Thermal Properties of Intumescent Passive Fire Protection Materials

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Intumescent materials have been applied for a long time to protect equipment and structure against fire exposure in chemical and petrochemical industry. In need of optimising use of protection, simulation by use of computer codes has been more and more applied. These codes are dependent on reliable property data as input to the code; data that are partly highly unreliably and partly non existent. The reason is that there is not yet developed a test method for testing of intumescing materials that can give reliable property data applicable in computer codes.

1 The Challenge

The purpose of a fire engineering simulation is to predict a thermal response, and a structural response, of a loaded structural element (e.g. a fire insulated steel structure). The thermal properties must be adaptable to the simulation programme. This is evident when trying to simulate active fire protection materials whose fire protection capabilities depend on endothermic reactions and intumescing (swelling) upon fire exposure. The base material (epoxy matrix or thin film materials for intumescent paints) has a relatively high thermal conductivity, whereas the reaction product (the char layer formed by the swelling) acts as a thermal insulator with a low thermal conductivity. The heat capacity of the material is a product of specific heat and density, but the density is reduced during the active process of swelling. Most thermal response simulators based on finite element (FEM) or finite volumes rely on a constant geometry element mesh, i.e. the swelling itself is not modelled. The conductivity function must therefore take into account the phase change from a solid material to a porous char and the increased thickness. Further, this process is dependent on thickness, mass of substrate, and probably also on the intensity and duration of the heat flux. The nature of the material changes dramatically during the fire exposure and the charring of the coating. The reduction in density may be accounted for by defining the resultant heat capacity, but this is normally not a tabulated value. It is vital for the validity of the thermal response simulation that all these aspects are evaluated. Tabulated thermal data derived from standardised test methods are not always directly applicable in simulations. The engineer needs to know the behaviour, as well as the physical and mechanical reactions, of the materials used in the simulation. Figure 1 shows an example where plaster boards are used as protection to a steel column. The temperature range of tabulated data for plaster boards spans from 0 to 1100 °C, but experiments show that these plaster boards break down when reaching temperatures between 600-700 °C. As the figure shows, a simulation will give completely different results depending on the validity of the input data. In this case the thermal conductivity is given a high value when the material reaches more than 660 °C to reflect the breakdown of the material. G. Berge and U. Danielsen (2007).

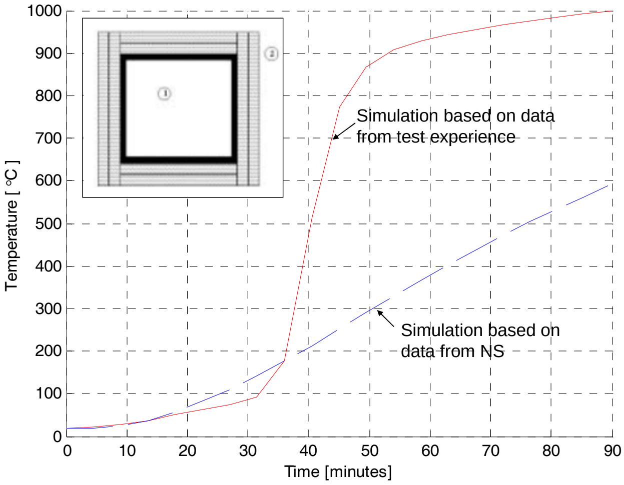

Figure 1 Results from simulations of temperature response in RHS 100x6.3 steel columns with 2x13mm plaster boards exposed to standard fire acc. to ISO 834. The curve showing the lowest temperature are using tabulated data taken from former Norwegian Standard 3478. The other curve is using data based on fire test experience. G. Berge and U. Danielsen (2007).

2 Proposal of Test Method for Determination of Thermal Conductivity

The main purpose of the new test method is to build a bridge between laboratory tests and simulation systems applied in engineering. For that reason, the test method must include both physical tests and simulations, and the results must be comparable. The test method must be flexible and reflect typical situations applied in design of industrial systems and plants. Properties that characterise the thermodynamic behaviour of a material are: specific heat (cp), density (or actually the mass taking part in the heating process) and heat conduction. For an intumescing material the density varies during the exposure period. The swelling process and its mechanism is complex and it is a rather difficult task to describe this process mathematically. Assuming that the change in original mass is limited, it should not be necessary to follow the swelling process in detail. Change in density of numerical simulations requires change in volume in order to maintain the mass. In stead of putting effort into modelling of the swelling process it is proposed to assume initial conditions with respect to mass and specific heat and take all changes to the property on the conduction parameter. What matters is the ability to describe the effect on the protected object.

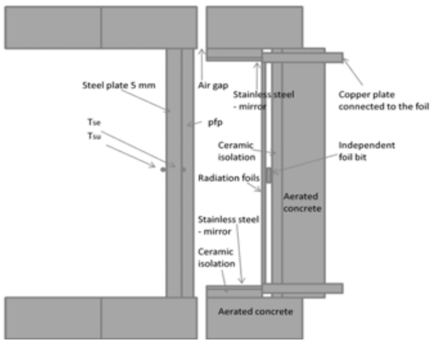

Figure 2 Schematic drawing of the proposed test stand. Krohn (2009)

Figure 2 shows the principle of the proposed test stand. It is an isolated box with a controlled heat source in one end and the specimen in the opposite end. The specimen is a steel plate insulated with the fire protection material to be tested. The heat source is a thin metal sheet (foil) heated by electricity. Electricity is used in order to have good control with the energy input. The electric effect was measured in addition to the temperature of the metal sheet. On the specimen, two thermocouples are docked into the steel in the centre of the squared plate as shown on. Temperature on both sides of the steel plate is measured. It is then possible to calculate the heat transport trough the steel. In addition it is possible to test the insulation under different conditions on the unexposed side of the steel plate. The unexposed side can be insulated or cooled if required. This system is fast and relative cheap in use. A range of tests can be performed over a short time period. As the experimental results are compared to simulations, the method can be flexible with respect to geometry of the specimen.

3 Experience from use of the Proposed Test Method

Under support from the Petroleum Safety Authority Norway a prototype of the proposed method has been built and tested. The figures below show the test facilities and a part of the numerical model. Two master students, Krohn (2009) and Løken (2008), were performing most of the work under supervision of the two authors of this article. The experiments were performed at the premises of the fire laboratory, SINTEF NBL AS. The numerical simulations were performed by use of Brilliant, a multiphysic computational fluid dynamic simulation system (CFD) Berge (2009).

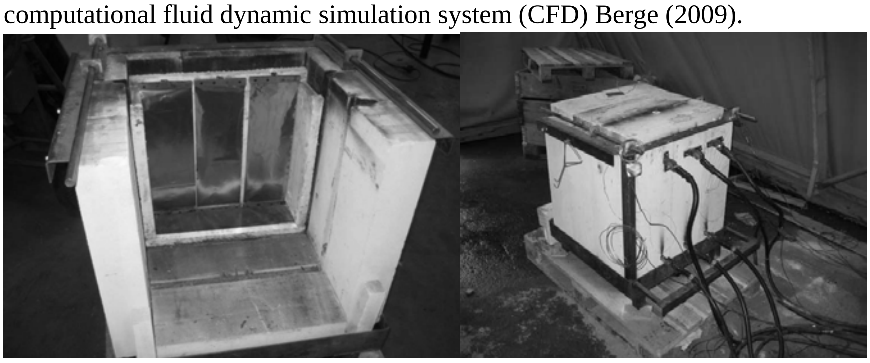

Figure 3 To the left: View inside the test equipment showing the electric heated foil. The specimen is placed just in front of the foil. To the right: Outside view of the experimental stand. Three phase electric supply is connected.

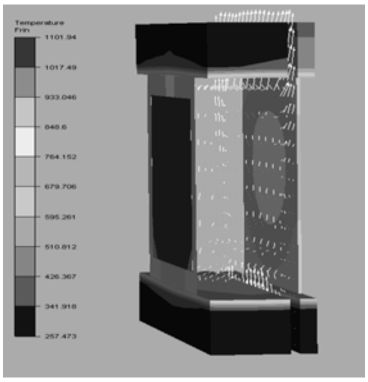

Figure 4 The view of the simulation model shows the heated foil to the left and the specimen to the right. The arrows show air flow through the slots and between the heating foil and the specimen.

3.1 Initial tests

The first step of testing the proposed method was to apply known passive material to see if expected "correct" properties could be repeated. The basic test was to test with plain steel. Some results are shown in the figures below. Also passive insulation materials was tested with good correspondence to earlier obtained material data; for instance Kaowool-1400. One of the challenges was to measure temperatures correctly, especially the temperature of the foil. This was done by measuring the temperature of a piece of foil placed behind the heated foils. This gave a temperature difference between the real temperature of the foil and the measuring piece, in the order of 20 to 100ºC. The input to Brilliant (the simulation system) was the energy supplied to the heating foil. Some of the electric energy was lost to heating up the copper in the support system and some was lost through conduction. The estimation of these losses was based on temperature measurements. The emissivity of the foil and steel was set to 0.7.

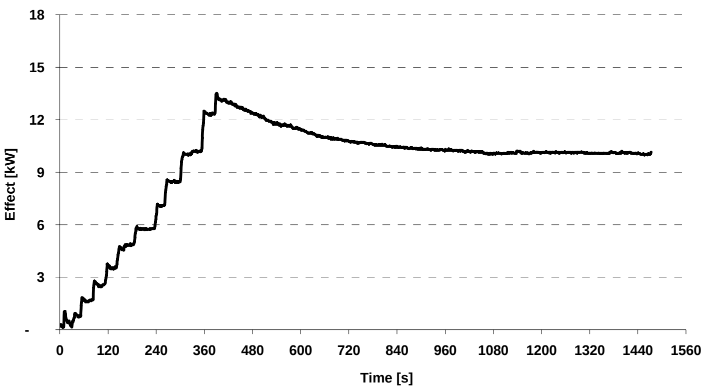

Figure 5 Effect curve from the experimental data. The curve is corrected for energy loss caused by heating of copper and conduction through electric conductors. The loss varies with time and is highest in the initial phase; about 20% of energy input. The curve is input to the simulations.

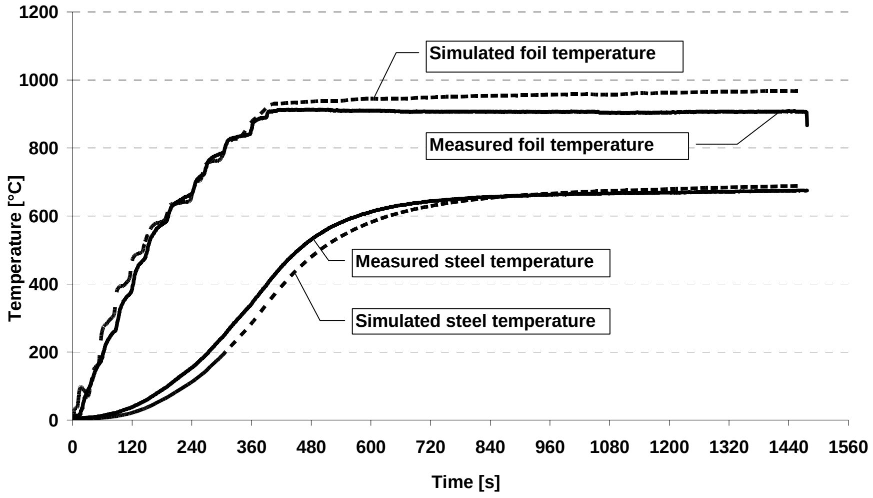

Figure 6 Simulation results compared to measurement for carbon steel. The two curves on the upper part of the figure are measures and simulated foil temperatures. The calculated temperature is expected to be lower than the measured because the foil temperature is indirectly measured. The lover curves are simulated and measured steel temperature on the exposed side. The results are based on the effect cure in Figure 5.

3.2 Test of intumescent material

Several tests were performed on different intumescent materials. A problem was that the materials caught fire after just a few minutes heating in the test oven. ProTek caught fire after 3 minutes and contributed to the heating. This lead to reduction to the supplied effect and it became clear that the measured effect curve could not be applied as basis for exposed heat. Instead the heat curve from the experiment with Kaowool-1400 was applied.

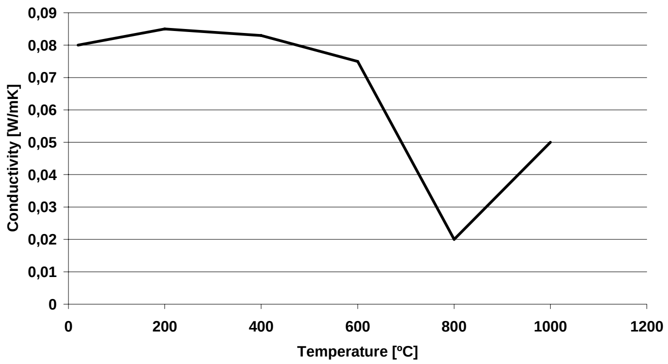

Figure 7 Conductivity for ProTek as function of temperature. The curve is based on a specific heat of 840J/kgK and a density of 1600 kg/m^3.

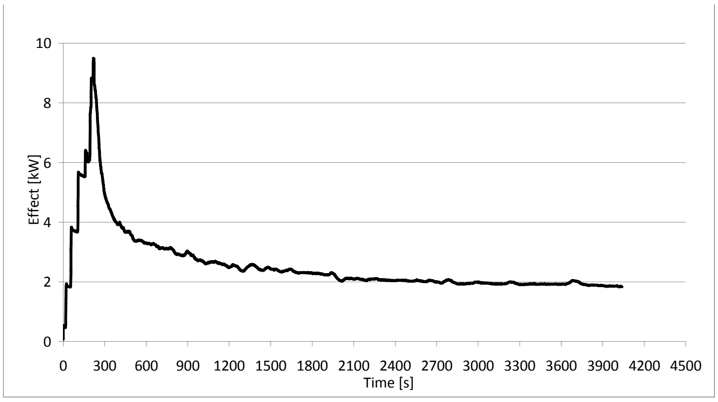

Figure 8 Effect curve used as input to the simulation for the results in Figure 9.

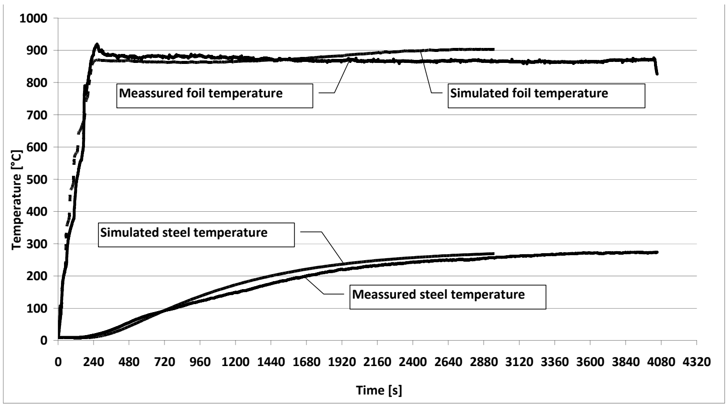

Figure 9 Simulation results compared to measurement for the intumescent material ProTek-A3. The two curves on the upper part of the figure are measures and simulated foil temperatures. The lover curves are simulated and measured steel temperature on the exposed side. The results are based on the effect cure in Figure 8.

4 Conclusion

The method has potential to give required material property data for application in engineering simulations. It will nevertheless need a better heating system.

5 References

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