of fire conditions.



4 TYPICAL RESULTS OBTAINED DURING STARMANIA TESTS

Four experimental studies have been led: two on fire dampers and two on fire doors. The results obtained during these tests have permitted to determine the values of differential pressure characteristic of modifications of the aeraulic behaviour of the test equipment. These transition values allow to assess the influence of the pressure stresses on the equipment structure and to define the level of tightness of the equipment on all the range of use (determination of the flow law $\Delta P=f(F_{leak})$). Moreover, the differential pressure value responsible for the equipment failure has been determined.

Moreover, the investigations on the aeraulic behaviour of fire doors and fire dampers have also permitted to define the main influential parameters necessary to consider.

First of all, some equipments have a different aeraulic behaviour according to the airflow direction. This difference, illustrated on Figure 5 and Figure 6, is due to the conception of the equipments, which have an opening side. Consequently, according to the airflow direction, the pressure stress can open the equipment (nominal airflow) or can close the equipment (reverse airflow).

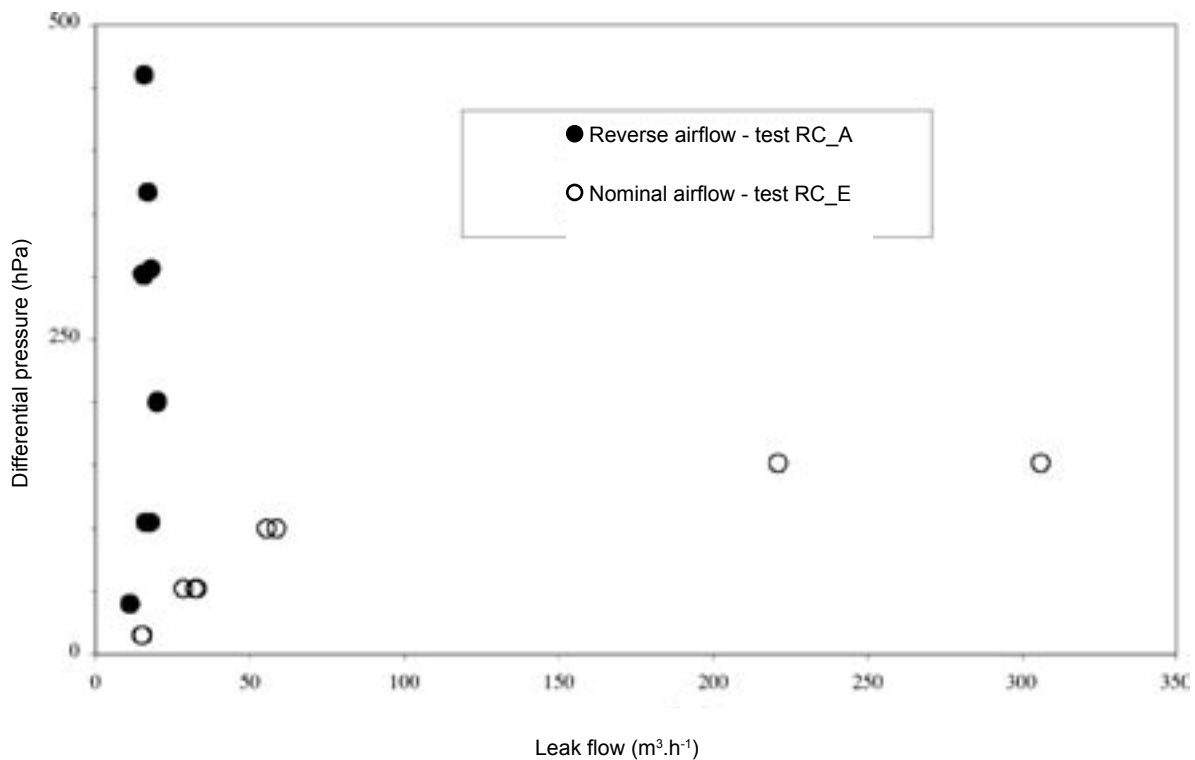


Figure 5: Fire damper differential pressure versus leak flow (RC damper)

If, during fire dampers tests, the aerolic behaviour difference is significant for relative high level of pressure stresses (up to 50 hPa), it's not the same for fire doors. Actually, according to the airflow direction, the aerolic behaviour of fire doors is different as soon as the level of pressure stress is up to 2 hPa. So, the pressure stress influence is significant as soon as the differential pressure set is up to 2 hPa. This influence leads to a decrease of the fire door tightness for the nominal airflow tests (airflow direction which could open the door).

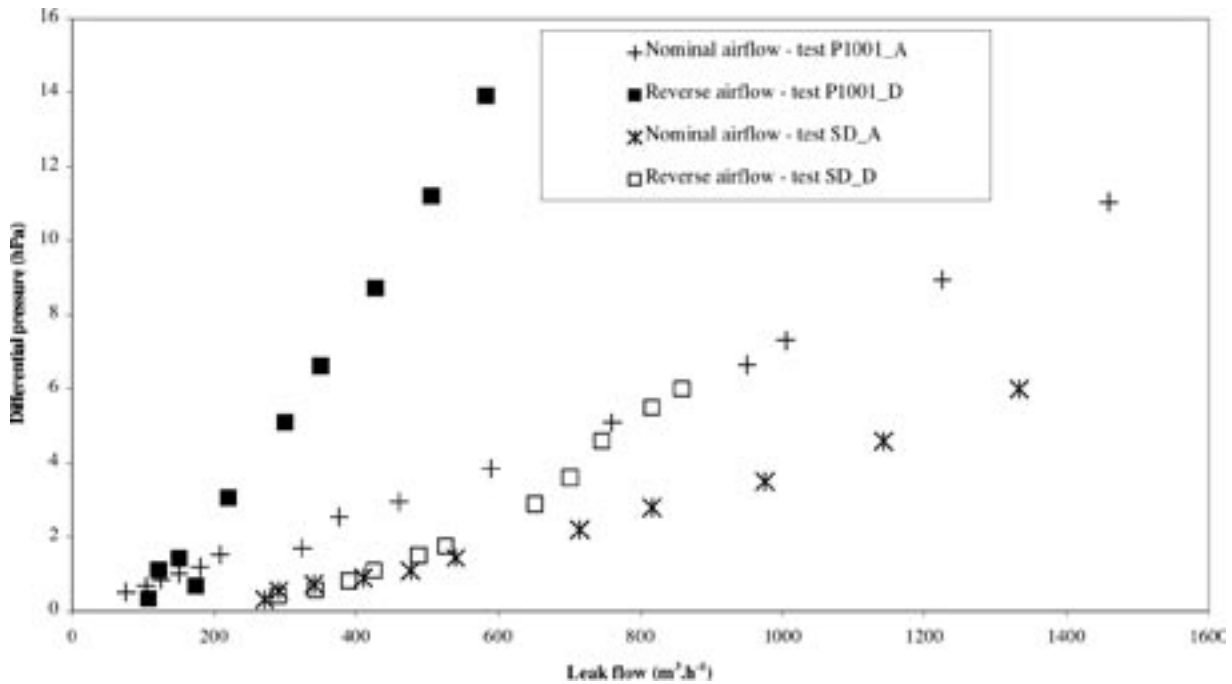


Figure 6: Fire doors differential pressure versus leak flow (P1001 and SD doors)

The Figure 7 illustrates the differential pressure influence on the tested fire doors. Actually, for a nominal airflow, the aerolic resistance of the doors decreases when the differential pressure is up to 2 hPa, which leads to a divergence from the initial quadratic flow law:

$$\Delta P = r \rho F_{leak}^2$$

with:

- ΔP differential pressure set on the fire door (Pa),
- ρ air density (kg.m⁻³),
- F_{leak} leak airflow (m³.s⁻¹),
- r aerolic resistance of the fire door (m⁻⁴).

On the other hand, for reverse airflow tests, the differential pressure set does not modify the tightness level of the fire doors; the aerolic resistance of each door could be considered as constant on all the pressure range investigated (less than 6 or 14 hPa). It is interesting to note that under 6 hPa of differential pressure, the leak flow during a nominal airflow test is roughly twice higher than during a reversed airflow test.

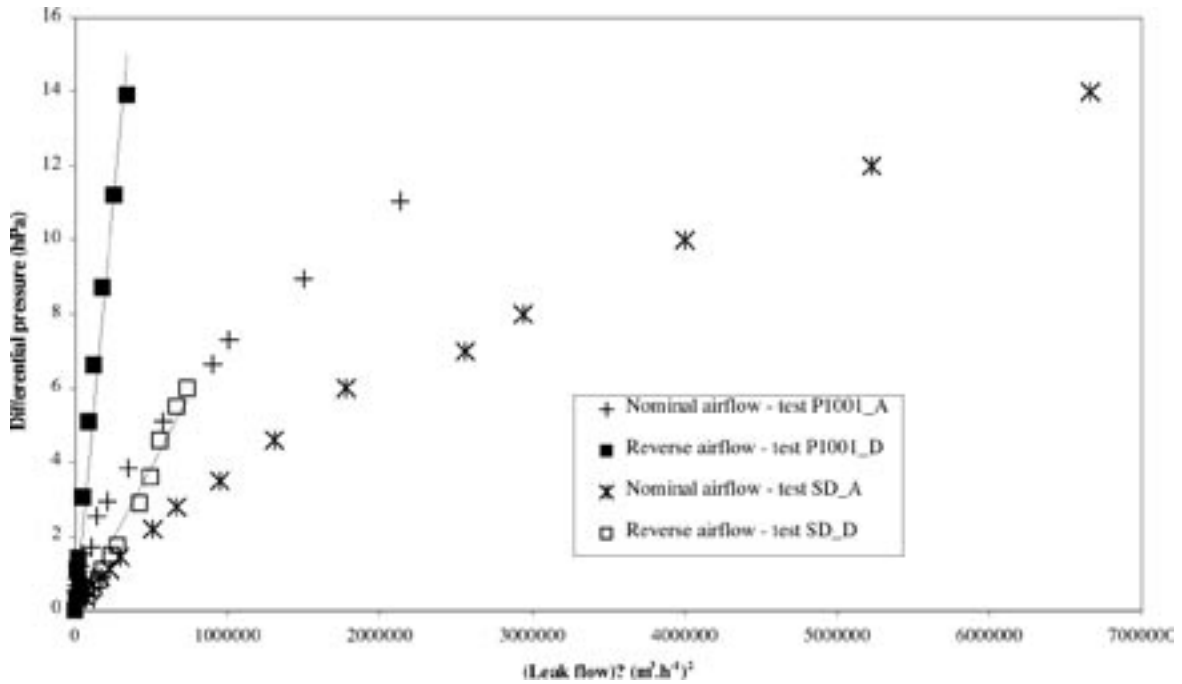


Figure 7: Aerodynamic resistance evolution of the fire doors P1001 and SD

The temperature increase can also influence the aerodynamic behaviour by increasing or decreasing the tightness. First of all, intumescent joints increase the tightness level during an increasing air temperature (see Figure 8). On the other hand, an increasing air temperature also leads to a tightness decrease because of thermal dilatation of the equipment components (see Figure 9).

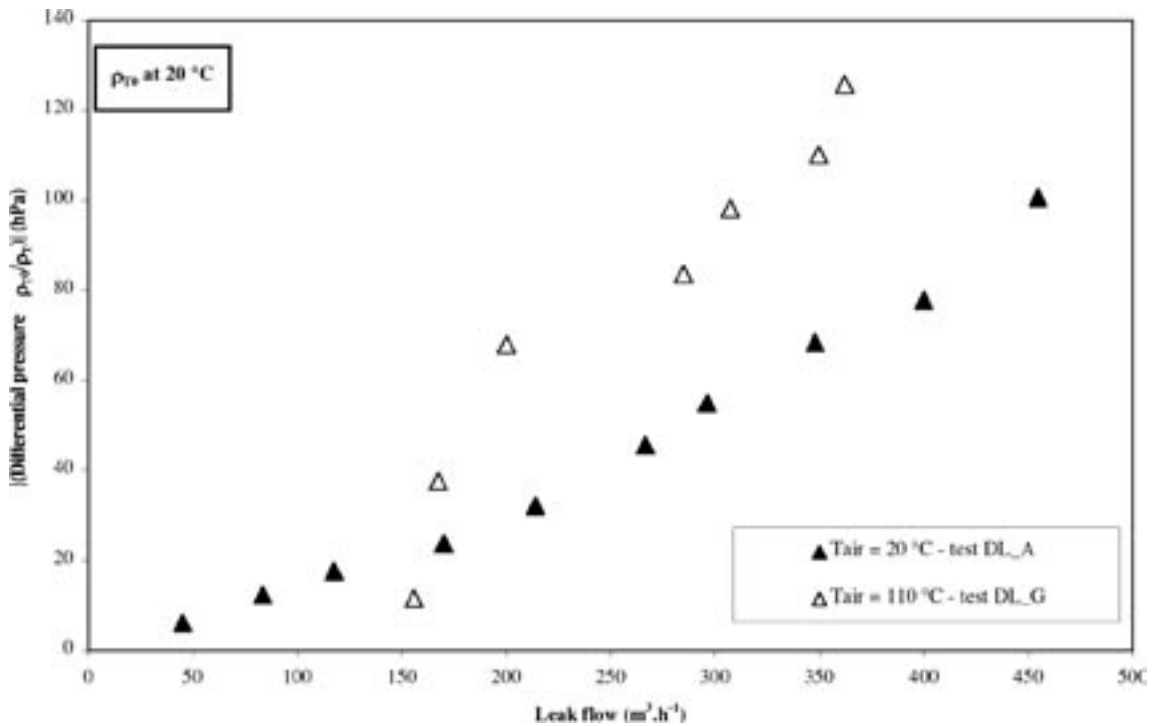


Figure 8: Air temperature influence on the aerodynamic behaviour of a fire damper with intumescent joint

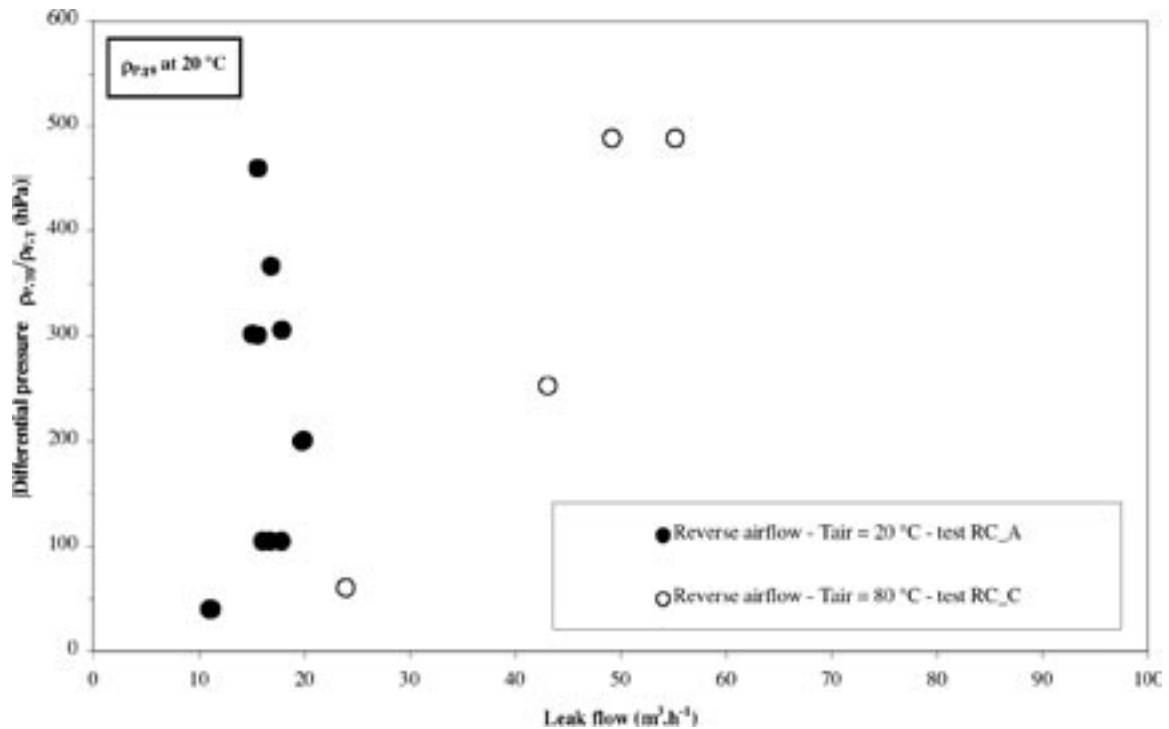


Figure 9: Air temperature influence on the aerolic behaviour of a fire damper without intumescent joint

The relative pressure value of the test bench is also an influential factor, especially when the pressure stresses could deform the equipment external casing. The Figure 10 illustrates this influence on a fire damper, which has different level of internal-external tightness according to the relative pressure value of the test bench. Moreover, this aerolic behaviour difference is also significant on the downstream-upstream tightness.

Others influential parameters could be considered as the surface of the equipment, the operating system of the equipment or the chemical composition of the airflow (steam presence for instance).

The main results have permitted to determine, on all the investigated pressure range, the aerolic resistance of the tested equipments. This aerolic resistance is an intrinsic data of the equipment and characterises the tightness level. Nevertheless, by calculating the aerolic resistance, generic behaviours of the containment equipments were found and separated in two different areas.

The first area is characterised by a maintaining or an increase of tightness level of the equipment under the pressure stress. In this area, the pressure stress is not strong enough to modify the equipment position (maintaining of the tightness level) or the stress gives an additional support of the mobile system (leaf for instance) on the static part of the equipment (frame for instance) and increases the tightness level of the equipment (reversed airflow tests).

The second area is characterised, on the other hand, by a tightness decrease of the test equipment. In this area, the pressure stress is strong enough to become a mechanical stress and to modify the equipment structure or to partly open the equipment.

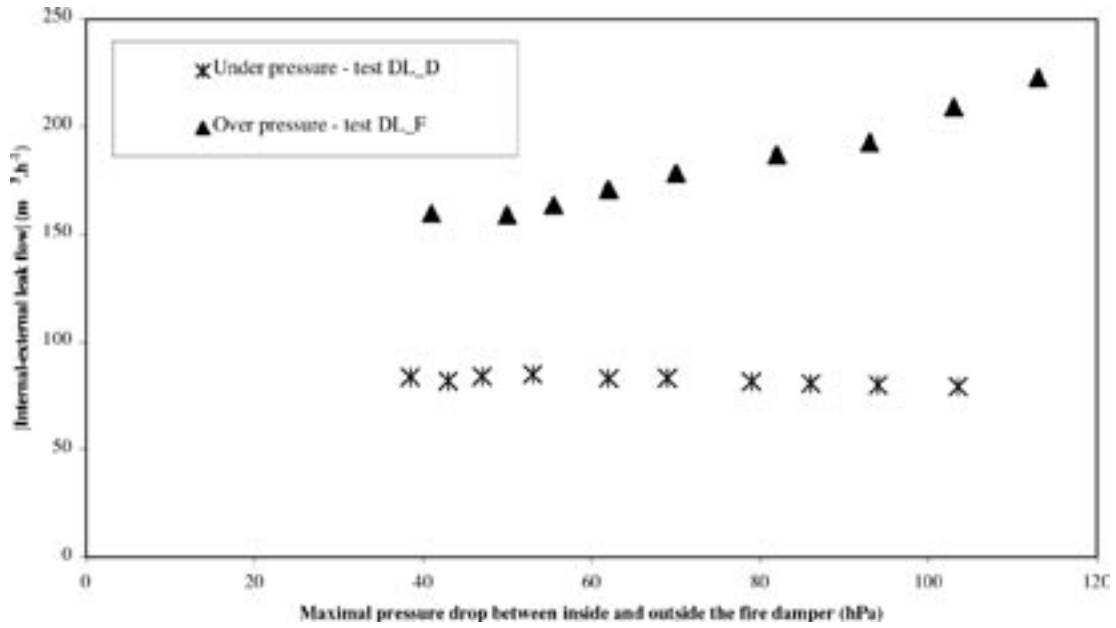


Figure 10: Relative pressure influence on the internal-external leak flow of a fire damper

At the end of the second area, the equipment failure (breakdown or opening) occurs under a pressure value characterising the mechanical strength. The Figure 11 and Figure 12 illustrate, for each airflow direction, the aeraulic resistance evolution of fire doors under pressure stresses.

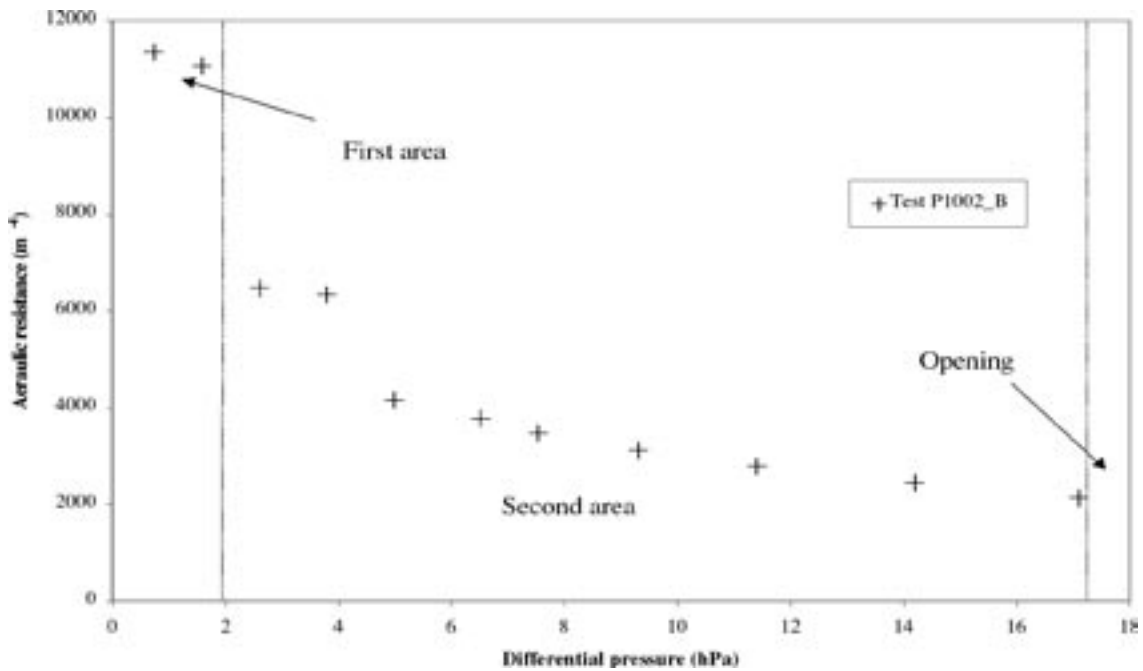


Figure 11: Aeraulic resistance evolution of a fire door under pressure stress (Nominal airflow test)

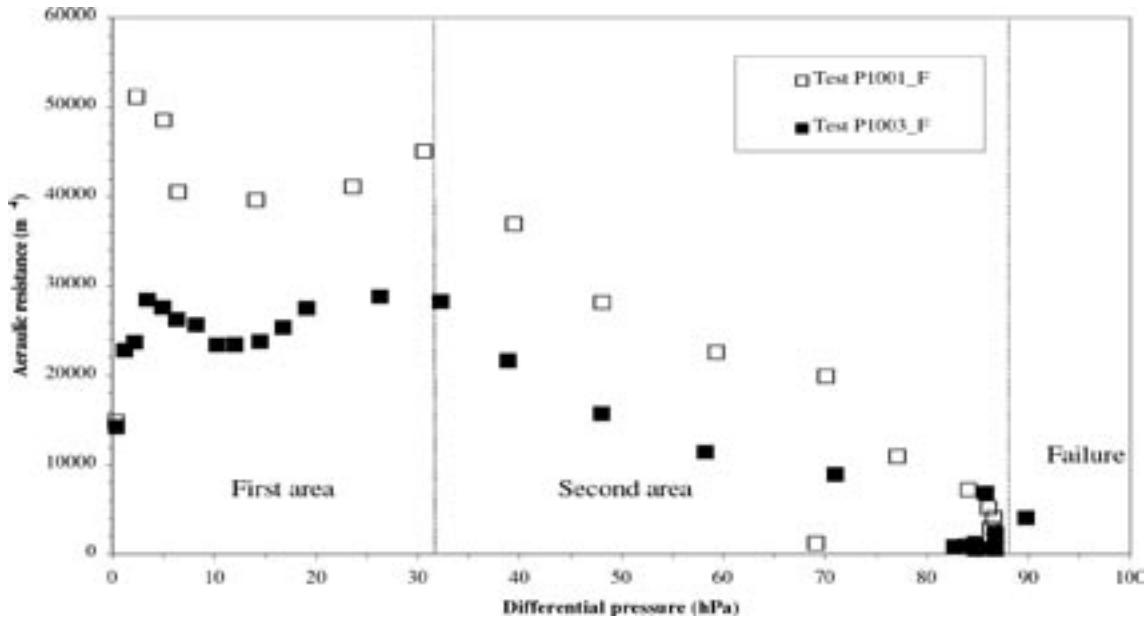


Figure 12: Aeraulic resistance evolution of two fire doors under pressure stress (Reversed airflow test)

5 CONCLUSION

The characterisation of the behaviour of containment equipment under accident conditions in STARMANIA facility has underlined the influence of pressure stresses on the integrity of the containment. Actually, the first investigations on fire dampers and fire doors have permitted to determine the values of pressure stresses specific of the modification of the equipment tightness. Moreover, the STARMANIA facility tests have shown that some equipments, as fire doors, could have quite high modification of their tightness at low pressure stresses. Theses observations show the necessity to take better into account the pressure effects on containment equipments in order to predict the behaviour of facility containment during accident conditions.

The next STARMANIA tests will concern the characterisation of the behaviour of fire doors under pressure stresses with higher air temperature (until 200 °C) and the characterisation of HEPA filters during disturbed conditions (steam injection) or accidental conditions (pressure stresses).

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