The explosion at the Buncefield fuel depot in the UK in December 2005, the biggest explosion in Europe since World War II, illustrated the awesome power that fire can wield.

Whilst the bravery of those involved in extinguishing the fire was unquestionable, the apparel and footwear that protected them also played a vital role. Heat and flame resistance have become big issues in footwear and clothing over the last decade and this has led to a plethora of tests being developed.

Testing to take the heat off feet

Understanding how materials and products perform when exposed to sources of heat and flame is fundamental to many test methods and the Satra Technology Centre in the UK now has the ability to carry out over 60 heat and flame test methods, approved by the United Kingdom Accreditation Service (UKAS), covering hundreds of different products. In addition to footwear, it also tests the burning behaviour of candles, clothing, automotive composites and furniture.

The centre has a long history of assessing specialist footwear against the effects of heat and flame as Austin Simmons from the technology centre explains. Since the introduction of the European Personal protective (PPE) Directive 89/686/EEC, it has been at the centre of development of safety and footwear standards and has become one of the leading authorities in this field.

Buncefield Oil Depot.
Chiltern Air Support Unit

It has also developed 'SID' (the Satra Instrumented Dummy) to assess the performance of clothing and footwear on an anthropomorphic body. Whilst the use of mannequins in European safety standards directly related to PPE testing and CE marking is still in its infancy, many organisations are interested in finding out how products perform when subjected to tests that better simulate real life fire scenarios.

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Standards

A number of footwear-related standards include flammability tests. Core safety footwear standard BSENISO 20344: 2004 provides the methods used to CE mark the vast majority of safety footwear applications, and includes a contact heat (sand bath) test.

There are also a number of specialist standards relating to footwear, which detail other heat and flame tests. These include prEN 15090 for fire fighters' footwear which is currently under development; the UK national standard for foundry footwear BS 4676: 2005; and public order footwear against BS 7971-5: 2004.

The technology centre has also developed a test method (TM 225) to assess the flammability of children's slippers to help manufacturers demonstrate compliance with more general legislation such as the European General Products Safety Directive. Typically, these standards specify performance levels for footwear against small ignition sources, radiant heat, contact heat and molten metal.

Tests

Contact heat — this is the most common heat and flame test carried out by Satra and is detailed in BSENISO 20344 to evaluate thermal insulation properties of heat resistance in outsoles by using a 'sand bath' incorporating a hot steel plate heated to temperatures of 150°C or 250°C. The apparatus is filled with sand to a depth of 30mm and a sample of the footwear, filled with steel balls, is placed on the sand and moved backwards and forwards until the best possible contact has been achieved between the footwear and the plate. The temperature rise within the footwear is monitored and any resulting damage that would affect proper functioning of the footwear is noted.

'SID' in action.
Satra

Radiant heat — this enables the protective effect of materials and composites to be determined when subjected to a radiant heat source. The duration and intensity of radiant heat exposure varies according to the application. Industrial workers or fire fighters may be exposed to either low radiation intensity over a long period of time or a high level for a shorter duration. It is therefore important to determine material characteristics so that material performance and wearer comfort can be established under various circumstances. Products therefore need to be tested and assessed under differing levels of radiated heat intensity (heat flux density).

The Satra radiant heat test is based on the requirements of European standard ISO 6942 Method of test: evaluation of materials and material assemblies when exposed to a source of radiant heat. This standard not only defines the test equipment, but also the test method and includes the facility to evaluate materials at different radiant heat levels.

Ideally, the material should be characterised by a heat transmission factor when it reaches a steady state. This factor should be sufficiently low to denote that the material can be worn for a long time under lower heat conditions. However, higher heat flux densities are liable to change the material such that its steady state conditions cannot be achieved. In this case it may not be possible to determine a heat transmission factor as the material may be changed by the test and no steady state achieved. Here, the time taken to reach different heat transfer levels is the most important factor.

The equipment basically consists of a test frame incorporating a radiation source at one end and a moveable sample holder and calorimeter connected to a suitable recording device at the other. The standard identifies three ranges of heat flux density:

Low level:	5 & 10 KW/m^2
Medium level:	20 & 40 KW/m^2
High level:	80 KW/m^2

The sample is introduced to the radiant source at a distance determined by previous use of the calorimeter to calculate the incident heat flux density. The method is in two parts. The first requires exposure for three minutes and a subsequent physical inspection. The calorimeter is retained in situ in the second method and the time for a set temperature rise is measured.

Molten metal splash – heat and flame PPE products often need to protect the wearer against the effects of molten metal splash, and Satra has developed equipment to simulate this. Testing of foundry footwear and gaiters using molten metal poured on to the product from a crucible is carried out at a local foundry using a Satra test rig. The molten metal is poured on to the test sample, fitted to a leg-shaped form and observations are made during and after pouring. Gaiters and footwear comply if there is no penetration by the molten metal within six seconds of the pouring ceasing; flaming does not continue for longer than five seconds; and materials do not ignite during the test.

Convective heat – heat transmission through footwear and clothing is largely determined by its thickness. Air gaps between layers will also influence how quickly heat penetrates to the inside. The convective heat test described in EN 367:1992 Method of determining heat transmission on exposure to flame enables materials to be ranked by calculating a heat transfer index, which is an indication of the relative protection under specified test conditions.

Test samples may be single layer or composites and are mounted horizontally 50mm above a flat topped wide-mouthed propane burner. A copper disc calorimeter is placed on top of the sample. The apparatus is calibrated prior to use without the sample in place. Gas flow rate and burner flame settings are adjusted to give a heat flux density of 80kW/m^2. Once this has been achieved, the sample is introduced and the test is started.

The burner flame is allowed to continue until a temperature increase of 24°C is reached behind the sample. At this point the flame is extinguished and the time is recorded. Physical changes to the sample such as shrinkage, scorching, charring, holing, glowing, melting and dripping are also noted. The test is repeated twice and the heat transfer index is calculated from the mean of the three test values rounded to the nearest whole number.

Contact and Radiant heat testing.

Satra

Taking tests a stage further

Whilst all these tests go some way to determining the ease of ignition, heat exchange, rate and extent of flame spread, etc., they do not simulate what happens in real life scenarios, such as that experienced by fire fighters or others where the footwear must give protection against large scale fires.

In these situations the design and construction, and the body position of the wearer, can have a crucial effect on the heat and flame protective qualities, as well as any interaction with other protective products such as clothing, leggings or gaiters. It is for this reason that 'SID' was developed.

The device uses an instrumented mannequin fitted with over 100 sensors, each consisting of a copper disc attached to a thermocouple. The thermocouples are linked to a data-logging device capable of handling 100 plus inputs at rates in excess of five readings per sensor per second. The sensors are spread around the body, including the foot area, and a number of burners direct flames on to the mannequin via a butane gas ring main.

The sensors are calibrated against known heat fluxes, so it is possible to measure the radiated heat intensity of over 100 locations during a test. The sensors measure the variation in temperature with time at the mannequin's surface during a test with the mannequin clothed. The variation in temperature over time enables the resultant heat flux at the mannequin's surface to be derived as well as the time of exposure for each sensor. The software for SID has been written to allow data to be taken from each sensor location and carry out calculations to determine whether human skin would suffer first, second or third degree burns as a result.