Efectis
P.O Box 554 - 2665 ZN Bleiswijk
Brandpuntlaan Zuid 16 - 2665 NZ Bleiswijk
The Netherlands
+31 88 3473 723
nederland@efectis.com

Introduction

Over the last decade Efectis Nederland has performed fire tests in order to help determine the fire performance of products and their contribution to the field of fire safety. By measuring deflection, temperature, radiation and visually observe a product during fire tests, the fire performance of a product can be accurately described and used for classification and certification. Besides these regular measurements, Efectis offers thermographic imaging as an extra measurement. Thermographic imaging is not included in the European standards for the determination of the fire resistance of a product, so can only be used to gain more insight in the fire behavior of these products. But what insight offers thermographic imaging exactly on the fire behavior of products?

To get a better understanding of what thermographic imaging can offer at fire tests, Efectis took thermographic recordings of over 30 fire tests during the last four months. These thermographic recordings have been analyzed, revealing thermal information that cannot be gathered with regular measurements nor with visual observations. In this paper the findings from the thermographic recordings of two fire tests will be presented.

What is thermography?

Thermography is the science of visualizing and analyzing heat with infrared cameras. Infrared cameras contain a detector, which detects thermal radiation and translates the measured radiation into a visual image. Thermal radiation is emitted by all objects on this earth. How much thermal radiation an object emits, depends on its temperature: the hotter an object is, the more thermal radiation it will emit. In the visual image created by an infrared camera, a higher thermal radiation intensity will appear brighter.

Therefore, a thermal image displays the heat distribution upon a viewed object with differences in brightness within the image. By analyzing the displayed heat distribution, thermal images allow insight into the thermal behavior of an object. How much thermal radiation an object emits doesn’t only depend on the temperature of the object, but also on the object’s intrinsic ability to emit thermal radiation (better known as an object’s emissivity). Two objects with different emissivity’s can have the same temperature, but one of the objects will appear hotter than the other in a thermal image.

Besides the thermal radiation emitted by an object, an infrared camera also measures thermal radiation reflected and transmitted by the object. A brighter area in a thermal image will always mean higher thermal radiation intensity, but to recognize whether this is caused by the temperature of your viewed object or by other radiation sources takes a trained eye.

Fire test 1: Loaded masonry wall

Set-up fire test

For the first presented fire test, a masonry wall specimen with a uniform thickness was placed in front of the vertical furnace and loaded with the help of an external loading frame, conform EN 1365-1. The load was applied uniformly upon the top of the specimen.
By placing the specimen in front of the furnace, in which a fire following the ISO curve was reproduced, only one surface of the specimen was exposed to heat. To determine the fire resistance of the masonry wall, deflection, temperature and radiation were measured on the unexposed side of the specimen.
In order to take thermographic recordings of the fire test, an infrared camera was placed viewing the unexposed side of the specimen. The influence of thermal radiation from other resources than the test specimen itself, has been neutralized, allowing the displayed heat distribution in the thermal imaging to be caused solely by the temperatures of the test specimen itself.

Thermographic expectations

The masonry wall will be evenly heated by the fire load on the exposed surface, triggering heat transfer through conduction between the exposed and unexposed surface of the specimen. The heat transfer through conduction might differ between the two used materials, brick and mortar. This causes differences in surface temperatures on the unexposed side of the specimen.
Besides differences in conductivities, brick and mortar also differ in emissivity. Therefore, the expected thermographic image can display heat differences between the brick and mortar. Because of the evenly applied fire load on the exposed surface, all bricks should have the same surface temperature. The same principle goes for the mortar.

Visual observations

During the fire test, 3 vertical cracks appeared on the unexposed surface of the masonry wall. The specimen bended towards the fire throughout fire test to the point of collapsing, which marked the end of the fire test.

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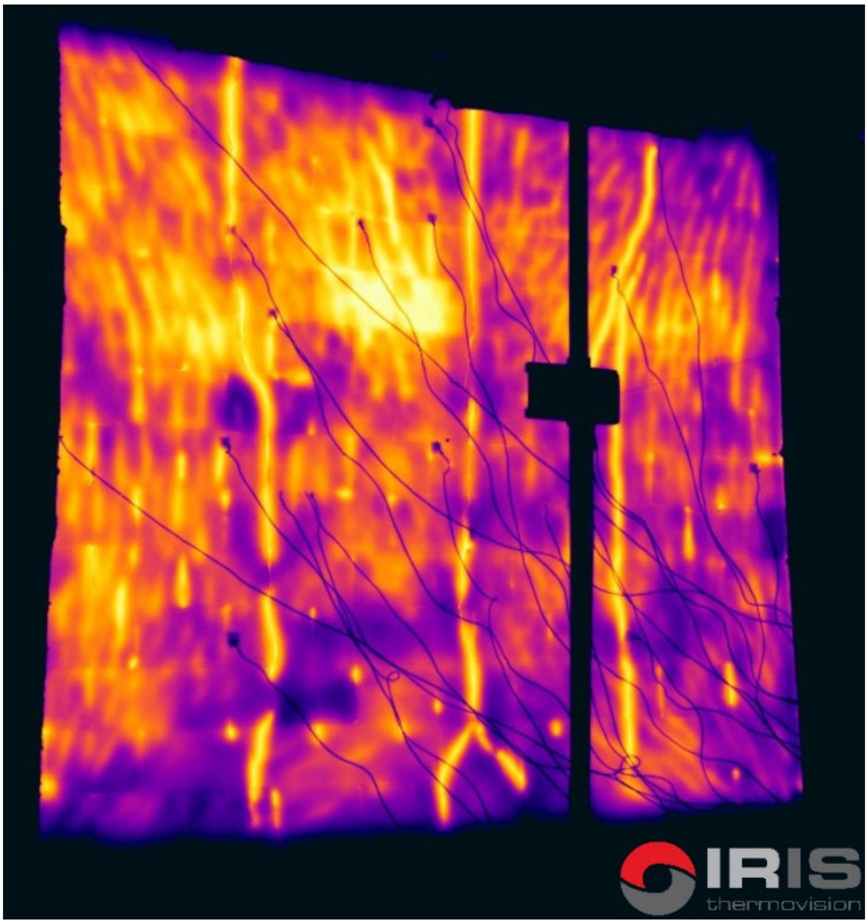

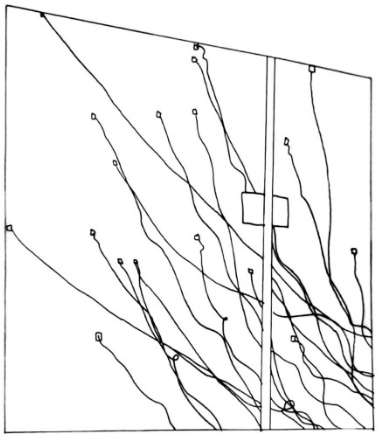

Figure 1

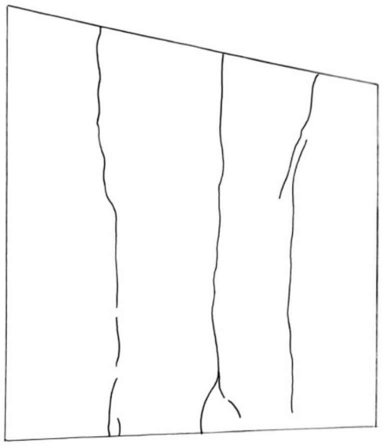

Figure 2

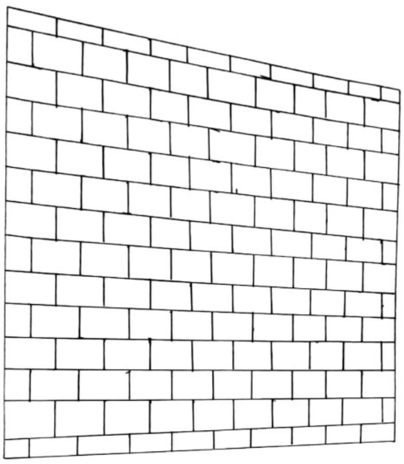

Figure 3

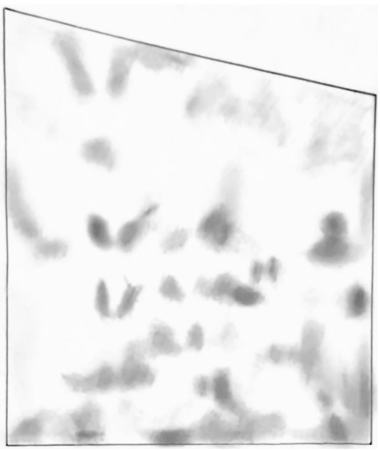

Figure 4

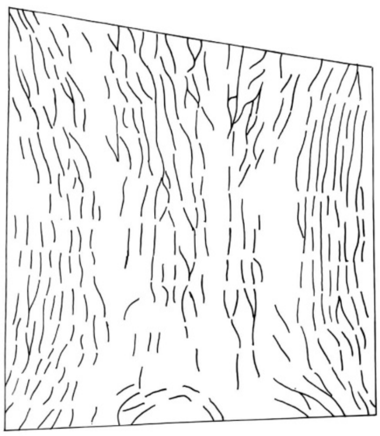

Figure 5

Figure 1 to 5 show the different lines and patterns which can be distinguished when analyzing thermal image as described in more detail below.

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Analysis of the thermal image

In order to measure temperature, thermocouples are attached to the unexposed surface of the test specimen. The thermocouples block the infrared camera's view on the unexposed surface of the test specimen, appearing as black lines with dots on the end in the thermal image above (Figure 1). The same goes for the radiation sensor in front of the unexposed surface of the specimen, appearing as a black vertical line with a rectangle in the middle in the thermal image above.

The 3 vertical cracks (Figure 2) which visually appeared on the unexposed surface of the test specimen, are clearly visible as hotter lines on the thermal image. These cracks allow the heat from the fire to transfer more easily through the masonry wall, due to the lack of material the heat has to pass through. Therefore the cracks are hotter than the rest of the unexposed surface.

The shape of the masonry (Figure 3) is slightly visible in the thermal image, due to the slightly hotter appearance of the mortar compared to the bricks. Which is as expected due to the differences in conductivity and emissivity between the two materials.
The blotted pattern (Figure 4) visible in the thermal image, cannot be explained by conductivity, emissivity or visually observed changes in the masonry wall. What could have caused this blotted pattern, is the different moisture contents between the individual bricks. The bricks in masonry contain an amount of moisture, which can vary per brick. Moisture, or water, has a high heat capacity, which means it needs a lot of thermal energy to heat up.

Bricks with a higher moisture content will therefore need more time to heat up, than bricks with a lower moisture content. In the thermal image bricks, or areas within bricks, with a higher moisture content will appear colder.

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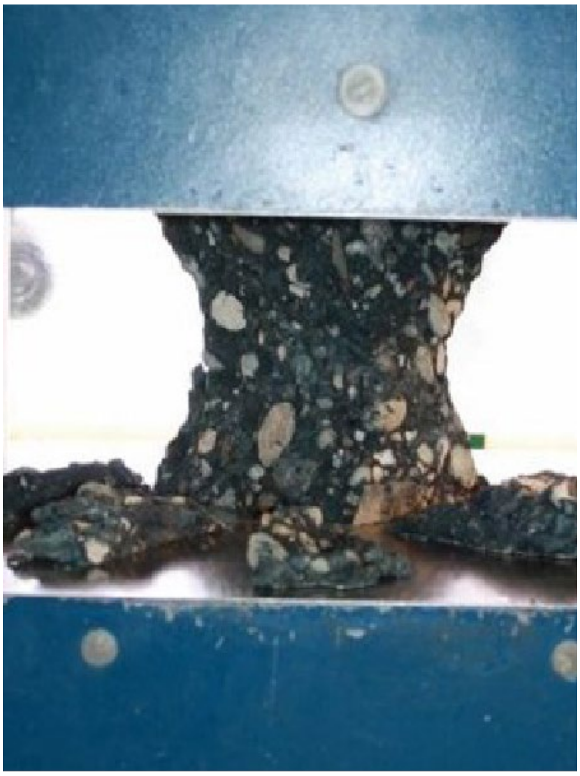
Finally the multiple dashed lines (Figure 5), which too cannot be explained by conductivity, emissivity or visually observed changes in the masonry wall. The dashed lines seem to indicate microcracks in the bricks on the exposed side as a result of the mechanical loading on the test specimen, given the characteristic failure behavior of stone like materials under pressure, as shown in the picture. Microcracks in the bricks of the masonry wall will have an impact on the heat transfer through the test specimen, by creating a bigger exposed surface. At the exposed surface, moisture from the bricks will evaporate, cooling the surface. Therefore the microcracks will, due to more surface evaporation, stay cooler than the intact parts of the test specimen.
In the thermal image unexposed surface areas behind which microcracks are located, will appear as colder dashed lines.



Bron: Cement Kennisplatform voor Betonconstructies

This theory was made plausible because microcracks were subsequently observed in all individual stones.

Fire test 2: Steel wall with plastered insulation material

Set-up fire test

For the second presented fire test, a steel wall specimen with six vertical stiffeners and plastered insulation material on the exposed side, was placed in front of the vertical furnace.
During the fire test, an ISO curve was reproduced in the furnace in order to test the specimen's fire resistance behavior, conform IMO Resolution MSC.307(88), FTP Code 2010, part 3. To determine the fire resistance of the steel wall deflection and temperature was measured on the unexposed side of the specimen. The set-up for the thermographic recordings was equal to the set-up of fire test 1.

Thermographic expectations

The steel wall will be evenly heated by the fire load on the exposed surface, triggering heat transfer through conduction between the exposed and unexposed surface of the specimen. Because of their geometry, the stiffeners will be exposed to the heat of the furnace from three sides as opposed to one side like the rest of the test specimen. Therefore the heat transfer through the test specimen will differ at the

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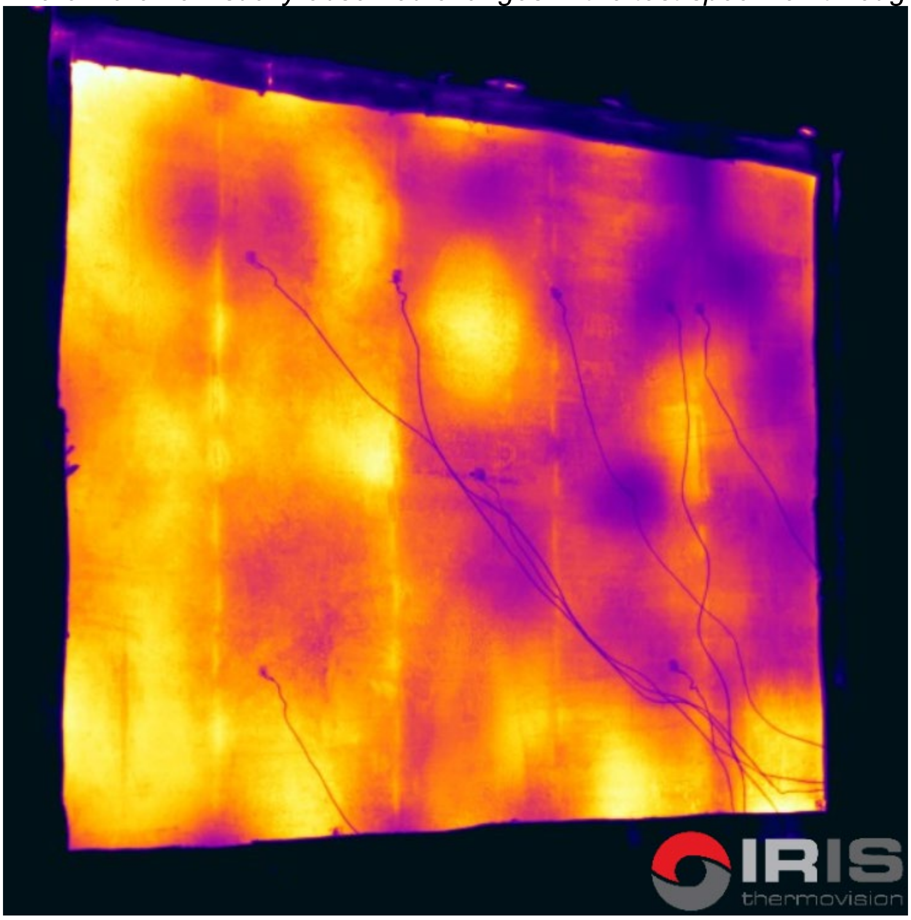
location of the stiffeners compared to the rest of the test specimen, causing differences in surface temperatures on the unexposed side of the specimen. Because of the evenly applied fire load on the exposed surface, all of the unexposed surface should have the same surface temperature, areas behind which stiffeners are located excluded.

There were no visually observed changes in the test specimen throughout the fire test.



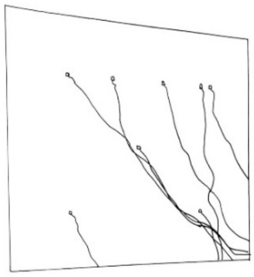


Figure 6

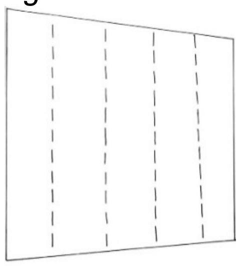


Figure 7

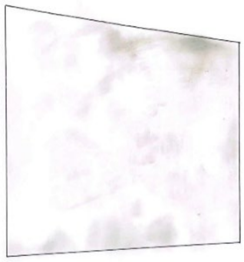


Figure 8

Figure 6 to 8 show the different lines and patterns which can be distinguished when analyzing thermal image as described in more detail below.

Analysis of the thermal image

In order to measure temperature, thermocouples are attached to the unexposed surface of the test specimen (Figure 6). The thermocouples block the infrared camera's view on the unexposed surface of the test specimen, appearing as dark purple lines with dots on the end in the thermal image above.
4 out of 6 vertical stiffeners appear as hotter dashed lines (Figure 7) on the thermal image. The other 2 stiffeners are located at the vertical sides of the test specimen, and are therefore not visible in the thermal image. The dashed pattern shows the locations where the stiffeners are welded to the steel wall, appearing hotter due to better conductivity through the welded parts.

The blotted pattern (Figure 8) visible in the thermal image, can only be explained by conductivity differences. Since the insulation material was plastered on the steel wall, it is plausible that differences in insulation thickness were applied. The conduction of heat from the exposed to the unexposed surface, takes up more time if the heat has to transfer through more material. Therefore, areas with a thicker layer of insulation will appear colder in the thermal image, causing the blotted pattern to display the differences in applied insulation thickness.

Conclusion

Thermographic imaging visualizes the heat distribution on the unexposed surface of a test specimen, revealing thermal information on the fire behavior of products that normally goes unnoticed with the regular measurements of a fire test and remain invisible to the human eye.
The thermographic imaging of the first fire test, displays the influence of moisture on the fire behavior of masonry and the presence of microcracks, which has never been noticed before. The thermographic imaging of the second fire test, displays differences in insulation thickness caused by the application method, while the insulation thickness was supposed to be even throughout the entire test specimen.
Regular measurements of a fire test are local point measurements providing concrete values, but lacking the information to explain what might have caused these values. Thermographic imaging can, with knowledge of the conductivity and emissivity of a test specimen, provide insight into the cause of measured values of regular measurements and much more. The information that patterns on thermal images show, can be used to better understand why a test specimen might have failed a fire test and help with further development of a product.
Taking thermographic recordings of fire tests, creates more substantive data on fire behavior of products that can be analyzed, creating more knowledge that benefits fire safety.

Recommendations

For future research it would be interesting to investigate whether the microcracks in the masonry wall of the first fire test, a regularly occurring phenomenon in loaded stone-like walls during fire tests are or just incidental, and whether this phenomenon is related to the failure of the test specimen. On a larger scale it would be interesting to research whether the visualization of heat distribution with thermographic imaging, show patterns which precursor the failure of a test specimen.
We see an important role for thermography in the future, along the regular measurements and determinations that we already make, in order to take fire safety to a higher level.

Author: Hannah Godding, certified Level 2 thermographer ITC