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ASSESSMENT OF THE UNIFORMITY OF THE INTERIM JET FIRE TEST PROCEDURE

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EXECUTIVE SUMMARY

In December 1993, the United Kingdom Health and Safety Executive (HSE) made available a report [1] entitled "Interim Jet Fire Test for Determining the Effectiveness of Passive Fire Protection Materials". The Interim Jet Fire Test (IJFT) procedure described in the report was based on a test pioneered by the Norwegian Fire Research Laboratory (SINTEF NBL), which involved a sonic release of propane vapour of 0.3 kg/s, directed at a flat test specimen constructed in the form of an open fronted steel box, 1.5 m wide, 1.5 m high and 0.5 m deep. Although the dimensions of the test specimen were small compared with those typical of items of structure and plant and the release rate of the gas was substantially less than that which might occur in practice, the nature and characteristics of the propane jet fire had been shown to be similar to full scale jet fires involving sonic releases of natural gas of 2 to 3 kg/s carried out by British Gas and Shell Research at the Spadeadam Test Facility. The size of the IJFT facility allows tests to be carried out economically either indoors or outdoors in an area protected from the environment, and is therefore attractive as a standard test procedure.

The IJFT procedure identifies three configurations of test specimen to test passive fire protection (pfp) material. The first configuration is designed to test panel materials that can stand alone or be used to protect a substrate. The panel material is used to form the rear wall of the test specimen. The second configuration is designed to represent a coating material applied to flat panels. In this case, the coating material is used to protect the inside surfaces of the test specimen. The third configuration is designed to represent the application of a coating material to a structural section such as an I-beam. In this case, a vertical central web is included in the test specimen, welded to the rear wall and positioned edge on to the jet fire. The coating material again covers the inside surfaces of the test specimen in addition to the web.

However, before the IJFT procedure can be adopted as an entirely appropriate test method for pfp materials designed to protect against jet fires, one essential requirement was to assess the uniformity of the results from nominally identical tests carried out at different test laboratories

OBJECTIVE

This report contains the results from a programme of tests carried out at three different test laboratories in accordance with the IJFT procedure. The purpose of the work was to assess the uniformity of the results obtained from the IJFT between the test laboratories.

OUTLINE

The generic type of pfp material selected to coat the test specimens was an epoxy intumescent. Epoxy intumescent was chosen since such material is used extensively for fire protection and can be vulnerable to jet fire attack. Consequently such material is suitable material for assessing the IJFT procedure. Two different proprietary epoxy intumescents were selected to ensure that the results from the tests were not material specific. The manufacturers of these materials were approached and both agreed to supply the material free of charge.

The configuration of the test specimen employed in these tests was the test specimen with the central web. This was selected since the central web provided the opportunity of testing the application of an epoxy intumescent on an edge feature, which is considered a particularly vulnerable arrangement under the conditions experienced in a jet fire.

The duration of the tests was selected to be one hour. One manufacturer was asked to provide pfp material which was designed to protect the test specimen for one hour and remain intact for this duration. The other manufacturer was asked to provide pfp material which was designed to provide protection for 40 minutes but would be expected to be damaged at the end of a one hour test. This would allow the assessment of the uniformity of the IJFT procedure for materials which survive and for materials which fail in the test.

Three test laboratories were selected to carry out the tests and they were SINTEF NBL, in Trondheim, Norway, the Southwest Research Institute (SwRI) in San Antonio, Texas, USA and the HSE's test facility at Buxton in Derbyshire, UK. Each test laboratory tested two test specimens, one protected by the first pfp material and the other protected by the second pfp material. Thus, six test specimens were manufactured and tested.

CONCLUSIONS

Test Specimens

The test specimens were manufactured in accordance with the engineering drawing provided at the rear of this report. They were coated with pfp material in accordance with the manufacturer's specification or where the application of the pfp material differed from the specification, the difference was approved by the manufacturer's representative who was present during the application. The application was undertaken in a manner which ensured that the pfp material on the test specimens was as uniform as reasonably practical. It is therefore concluded that the test specimens and pfp material were as uniform as could be reasonably expected.

Test Procedure

The three test laboratories carried out the tests on the test specimens generally in accordance with the IJFT procedure. At SwRI no protection was installed around the sides or across the top of the specimen and rear box. There was no evidence of the flames passing around the sides or top of the specimen, however it was not possible to determine whether or not radiation from the flames incident upon the rear box was significant since appropriate measurements were not made.

Some minor changes and additions were made to the IJFT procedure, namely

a) the method of installing thermocouples in the central web,

b) the attachment of thermocouple to the rear wall, and

c) the provision of engineering drawings.

These changes and additions are considered to have improved the IJFT procedure. It is concluded that the IJFT procedure is a workable procedure which can be used by test laboratories to carry out jet fire testing.

The test reports issued by the test laboratories vary in content and presentation and consideration should be given to ensuring more uniformity in the reporting of the results.

Testing Indoors v Outdoors

From the testing carried out at Buxton, it would appear that there are particular problems in undertaking IJFT tests outdoors which are not present when the IJFT's are carried out indoors. A number of suggestions have been made in an attempt to account for the differences in the jet fire witnessed at Buxton. It is concluded that further work is necessary to investigate the design of test enclosures used for IJFT's undertaken outdoors.

Performance of pfp Material on Rear Wall

The condition of the char and the temperatures measured on the rear wall of the test specimens showed that there was a high level of uniformity in the results from the three test laboratories. It is therefore concluded that the IJFT procedure provides a uniform test for the rear wall of test specimens.

Performance of the pfp Material on the Central Web

The condition of the char and the temperatures measured on the central web of the test specimens showed that there was not a high level of uniformity in the results from the three test laboratories.

RECOMMENDATIONS

IJFT Procedure

It is recommended that the following changes be made to the IJFT procedure:-

a) full engineering drawings should replace the diagrams in the procedure

b) the methods outlined in this report to attach the thermocouples to the rear wall should be adopted

c) stainless steel sheathed thermocouples should be used in the central web

d) a report format should be included

e) the IJFT procedure should insist that the report from the test laboratory should contain a section on the measurement and control of the propane flow rate.

Outdoor Testing

It is recommended that further work be undertaken to investigate the design of test enclosures to be used outdoors. This work should determine an optimum size, shape, orientation, construction material and ventilation procedure for the test enclosure.

Application of pfp Material to the Rear Wall

From the observations made during the IJFT's carried out at the three test laboratories, the pfp material applied to the rear wall of the test specimens responded uniformly. Therefore it appears that the IJFT procedure may be appropriate for the testing of pfp materials in such a configuration. However, further consideration should be given to the performance of the pfp material during an IJFT compared to its performance in a jet fire representative of that which might occur in practice.

Application of pfp Material to the Central Web

From the observations made during the IJFT's carried out at the three test laboratories, the pfp material applied to the central web of the test specimens did not respond uniformly. Therefore further consideration needs to be given to the IJFT procedure which may include:

a) the design of the test specimen

b) the configuration of the test specimen and test set-up

c) the orientation and arrangement of the jet fire

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1. INTRODUCTION

1.1 BACKGROUND

In December 1993, the United Kingdom Health and Safety Executive (HSE) made available a report [1] entitled "Interim Jet Fire Test for Determining the Effectiveness of Passive Fire Protection Materials". The Interim Jet Fire Test (IJFT) procedure described in the report was based on a test pioneered by the Norwegian Fire Research Laboratory (SINTEF NBL), which involved a sonic release of propane vapour of 0.3 kg/s, directed at a flat test specimen constructed in the form of an open fronted steel box, 1.5 m wide, 1.5 m high and 0.5 m deep. Although the dimensions of the test specimen were small compared with those typical of items of structure and plant and the release rate of the gas was substantially less than that which might occur in practice, the nature and characteristics of the propane jet fire had been shown to be similar to full scale jet fires involving sonic releases of natural gas of 2 to 3 kg/s carried out by British Gas and Shell Research at the Spadeadam Test Facility. The size of the IJFT facility allows tests to be carried out economically either indoors or outdoors in an area protected from the environment, and is therefore attractive as a standard test procedure.

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However, before the IJFT procedure can be adopted as an entirely appropriate test method for pfp materials designed to protect against jet fires, one essential requirement was to assess the uniformity of the results from nominally identical tests carried out at different test laboratories

1.2 OBJECTIVE

This report contains the results from a programme of tests carried out at three different test laboratories in accordance with the IJFT procedure. The purpose of the work was to assess the uniformity of the results obtained from the IJFT between the test laboratories.

1.3 OUTLINE

The generic type of pfp material selected to coat the test specimens was an epoxy intumescent. Epoxy intumescent was chosen since such material is used extensively for fire protection and can be vulnerable to jet fire attack. Consequently such material is suitable material for assessing the IJFT procedure. Two different proprietary epoxy intumescents were selected to ensure that the results from the tests were not material specific. The manufacturers of these materials were approached and both agreed to supply the material free of charge.

The configuration of the test specimen employed in these tests was the test specimen with the central web. This was selected since the central web provided the opportunity of testing the application of an epoxy intumescent on an edge feature, which is considered a particularly vulnerable arrangement under the conditions experienced in a jet fire.

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Three test laboratories were selected to carry out the tests and they were SINTEF NBL, in Trondheim, Norway, the Southwest Research Institute (SwRI) in San Antonio, Texas, USA and the HSE's test facility at Buxton in Derbyshire, UK. Each test laboratory tested two test specimens, one protected by the first pfp material and the other protected by the second pfp material. Thus, six test specimens were manufactured and tested.

2. PREPARATION OF TEST SPECIMENS

This section describes the design and manufacture of the six test specimens, including the instrumentation installed to measure the thermal response of the rear wall and central web. In addition, the design and application of the pfp material and associated mesh retention system is described together with the precautions taken for the shipment of the test specimens to the test laboratories. A timetable of the various stages involved in the manufacture and preparation of the test specimens is given in Appendix A.

2.1 DESIGN OF TEST SPECIMENS

2.1.1 Current Position

The IJFT procedure [1] contains a limited description and diagrams of the test specimens to be used in carrying out tests. The diagrams of the test specimens are limited in the information they present and contain no construction details.

The method of installing the thermocouples in the central web is such that repairs to faulty thermocouples in the web are impractical. The thermocouples are spot welded inside a groove, machined in one half of the central web, prior to the two halves of the web being welded together. The thermocouples must be fitted during the manufacture of the test specimen. They are therefore vulnerable to damage during manufacture, application of the pfp, transport and setting up of the test. Damage to a web thermocouple during any of these stages cannot be repaired. For this reason, the design of the test specimen was modified from that specified in the IJFT procedure to accommodate 3 mm diameter stainless steel sheathed thermocouples that can be inserted into the web shortly before the test specimen is to be tested.

According to the IJFT procedure, three thermocouples must be installed in the central web to measure its temperature during the test. For the tests described in this report, two additional thermocouples were installed in the web in the area directly impinged by the jet fire, the 'target area'. This was done to provide more data to be used in assessing the uniformity of the IJFT between the different test laboratories.

2.1.2 Description of Test Specimens

Engineering drawings of the test specimens described in this report have been produced and are provided at the rear of this report.

The test specimens were constructed in the form of open fronted boxes, generally using mild steel 10 mm in thickness. The internal dimensions of the boxes, prior to coating, were 1,500 mm wide, 1,500 mm high and 500 mm deep. The central web was 20 mm thick and 250 mm deep and was formed from two plates each 10 mm thick, welded together.

A plate, 1,620 mm wide and 1,565 mm high formed the rear wall of the test specimen and provided 50 mm flanges around three sides of the test specimen. Thirteen, 18 mm diameter holes were drilled in the flanges to permit the bolting of the test specimen to the 1 m deep uninsulated steel box used to protect the rear of the test specimen from draughts. Four plates, 1,500 mm by 500 mm were welded to the rear wall and to each other and formed the sides of the test specimen. The welds were continuous 5 mm fillet welds made on the inside and outside of the test specimen. Lifting lugs were welded to the top plate of the test specimen to ease handling. A flange was not provided along the bottom of the test specimen.

The central web of the test specimen was constructed from two 1,500 mm by 250 mm plates, each 10 mm thick. Five slots were machined into each of the plates to accommodate the thermocouples at locations 187.5 mm; 375.0 mm; 562.5 mm; 750 mm and 1125 mm from the base of the test specimen. On the first plate, the slots were machined to a length of 120 mm with a 5 mm diameter ball nosed cutter and to a further 120 mm with a 4 mm diameter ball nosed cutter. The depth of the slots were 5 mm and 4 mm for the first and second 120 mm lengths respectively. On the second plate, the slots were machined to a length of 120 mm with a 5 mm diameter ball nosed cutter, 5 mm deep. The front and rear edges of the two plates were machined in preparation for welding. A continuous fillet weld joined the two plates along the front edge and an intermittent fillet weld joined the two plates at the rear, to avoid the slots. The intermittent fillet weld at the rear was ground flush to allow the central web to be welded to the rear wall. The fillet weld at the front edge was left as welded. A continuous 5 mm fillet weld either side of the central web joined it to the rear wall.

Prior to the welding of the central web to the rear wall, five holes were drilled and tapped to 1/8 inch BSP in the rear wall at locations corresponding to the locations of the slots in the central web. These drilled and tapped holes were employed in the fitting of the central web thermocouples, (see Section 2.3).

2.2 MANUFACTURE OF TEST SPECIMENS

The manufacture of the test specimens was carried out by Hartlepool Steel Fabrications Ltd. of Hartlepool, UK.

The following steps outline the sequence of manufacture:

i) All plating was cut to the required size and any burrs were removed.
ii) The flange bolt holes were drilled in the rear wall.
iii) The lifting lugs were drilled and welded to the top plate of the test specimen.
iv) The four side plates were welded to the rear wall and to each other.
v) The slots and weld preparations were machined in the plates of the central web.
vi) The central web plates were welded together. Care was taken to ensure that the slots in the plates were properly matched up before the plates were clamped and then welded together. 3 mm diameter steel rods were inserted in the slots to check the alignment. The fillet weld on the rear edge of the central web was ground flush.
vii) Holes were drilled and tapped to 1/8 inch BSP in the rear wall.
viii) The central web was welded to the rear wall and the top and bottom side plates. Care was taken to ensure that the slots in the central web corresponded to the holes in the rear wall before the web was clamped and welded. 3 mm diameter steel rods were inserted into the slots to check the alignment prior to welding.
ix) All welds on the test specimen were cleaned and deburred.

2.3 INSTRUMENTATION OF TEST SPECIMENS

The test specimens were instrumented in accordance with the IJFT procedure, with an additional two thermocouples located in the central web. Thus, 13 thermocouples were attached to the rear wall of each test specimen and 5 thermocouples were inserted in the central web. The location of the thermocouples is shown in Figure 1.

2.3.1 Rear Wall Thermocouples

The thermocouples on the rear wall were made using 0.5 mm diameter, Type K thermocouple compensating cable. The cable consisted of one pair of solid conductors, each conductor was double glass fibre lapped, glass fibre braided, and silicone varnished. This insulation system was suitable for continuous use up to 480 C and for short term use up to 540 C.

Each selected attachment area on the back of the rear wall was cleaned to bright metal using a hand held grinder. Approximately 10 mm of fibreglass insulation was stripped back from each conductor. One conductor was positioned correctly on the substrate and attached using capacitive discharge spot welding. The other conductor was attached to the substrate, parallel to; in the same manner as; and a maximum of 3 mm from the first conductor , thus forming the thermocouple junction. A small rectangle of 0.002 inch thick stainless steel shim, approximately 25 mm by 15 mm was spot welded over the thermocouple junction. Similar small pieces of 0.002 inch thick shim were spot welded over the thermocouple cables onto the wall, thereby protecting the thermocouple junctions during handling of the test specimens. A typical thermocouple installed on the rear wall is shown in Photograph 1.

The device used in the capacitive discharge spot welding was a Model 700 Portable Strain Gauge Welding and Soldering Unit from Measurements Group Inc of Raleigh, North Carolina, US.

2.3.2 Central Web Thermocouples

The thermocouples in the central web were 3 mm diameter, 330 mm long, stainless steel sheathed, Type K thermocouples. These were mineral insulated, metal sheathed assemblies suitable for continuous use up to 1,100 C and for short terms up to 1,350 C. The thermocouple conductors from the sheaths were connected to 0.5 mm diameter Type K thermocouple compensating cable. This connection at the rear of the stainless steel sheath was insulated by ceramic fibre wrapped around the connection and held in place with twisted steel wire. This connection was considered suitable for temperatures up to 480 C.

Each 3 mm diameter stainless steel sheathed thermocouple was fitted with a stainless steel adjustable compression fitting with an 1/8 inch BSP tapered thread. The technique used to install these thermocouples in the central web is described below.

The 3 mm diameter sheathed thermocouple was inserted into the slot in the central web from behind the rear wall, Photograph 2. The front part of the adjustable compression fitting, which has the tapered thread, was screwed hand tight into the threaded hole in the rear wall. It was then unscrewed one turn. The rear part of the compression fitting was then tightened onto the front part. The thermocouple was then pushed fully into the slot. This was checked by measuring the length of thermocouple sheath protruding from the rear wall. Finally, the front part of the compression fitting was re-screwed back into the rear wall one turn, thereby pushing the thermocouple tip at the front of the slot into positive contact with the end of the slot.

2.4 APPLICATION OF PASSIVE FIRE PROTECTION

Two epoxy intumescent pfp materials were selected to coat the test specimens and in this report they will be referred to as Type 1 and Type 2. These materials were chosen since epoxy intumescents are used extensively for fire protection and can be vulnerable to jet fire attack. Consequently such material is suitable for the IJFT procedure. Two proprietary epoxy intumescents were selected to ensure that the results from the tests were not material specific.

The manufacturers of these materials were approached and asked to provide a specification for the application of their materials such that Type 1 would protect the test specimens for 40 minutes and Type 2 for 1 hour. Both materials were to be tested for 1 hour and it was expected that Type 1 material would fail before the end of the test and expose the bare metal of the test specimen. Type 2 material was not expected to fail before the end of the test. The following sections describe the preparation of the test specimens, the application of the pfp material and associated mesh retention systems.

For both Type 1 and Type 2 pfp materials, the application was carried out, with the agreement of the manufacturers, by Barrier Ltd. of Wallsend, Tyne and Wear, UK. The application was witnessed by representatives of British Gas and the respective manufacturers.

2.4.1 Type 1 pfp Material

Specification

The manufacturer of Type 1 pfp material specified the following preparation and application schedule:

The test specimens shall be grit blasted in accordance with Swedish Standard Sa 2.5 [2] with a minimum profile of 40 microns.

The area to be coated with the Type 1 pfp material shall be primed with an epoxy polyamide system from the manufacturers approved primers list. The maximum dry film thickness shall not exceed 50 microns.

3 mm diameter copper coated steel pins, 37 mm long, shall be welded to the test specimen at 300 mm centres on the areas to be coated. A metal mesh of 19 gauge galvanised steel with a 12.7 mm pitch shall be attached to the test specimens using the copper coated steel pins. On the rear wall and the side plates of the test specimen, the mesh shall be held flush with the surface. On the central web the mesh shall be held clear of the surface by 2 mm. No gaps in the mesh arrangement are permissible, all edges must be overlapped by a minimum of 50 mm and pinned at the edges.

Before application of the Type 1 pfp material, the surface of the primer must be clean and dry. An initial coat of 3 to 4 mm of the Type 1 pfp material shall be sprayed onto the test specimen. This material is to be trowelled and rolled to ensure good wetting of the surface of the test specimen and to eliminate voids. The rolling involves the use of a roller sprayed with a solvent. Once the solvent has evaporated from the surface, subsequent coats of the Type 1 pfp material shall be applied.

Only two component, solventless application is acceptable.

Once the Type 1 pfp material has cured, the thickness of the coating shall be measured by drilling holes through the coating and using conventional depth gauges. A minimum of 5 holes shall be drilled per plate.

A final thickness of 6 mm was specified for the rear wall and side plates and a final thickness of 10 mm was specified for the central web.

Pinning

The layout of the metal pins, used to attach the reinforcement mesh to a test specimen, is shown in Figure 2. The pin locations on each test specimen were ground down to bright metal and then 3mm diameter copper coated mild steel pins of 37mm length were welded at 300mm centres. This was carried out on 25th September 1994 using a Cutlass Clipper 8 capacitance discharge welding kit and this operation is shown in Photograph 3.

Surface Preparation

The surfaces of the test specimens were grit blasted prior to application of the Type 1 pfp material. The blasting was carried out on the 26th September 1994, in accordance with Swedish Standard Sa 2.5 [2]. Following the blasting, the surface profiles on each of the test specimens was measured by Barrier Ltd using an ISO surface profile comparator, and were found to be between 60 and 90 microns with an average of 75 microns on each test specimen. This was in excess of the minimum profile of 40 microns required and therefore met the manufacturer's specification.

Priming

A primer was applied to each sample to protect the surface from oxidisation after blasting. The primer used was an epoxy polyamide, Amercoat 71 manufactured by Ameron Protective Coatings. The test specimens were primed on 26th September 1994. The application was carried out using a spray applicator and is shown in Photograph 4. This product is one of the primers that the manufacturers of Type 1 pfp material have approved. The primer was spray applied to each of the test specimens in turn and both wet and dry film thickness measurements were carried out by a Barrier Ltd. The dry film thickness measurements were between 40 and 70 microns on each test specimen. The maximum allowable thickness defined in the specification was 50 microns. However, following discussions with the manufacturer's representative who was present throughout the application, the additional thickness of primer on the specimens was not considered sufficient to warrant removing and re-applying the primer. (It should be noted that the manufacturer does allow a primer thickness of up to 100 microns in areas of overlap between adjacent applications).

Mesh Installation

A 19 gauge, 12.7 mm galvanised metal mesh was installed on the 3rd October 1994. The arrangement of the mesh is shown in Figure 3, with overlaps as shown. 2 mm diameter galvanised steel wire was wrapped around the pins on the central web to facilitate a 2 mm stand-off of the wire mesh on the web. All edges were overlapped by a minimum of 50 mm and pinned at the edges.

Each test specimen was supplied with seven sections of metal mesh. The order of installation of the mesh was as follows:

Rear Wall	2 sections of mesh either side of the central web.
Upper and Lower Sides	1 section of mesh each, overlaps 50 mm with rear wall mesh
Left and Right Sides	1 section of mesh each, overlaps 50 mm with rear wall and upper and lower side meshes
Central Web	1 section of mesh wrapped around the web, overlaps 50 mm with rear wall and upper and lower side meshes

Application of Type 1 pfp Material

The Type 1 pfp material was applied to three of the test specimens over a two day period, on the 3rd and 4th October 1994.

The Type 1 pfp material was a two component system, a resin and a hardener which were required to be heated to a specific temperature and mixed in a specific ratio to allow the material to cure correctly.

The material was supplied by the manufacturer in metal containers which were stored, prior to application, in a compartment maintained at an elevated temperature.

The application was carried out using a Hydrocat airless, solventless, plural pump unit. This unit employs positive displacement pumps to provide an accurate delivery of specific quantities of the material, Photograph 5. The two components of the Type 1 pfp material were poured into separate containers which fed the positive displacement pumps of the Hydrocat unit. The components were heated using inline, controllable fluid heaters to 50 to 60 C. The plural pump unit supplied the two components to separate 3/4" I.D. hoses which were heated with water jackets to maintain the temperature of the components. The two components were mixed in a manifold and supplied to a mastic gun fitted with a tip which applied the Type 1 pfp material as a fan shaped spray approximately 150 mm to 250 mm in width.

The work carried out on the test specimens was undertaken in a large unheated building. To ensure suitable conditions for the application of the pfp material, the test specimens were located in an enclosure which provided a protected environment. The enclosure was formed from plastic sheeting and maintained at an ambient temperature of 18 to 20 C.

On the first day, the ambient temperature and relative humidity were measured inside the enclosure at 18 C and 73% respectively. The feed rate of the two components of the Type 1 pfp material from the Hydrocat pump was checked by removing the mixer manifold and measuring the mass of each component supplied by the pump in a known time period. This was measured as 2.64:1 resin to hardener which was within the manufacturer's tolerance. The temperature of the resin and hardener were 50 C and 48 C respectively, which was again within the manufacturers tolerance.

The application of the Type 1 pfp material to each of the test specimens was carried out by a team of three applicators. The first member of the team was equipped with the spray gun and applied the material to the test specimen. The material was then worked into the mesh and over the surface of the test specimen to an approximately even finish by the second member of the team using a trowel. The third member of the team then smoothed the surface of the Type 1 pfp material using a roller soaked in a solvent. The solvent, commonly known as PMA (2-Propyl 1- Methoxy Acetate), was used to slightly reduce the viscosity of the Type 1 pfp material and hence allow it to be worked further into the metal mesh and over the surface of the test specimen to ensure a uniform thickness of application.

The Type 1 pfp material was applied to a thickness of 3 mm to ensure good wetting of the test specimen surface and to encapsulate the metal mesh. Probes were used to check the thickness of the Type 1 pfp material over the test specimen as the application was being undertaken.

The Type 1 pfp material was applied to the test specimens in three stages. The first stage was to coat the inside surface of the top plate of a test specimen (including 50 mm of the outside surface as required in the IJFT procedure). This was repeated for each of the three test specimens in turn. The next stage was to coat the vertical sides (including 50 mm of the outside surface), central web and rear wall of each of the three test specimens in turn. The final stage was to coat the inside surface of the bottom plate (including 50 mm of the outside surface) of each of the three test specimens in turn. This process was repeated as the thickness of the Type 1 pfp material was built up.

When rolling of the Type 1 pfp material had been completed and the solvent evaporated, more material was spray applied to build up the thickness. The thickness was built up to 5 mm on the rear wall and all side plates and 9 mm on the central web. Again the material was trowelled and rolled to ensure an even thickness and to ensure that it was worked into the material which had been applied previously.

The Type 1 pfp material was then allowed to cure for 24 hours. After this time small holes were drilled into the material at a number of locations using an electric drill with a 1.5 mm diameter bit. Thickness gauges were inserted into the drilled holes to determine the thickness and hence the amount of Type 1 pfp material required to build up to the required thickness.

On the second day, the ambient conditions were a temperature of 13 C and a relative humidity of 59%. Resin and hardener samples taken from the Hydrocat, gave temperatures of 50 C and 48 C respectively and the mass ratio was 2.57:1. These values were within the manufacturer's tolerance.

The final coating of the Type 1 pfp material was then spray applied and rolled such that the thickness on the test specimens were 10 mm on the web and 6 mm on the other surfaces.

Thickness Checks

The thickness checks on the Type 1 pfp material coatings applied to the test specimens were carried out 4th October 1994. The measurements were taken approximately two hours after the final coating of Type 1 pfp material had been applied. An electric hand drill with a 2 mm diameter bit was used to drill through the Type 1 pfp material down to the underlying steel surface of the test specimen. The thickness of the Type 1 pfp material was measured using a depth gauge. The measurements of the thickness of the pfp material are presented in Section 4.1.

2.4.2 Type 2 pfp Material

Specification

The manufacturer of the Type 2 pfp material specified the following preparation and application schedule.

The test specimens shall be grit blasted to Swedish Standard SA 2.5 [2].

The area to be coated with the pfp material shall be primed, within four hours of grit blasting, with a suitable two pack epoxy rich zinc primer. The thickness of the primer to be between 40 and 80 microns although up to 120 microns is allowable in small areas of overlap. The primer shall be allowed to dry at room temperature for a minimum of 16 hours.

3 mm diameter steel pins, 25 mm long shall be welded to the test specimen in pairs, at a maximum of 300 mm centres on the areas to be coated with the Type 2 pfp material.

The reinforcement systems shall be installed and shall consist of:

i) 19 gauge, prewelded, galvanised steel mesh with 13 mm square openings, positioned nominally 5 mm from the steel substrate.

ii) a fabric mesh with 4 to 5 mm nominal free openings and a mass of 200 g/square metre or equivalent, positioned nominally 10 mm from the steel substrate. This is to be rolled into the wet coating during spray application of the Type 2 pfp material. Adjacent sections of fabric mesh shall be overlapped by 50 mm.

An initial coating of the Type 2 pfp material shall be applied to totally encapsulate the metal mesh. The initial coating shall be trowelled to ensure good wetting of the substrate, achieve the encapsulation of the mesh and eliminate voids. Further material shall be added until a thickness of 10 mm is achieved The fabric mesh shall be applied and rolled into the surface of the wet material. Further material shall be added until the total thickness is 13 mm (tolerance +1.5 mm, - 0.0 mm) The surface shall be trowelled and rolled to an acceptable finish. The trowels and roller may be lightly wetted with solvent.

The coated test specimens shall be allowed to cure for a minimum of 14 days, (preferably at 25 to 30 C in a heated chamber but at curing ambient temperature is acceptable) before being fire tested.

Pinning

The layout of the metal pins, used to attach the reinforcement mesh to a test specimen, is shown in Figure 2. The pin locations on each test specimen were ground down to bright metal and then pairs of 3mm diameter steel pins of 25 mm length were welded at 300mm centres. These areas were then primed using brush application. This was carried out on 21st September 1994 using a Cutlass Clipper 8 capacitance discharge welding kit.

Surface Preparation

The surfaces of the test specimens were grit blasted prior to application of the Type 2 pfp material. The blasting was carried out on the 22nd September 1994, in accordance with Swedish Standard Sa 2.5 [2]. The surface profiles on each of the test specimens was measured by Barrier Ltd using an ISO surface profile comparator and were found to be between 55 and 85 microns with an average of 70 microns on each test specimen.

Priming

A primer was applied to each sample to protect the surface from oxidisation after blasting. The primer used was an epoxy polyamide, Amercoat 71 manufactured by Ameron Protective Coatings. The test specimens were primed on 22nd September 1994. The primer was spray applied to each of the test specimens in turn and both wet and dry film thickness measurements were taken by a Barrier Ltd. The dry film thickness measurements were between 40 and 80 microns on each test specimen.

This was not the primer specified by the manufacturer, however, the manufacturer's representative who was present at the application agreed to its use.

In a written reply [3] to a subsequent query regarding this primer, the manufacturer stated that it was similar to one of their approved primers and they were satisfied as to its compatibility with their pfp material.

Mesh Installation

This section refers to the installation of the steel mesh prior to the application of the Type 2 pfp material. The fabric mesh was installed during the application of the Type 2 pfp material and will be described in that section below.

The 19 gauge, 12.7 mm galvanised metal mesh was installed on 29th September 1994. The arrangement of the mesh is shown in Figure 4. Before the mesh was installed, one of the pins in each pair was bent over to create a 5 mm stand off of the mesh from the steel substrate.

Each test specimen was supplied with seven sections of metal mesh. The order of installation of the mesh was as follows:

Rear Wall	2 sections of mesh either side of the central web.
Upper and Lower Sides	1 section of mesh each.
Left and Right Sides	1 section of mesh each.
Central Web	1 section of mesh wrapped around the web.

Application of Type 2 pfp Material

The Type 2 pfp material was applied to three of the test specimens over a two day period, on the 29th and 30th September 1994.

The Type 2 pfp material was a two component system, a resin and a hardener which were required to be heated to a specific temperature and mixed in a specific ratio to allow the material to cure correctly.

The material was supplied by the manufacturer in metal containers which were stored, prior to application, in a compartment maintained at an elevated temperature.

The application was carried out using a Hydrocat airless, solventless, plural pump unit. This unit employs positive displacement pumps to provide an accurate delivery of specific quantities of the material. The two components of the Type 2 pfp material were poured into separate containers which fed the positive displacement pumps of the Hydrocat unit. The components were heated using inline, controllable fluid heaters to 45 to 60 C. The plural pump unit supplied the two components to separate 3/4" I.D. hoses which were heated with water jackets to maintain the temperature of the components. The two components were mixed in a manifold and supplied to a mastic gun fitted with a tip which applied the Type 2 pfp material as a fan shaped spray approximately 150 mm to 250 mm in width.

The work carried out on the test specimens was undertaken in a large unheated building. To ensure suitable conditions for the application of the pfp material, the test specimens were located in an enclosure which provided a protected environment. The enclosure was formed from plastic sheeting and maintained at an ambient temperature of 18 to 20 C.

On the first day, the ambient temperature and relative humidity were measured inside the enclosure at 18 C and 73% respectively. The feed rate of the two components of the Type 2 pfp material from the Hydrocat pump was checked by removing the mixer manifold and measuring the mass of each component supplied by the pump in a known time period. This was measured as 2.77:1 resin to hardener which was within the manufacturer's tolerance. The temperature of the resin and hardener were 55 C and 45 C respectively, which was again within the manufacturer's tolerance.

The application of the Type 2 pfp material to each of the test specimens was carried out by a team of three applicators. The first member of the team was equipped with the spray gun and applied the material to the test specimen. The material was then worked into the mesh and over the surface of the test specimen to an approximately even finish by the second member of the team using a trowel. The third member of the team then smoothed the surface of the Type 2 pfp material using a roller lightly wetted with a solvent. The solvent, commonly known as PMA (2-Propyl 1- Methoxy Acetate), was used to slightly reduce the viscosity of the Type 2 pfp material and hence allow it to be worked further into the metal mesh and over the surface of the test specimen to ensure a uniform thickness of application. Photographs 6, 7 and 8 show the spraying, trowelling and rolling operations being carried out.

The Type 2 pfp material was applied to a thickness of 3 mm to ensure good wetting of the test specimen surface. Probes were used to check the thickness of the Type 2 pfp material over the test specimen as the application was being undertaken, Photograph 9.

2.5 SHIPMENT OF TEST SPECIMENS

Following the application of the Type 1 and Type 2 pfp materials to the test specimens, they were removed from the heated enclosure and stored in wooden crates which were located in a large unheated building. The crates had been purpose built to protect the coated test specimens during shipment to the test laboratories.

The crated test specimens were transported from Barrier Ltd on 7th October 1994. The two specimens to be tested at Buxton were delivered to the British Gas Engineering Research Station (ERS) at Killingworth, UK to allow inspection by members of the Jet Fire Working Group. Two specimens were shipped directly to SINTEF, arriving on the 20th October 1994, and two went directly to SwRI, arriving on the 11th November 1994. The two test specimens destined for Buxton were shipped from ERS on the 11th November 1994, arriving at Buxton on the 14th November 1994.

Digital thermometers were attached to the test specimens prior to crating to record the maximum and minimum temperatures experienced by the test specimens during transport. The digital thermometers were equipped to record the temperature measured by a probe attached to the test specimen and also to record the temperature measured inside the thermometer itself. The measurements made by the thermometers are presented in Section 4.1.

The Type 2 pfp material was applied to the test specimens in three stages. The first stage was to coat the inside surface of the top plate of a test specimen (including 50 mm of the outside surface as required in the IJFT procedure). This was repeated for each of the three test specimens in turn. The next stage was to coat the vertical sides (including 50 mm of the outside surface), central web and rear wall of each test specimen in turn. The final stage was to coat the inside surface of the bottom plate (including 50 mm of the outside surface) of each of the three test specimens in turn. This process was repeated as the thickness of the Type 2 pfp material was built up.

A further 6 mm of material was added in two steps of 3 mm. Thickness checks were made during the application, Photograph 9. At this stage the fabric mesh was installed. The mesh was in five sections and was installed as shown in Figure 5. Whilst the Type 2 pfp material was still wet, the sections of fabric mesh were laid on its surface and then, using a roller soaked in solvent, were worked into the still wet material, as shown in Photographs 10, 11 and 12. The sequence of applying the mesh was:

Upper and Lower Sides	1 section of mesh each
Left and Right Sides	1 section of mesh each, this mesh also covered half of the rear wall and overlapped upper and lower sides by 50 mm
Central Web	1 section of mesh, this mesh covered the remainder of the rear wall with a 50 mm overlap and overlapped the upper and lower sides by 50 mm

When the fabric mesh had been installed, more material was spray applied to encapsulate the mesh and to build up the thickness to 10 mm Again the material was trowelled and rolled to ensure an even thickness and that it was worked into the material which had been applied previously.

The Type 2 pfp material was then allowed to cure for 18 hours. After this time small holes were drilled into the material at a number of locations using an electric drill with a 1.5 mm diameter bit. Thickness gauges were inserted into the drilled holes to determine the thickness and hence the amount of Type 2 pfp material required to build up to the required thickness.

On the second day, the ambient conditions were a temperature of 18 C and a relative humidity of 65%. Resin and hardener samples taken from the Hydrocat, gave temperatures of 50 C and 48 C respectively and the mass ratio was 2.77:1. These values were within the manufacturer's tolerance.

The final coating of the Type 2 pfp material was then spray applied and rolled such that the thickness on the test specimens was 13 mm overall.

Thickness Checks

No further thickness check were made at Barrier Ltd after the final application of the Type 2 pfp material. The manufacturer was satisfied that the correct amount of material had been applied in the final application and that the thickness checks made during the application confirmed this.

3. TEST ARRANGEMENT

In this section, the test arrangements, procedures and measurements undertaken at the three test laboratories are described.

3.1 TEST FACILITY AND TEST SET-UP

3.1.1 SwRI

The IJFT procedure tests undertaken at SwRI were carried out in a large steel framed test hall, 12.2 m wide, 18.3 m long and 9.1 m high, Photograph 13. The sides and roof of the test hall were constructed from corrugated steel plates attached to the steel frame. Access to the test hall was through a large opening in one of the sides, Photograph 14. In addition, a door at the rear of the test hall was used as a location from which the tests were witnessed, Photograph 13. A second door in the middle of one of the sides of the test hall, led to the control room. The control room was continuously manned during the tests. Louvered openings were located around the base of the side walls of the test hall. A plan view of the test hall is shown in Figure 6.

The test specimen was located near the centre of the test hall on top of a steel framework which was protected by ceramic fibre blankets, Photographs 15 and 16. It was clamped, not bolted, to the 1 m deep uninsulated steel box which was used to protect the rear of the test specimen from draughts, Photograph 17. The base of the test specimen was approximately 1 m above the floor of the test hall. The floor of the test hall was protected by plaster boards, Photograph 18. During the tests, water was sprayed over the steel framework supporting the test specimen and also onto the floor. The test specimen was oriented such that it faced into the test hall away from the large opening in the side wall.

3.1.2 SINTEF

The IJFT procedure tests undertaken at SINTEF were carried out in a large double skinned test hall, 18 m wide, 36 m long and 22 m high, Photograph 19. The sides and roof of the test hall were constructed from two layers of corrugated steel plates attached to a steel frame. Air was blown between the two skins of corrugated steel to provide cooling to the walls. Access to the test hall was through a large opening in one of the walls, Photograph 20. The control room, containing the data logging equipment, was located beside the test hall, however access to the control room was some distance from the location from which the tests were witnessed. The control room was not continuously manned during the tests. A plan view of the test hall is shown in Figure 6.

The test specimen was bolted to the 1 m deep uninsulated steel box which was used to protect the rear of the test specimen from draughts, Photograph 21. The test specimen and steel box were placed on top of aerated concrete blocks, which were also built around the sides of the test specimen, Photograph 22. The gaps between the blocks and the test specimen were filled with a ceramic fibre blanket, Photograph 23. The base of the test specimen was approximately 1 m above the floor of the test hall and the test specimen itself was approximately 15 m from the large opening in the side of the hall. The floor of the test hall in front of the test specimen was protected by aerated concrete blocks, Photograph 22. During the tests, water was sprayed over the floor of the test hall. The test specimen was oriented such that it faced towards the large opening in the side wall and tests were witnessed through this large opening.

3.1.3 Buxton

The IJFT procedure tests undertaken at Buxton were carried out in a U shaped enclosure situated in the open air, Photograph 24. The enclosure was 4 m high, 3 m wide and 8 m long and consisted of brick walls on three sides. The walls were constructed from clay common bricks with a refractory brick lining. Access to the test enclosure was through the open side. The control room was located in a separate cabin a short distance from the test enclosure and was continuously manned during the tests. A plan view of the test enclosure and control room is shown in Figure 6.

The test specimen was bolted to the 1 m deep uninsulated steel box which was used to protect the rear of the test specimen from draughts. The test specimen and steel box were supported on a scaffolding frame and on a lightweight block wall at its front edge. The base of the test specimen was approximately 1 m above the floor of the enclosure. The concrete floor of the enclosure was covered in sand to protect the concrete. The lightweight block wall was positioned 3.8 m from the open side of the test enclosure. These blocks were also built up around the test specimen, Photograph 25. The gaps between the block walls and the test specimen were filled with a ceramic fibre blanket. The test specimen was oriented such that it faced towards the open side of the test enclosure and the tests were witnessed from this location.

3.2 GAS STORAGE AND DELIVERY SYSTEM

3.2.1 SwRI

SwRI was equipped with storage vessels capable of holding 3800 kg of commercial propane as a liquid under pressure. A vaporiser with a capacity of 1536 kg/hr was used to supply the test rig with propane vapour without a liquid fraction. The flow from the vaporiser was measured using a Daniels Model 2470 orifice plate flow meter which was located in a length of 76 mm diameter pipe downstream of the vaporiser. An upstream static pressure, a differential pressure across the orifice plate and a temperature compensation measurement were made and transferred to a computer which calculated the flow rate. The flow rate was controlled by a manually operated throttle valve downstream of the orifice plate flow meter.

3.2.2 SINTEF

Storage vessels at SINTEF were capable of storing approximately 24500 kg of commercial propane as a liquid under pressure. A vaporiser with a capacity of 4000 kg/hr was used to supply the test rig with propane vapour without a liquid fraction. The mass flow rate of the propane was measured using an ISA nozzle flow meter in the flow line. The meter, which was manufactured by Seiko Mess and Regeltechnik, Stockerau, Austria, measured the total and differential pressure and the gas temperature and this information was passed to a Contrec 415A flow computer mounted close to the flow meter. The computer calculated the flow rate and the accumulated consumption and displayed this information on an LCD on the flow computer. The information on pressure, temperature and gas flow was also passed to the data logger in the control room at 15 second intervals. The engineer responsible for monitoring and controlling the flow rate, used the flow rate displayed on the LCD to determine if any adjustments were necessary. Adjustments were made manually to a control valve in the flow line.

3.2.3 Buxton

The storage facilities at Buxton consisted of two 1700 kg capacity propane storage vessels mounted on a rectangular steel frame supported by a load cell at each corner. A vaporiser with a capacity of 2000 kg/hr was used to supply the test rig with propane vapour without a liquid fraction. The mass flow control system fitted to the test rig consisted of a 2 m long straight section of 2 inch pipework containing a pitot tube and a Camflex control valve. The pitot was connected to static and differential pressure transmitters, which sent signals to a controller situated in the control room. The controller used an algorithm to determine mass flow rate, and any difference between the measured flow rate and the controllers set point flow rate generated a signal to either open or close the Camflex control valve. The temperature of the propane in the flow control pipework was not used in the algorithm to calculate the mass flow rate, an assumed value of 20 C was used.

3.3 TEST PROCEDURE

The test procedure was similar for all three test laboratories and is described below. Where the procedure of one laboratory differed from those of the others, it is also noted below.

Before the Test

A test specimen was attached to the rear steel box and positioned on the support structure. Ceramic fibre blankets were positioned under the front edge of the test specimen. At SINTEF and Buxton, insulating blocks were positioned around the sides and top of the test specimen. The release nozzle was positioned perpendicular to the test specimen, 1.0 m from the rear wall, 0.375 m above the bottom plate and directed at the central web. At SINTEF, propane from the vaporiser was vented from the delivery pipework for a short time to check the flow.

Immediately Before the Test

Shortly before the start of the test, the thermocouples were checked at SwRI and Buxton. The ambient temperature and relative humidity were measured and recorded. At SwRI and SINTEF, cooling water for the floor was started. 35 mm photographs were taken of the test specimen. The data logging system was started. The video recording equipment was started. At SwRI a small pilot light in front of the nozzle was ignited.

Start of Test

The control valve was opened and the release of propane from the nozzle was ignited. At SINTEF and Buxton this was done by a technician with a burning rag on a long pole. At SwRI, the pilot light ignited the propane. The propane flow rate was increased to 0.3 kg/s and a stop watch was started.

During the Test

At SwRI and SINTEF, the flow rate was checked and manually adjusted as necessary. 35 mm photographs were taken at frequent intervals and a record was made of noticeable occurrences. Temperatures were monitored frequently.

End of Test

At the end of the test, the control valve was closed and once it was safe to do so, 35 mm photographs were taken of the test specimen.

One Hour After Test

At one hour after the flame had been extinguished, 35 mm photographs were taken of the test specimen and a post test investigation carried out. At Buxton, the temperature of the ground prevented this and the inspection was carried out later. (For test specimen C1 it was 1 hour 40 minutes after the end of the test and for test specimen C2 it was 18 hours after the end of the test).

3.4 DATA LOGGING

The procedure for monitoring and recording the temperature measurements made by the test specimen thermocouples was similar for all three test laboratories.

The thermocouples on the test specimen were connected to type K compensating cable which was in turn connected to the data logging system. The thermocouples were scanned throughout the test and measurements were recorded every 15 seconds. The temperatures were displayed on a computer screen in the control room. The flow rate was also monitored and recorded by the data logging system. The results from the tests were stored on floppy disk in LOTUS 1-2-3 format.

4. TEST RESULTS

In this section, the results from the tests undertaken at the three test laboratories are presented.

The six test specimens were identified by a two digit code according to the pfp material applied and the test laboratory where the testing occurred. The first digit was either A, B or C which referred to SwRI, SINTEF and Buxton respectively. The second digit was either 1 or 2 which referred to Type 1 and Type 2 pfp material respectively.

4.1 PRE-TEST INSPECTION

4.1.1 SwRI

Transportation Temperatures

Digital thermometers were attached to the test specimens prior to crating to record the maximum and minimum temperatures experienced by the test specimens during transport. The results from the thermometers are presented in Table 1. The digital thermometers were equipped to record the temperature measured by a probe attached to the test specimen and also to record the temperature measured inside the thermometer itself.

Visual Inspection

Both test specimens, A1 and A2, were inspected visually for signs of damage, shortly before testing. Slight abrasion was noticed on one outside edge of specimen A2, the length of the abraded area being less than 100 mm. This was considered insignificant. No other damage was visible.

Hardness Measurements

Hardness measurements were made at three locations, selected at random on both test specimens, shortly before testing. The areas selected were lightly sanded to ensure a flat surface and a hand held Shore 'D' hardness gauge was used to measure the hardness. Photographs 26 and 27 show a typical surface preparation carried out and the hardness gauge used. The locations where these measurements were taken are shown in Figure 7 and the results are presented in Table 2.

Thickness Measurements

Thickness measurements were made at 60 locations on both specimens, shortly before testing. On the rear wall and on the front edge of the central web, holes were drilled through the pfp material using a hand held electric drill with a 1.5 mm diameter bit. When the bit reached the steel substrate, the change in noise and the rate of penetration of the drill indicated that the steel had been reached. A 1 mm diameter steel rod was inserted into the hole and the depth of the hole marked on the rod. The rod was then withdrawn and the depth measured using a steel rule. The accuracy of this method was estimated as +/- 0.5 mm. The total thickness of the pfp material on both sides of the central web was measured using callipers. This measurement includes the thickness of the central web itself, 20 mm. The results from the thickness measurements are shown in Figures B1 to B6 in Appendix B. An average thickness on the rear wall and the central web was calculated for each test specimen and the results are presented in Table 3. Also presented in this table is the standard deviation of the thickness measurements from the mean thickness and the range of thickness measurements from minimum thickness to maximum thickness.

Thermocouple Checks

Each thermocouple on the test specimens was checked shortly before each test commenced. This was done by applying heat, from a small butane fuelled torch, to each thermocouple in turn and monitoring its response on the data logging system in the control room.

4.1.2 SINTEF

Transportation Temperatures

Digital thermometers were attached to the test specimens prior to crating to record the maximum and minimum temperatures experienced by the test specimens during transport. The results from the thermometers are presented in Table 1. The digital thermometers were equipped to record the temperature measured by a probe attached to the test specimen and also to record the temperature measured inside the thermometer itself.

Visual Inspection

Both test specimens, B1 and B2, were inspected visually for signs of damage, shortly before testing. No damage was visible.

Hardness Measurements

Hardness measurements were made at three locations, selected at random on both test specimens, shortly before testing. The areas selected were lightly sanded by hand to ensure a flat surface and a hand held Shore 'D' hardness gauge was used to measure the hardness. The locations where these measurements were taken are shown in Figure 8 and the results are presented in Table 2.

Thickness Measurements

Thickness measurements were made at 60 locations on both specimens, shortly before testing. On the rear wall and on the front edge of the central web, holes were drilled through the pfp material using a hand held electric drill with a 1.5 mm diameter bit. When the bit reached the steel substrate, the change in noise and the rate of penetration of the drill indicated that the steel had been reached. A Hydrocone needle gauge was used to measure the thickness and the accuracy of this method was estimated as +/- 0.5 mm. The total thickness of the pfp material on both sides of the central web was measured using callipers. This measurement includes the thickness of the central web itself, 20 mm. The results from the thickness measurements are shown in Figures B1 to B6 in Appendix B. An average thickness on the rear wall and the central web was calculated for each test specimen and the results are presented in Table 3. Also presented in this table is the standard deviation of the thickness measurements from the mean thickness and the range of thickness measurements from minimum thickness to maximum thickness.

Thermocouple Checks

Each thermocouple on the test specimens was checked shortly before each test commenced. This was done by applying heat, from a small butane fuelled torch, to each thermocouple in turn and monitoring its response on the data logging system in the control room.

4.1.3 Buxton

Transportation Temperatures

Digital thermometers were attached to the test specimens prior to crating to record the maximum and minimum temperatures experienced by the test specimens during transport. The results from the thermometers are presented in Table 1. The digital thermometers were equipped to record the temperature measured by a probe attached to the test specimen and also to record the temperature measured inside the thermometer itself.

Visual Inspection

Both test specimens, C1 and C2, were inspected visually for signs of damage, shortly before testing. No damage was visible.

Hardness Measurements

Hardness measurements were made at three locations, selected at random on both test specimens. The measurements were made on the 9th October 1994 while the specimens were at ERS. The areas selected were lightly sanded by hand to ensure a flat surface and a hand held Shore 'D' hardness gauge was used to measure the hardness. The locations where these measurements were taken are shown in Figure 9 and the results are presented in Table 2.

Thickness Measurements

Thickness measurements were made at 60 locations on both specimens, shortly before the tests. At all the locations, holes were drilled through the pfp material using a hand drill with a 1.5 mm bit. When the bit reached the steel substrate, the change in noise and the rate of penetration of the drill indicated that the steel had been reached. A Hydrocone needle gauge was used to measure the thickness and the accuracy of this method was estimated as +/- 0.5 mm. The results from the thickness measurements are shown in Figures B1 to B6 in Appendix B. An average thickness on the rear wall and the central web was calculated for each test specimen and the results are presented in Table 3. Also presented in this table is the standard deviation of the thickness measurements from the mean thickness and the range of thickness measurements from minimum thickness to maximum thickness.

Thermocouple Checks

Each thermocouple on the test specimens was checked shortly before each test commenced. This was done by applying heat, from an electric heat gun, to each thermocouple in turn and monitoring its response on the data logging system in the control room.

4.2 TEST CONDITIONS

4.2.1 SwRI

The temperature in the test hall at the start of the test on specimen A1 was 23 C and at the start of the test on specimen A2 was 13 C. The relative humidity was not measured.

4.2.2 SINTEF

The temperature and relative humidity in the test hall at the start of the test on specimen B1 was 8 C and 52% and at the start of the test on specimen B2 was 12 C and 52%.

4.2.3 Buxton

The temperature and relative humidity near the test enclosure at the start of the test on specimen C1 was 10 C and 96% and at the start of the test on specimen C2 was 12 C and 94%.

During the test on specimen C1, the wind speed varied between 3.0 and 10.0 m/s, but for most of the time was between 4.0 and 8.0 m/s. The wind direction was fairly stable and was generally blowing from an angle of -45 degrees to the central axis of the jet flame, where 0 degrees is in the direction of the jet flame and positive rotation is clockwise. The wind direction showed a maximum variation of +30 and -40 degrees from its general direction of -45 degrees, as shown in Figure 10a.

During the test on specimen C2, the wind speed varied between 2.0 and 8.5 m/s, but for most of the time was between 4.0 and 8.0 m/s. The wind direction was fairly stable and was generally blowing from an angle of -45 degrees to the central axis of the jet flame where 0 degrees is in the direction of the jet flame and positive rotation is clockwise. The wind direction showed a maximum variation of +80 and -70 degrees from its general direction of -45 degrees, as shown in Figure 10b.

4.3 TEST OBSERVATIONS

The photographs referred to in this section can be found in Appendix C.

4.3.1 SwRI

Test Specimen A1

The following observations were made during the testing of test specimen A1, which is shown, prior to the start of the test, in Photograph C1.

Time	Observation
0 min	Start of test. The main flow valve was opened and the flow of propane was ignited at the nozzle. The flow rate was increased to 0.3 kg/s. The main door of the test hall was fully open throughout the test.
10 sec	The test specimen was completely filled with flames, Photograph C2, and large pieces of char were blown off the test specimen.
2 min to 15 min	Continued to lose large pieces of char.
15 min to 41 min	Occasional loss of small pieces of char.
41 min to 70 min	Very little change seen during this period.
70 min	The main flow valve was closed and within 5 seconds the flame was extinguished.
0 min to 70 min	The flame was very stable throughout the test, Photographs C3 and C4.

Test Specimen A2

The following observations were made during the testing of test specimen A2, which is shown, prior to the start of the test, in Photograph C5.

Time	Observation
0 min	Start of test. The main flow valve was opened and the flow of propane was ignited at the nozzle. The flow rate was increased to 0.3 kg/s. The main door of the test hall was half closed at the start of the test, due to strong winds blowing outside.
10 sec	The test specimen was completely filled with flames, Photograph C6 and large pieces of char were blown off the test specimen.
2 min to 13 min	Occasional loss of large and small pieces of char.
13 min	Test hall door almost closed.
13 min to 17 min	Occasional loss of large and small pieces of char.
17 min	Test hall door fully closed.
17 min to 27 min	Occasional loss of large and small pieces of char.
27 min to 60 min	Very little change seen during this period.
60 min	The main flow valve was closed and within 5 seconds the flame was extinguished.
0 min to 60 min	The flame was very stable throughout the test, Photograph C7.

4.3.2 SINTEF

Test Specimen B1

The following observations were made during the testing of test specimen B1, which is shown, prior to the start of the test, in Photograph C8.

Time	Observation
0 min	Start of test. The main flow valve was opened and the flow of propane was ignited at the nozzle. The flow rate was increased to 0.3 kg/s. This took approximately 30 seconds. The main door of the test hall was fully open throughout the test.
30 sec	The test specimen was completely filled with flames, Photograph C9 and large pieces of char were blown off the test specimen.
2 min 30 sec	The rate at which char was blown off the specimen decreased.
7 min	The area on the test specimen impinged directly by the flame had turned black, other areas were grey/white.
11 min 30 sec	A few large pieces of char were blown off the test specimen.
12 min to 40 min	Small pieces of char continued to be blown off the test specimen throughout this period.
40 min to 70 min	Very little change was seen during this period.
70 min	The main flow valve was closed and within 5 seconds the flame was extinguished.
0 min to 70 min	The flame was very stable throughout the test, Photographs C10 and C11.

Test Specimen B2

The following observations were made during the testing of test specimen B2, which is shown, prior to the start of the test, in Photograph C12.

Time	Observation
0 min	Start of test. The main flow valve was opened and the flow of propane was ignited at the nozzle. The flow rate was increased to 0.3 kg/s. This took approximately 30 seconds. The main door of the test hall was fully open throughout the test.
30 sec	The test specimen was completely filled with flames and large pieces of char were blown off the test specimen, Photograph C13.
30 sec to 14 min	Large pieces of char blown off during this period.
15 min	The area on the test specimen impinged directly by the flame had turned dark brown by this time.
15 min to 53 min	Very little change was seen in this period.
53 min	A large piece of char was blown off the test specimen.
53 min to 60 min	Small pieces of char blown off occasionally.
60 min	The main flow valve was closed and within 5 seconds the flame was extinguished.
0 min to 60 min	The flame was very stable throughout the test, Photographs C14 and C15.

4.3.3 Buxton

Test Specimen C1

The following observations were made during the testing of test specimen C1, which is shown, prior to the start of the test, in Photograph C16.

Time	Observation
0 sec	Start of data logging.
15 sec	The manual valve was cracked open, the flow of propane to the nozzle was established and the jet was ignited.
20 sec	The manual valve was fully opened to give a flow rate of 0.3 kg/s. The flames completely filled the test specimen, Photograph C17.
20 sec to 16 min	Water vapour was seen to emanate from the walls and floor of the test cell.
1 min to 11 min	Small pieces of char were blown off the test specimen on approximately 8 occasions. On 3 of these occasions, larger pieces of char, 200 mm across, were blown off the test specimen.
20 min to 68 min	On at least 25 occasions, blooming of the jet flame was observed, sometimes accompanied by swirling flames and /or heavy smoke. The blooming lasted between 2 and 20 seconds but usually less than 10 seconds.
68 min	The liquid propane supply to the vaporiser was switched off.
70 min 20 sec	The jet flame was extinguished.
74 min	All flames on the test specimen were extinguished.
0 min to 70 min	The flame changed characteristics throughout the test. It altered between: i) the flame shown in Photograph C18, which produced very little smoke and was similar to the flames seen at SwRI and SINTEF (except that at Buxton it hugged the left hand wall of the test enclosure) and ii) the flame shown in Photograph C19, which was a swirling flame which engulfed the whole enclosure and produced heavy smoke.

Test Specimen C2

The following observations were made during the testing of test specimen C2, which is shown, prior to the start of the test, in Photograph C20.

Time	Observation
0 min	Start of data logging.
15 sec	The manual valve was cracked open, the flow of propane to the nozzle was established and the jet was ignited
20 sec	The manual valve was fully opened to give a flow rate of 0.3 kg/s. The flames completely filled the test specimen, Photograph C21.

1 min 24 sec	A plume of dense black smoke was observed, lasting a few seconds.
1 min to 16 min	On about 14 occasions, showers of small fragments of char were seen to be blown off the test specimen. On 3 of these occasions, larger fragments of char, approximately 200 mm across, were blown off the test specimen.
16 min to 31 min	Slight blooming of the flame was noticed on approximately 10 occasions. The blooming lasted between 3 to 10 seconds on these occasions.
31 min to 58 min	Stronger blooming and swirling of the jet flame occurred on about 30 occasions, sometimes accompanied by thick, black smoke, Photograph C23. The blooming lasted between 5 and 20 seconds but usually 5 to 6 seconds.
58 min	The liquid propane supply to the vaporiser was switched off.
60 min	The jet flame was extinguished.
71 min	All flames on the test specimen were extinguished.
0 min to 60 min	The flame changed characteristics throughout the test. It altered between: i) the flame shown in Photograph C22, which produced very little smoke and was similar to the flames seen at SwRI and SINTEF (except that at Buxton it hugged the left hand wall of the test enclosure) and ii) the flame shown in Photograph C23, which was a swirling flame which engulfed the whole enclosure and produced heavy smoke.

4.4 POST-TEST INSPECTION

4.4.1 Type 1 pfp Material

The results from the post test inspections carried out on the test specimens protected by Type 1 pfp material are presented in Appendices D and E. Appendix D contains photographs of the test specimens taken after the end of each test and Appendix E contains the results from detailed thickness measurements and sketches showing the locations of areas on the test specimens subjected to detailed destructive examination.

4.4.1.1 SwRI

Visual Inspection

A visual inspection was undertaken on the test specimen A1 one hour after the test had been terminated, Photographs D1 and D2. Figure 11 shows the locations a) to d) referred to below.

a) Black char was observed on the central web and on the rear wall of the area directly impinged by the jet fire. The char was strong and firmly bonded to the underlying material. The steel retaining mesh was fully enclosed in the char and was not visible, Photograph D3.

5. Right rear wall, mid height	Weak grey/white char, easily damaged. Steel mesh was intact and strong, no evidence of damage. No un-reacted pfp material.

4.4.1.2 SINTEF

Visual Inspection

A visual inspection was undertaken on the test specimen B1 one hour after the test had been terminated, Photographs D9 and D10. Figure 11 shows the locations a) to d) referred to below.

a) Black char was observed on the central web and on the rear wall of the area directly impinged by the jet fire. The char was strong and firmly bonded to the underlying material. The steel retaining mesh was fully enclosed in the char and was not visible, Photograph D11.

b) The lower 2/3 of both the left and right halves of the rear wall was covered in a light grey char which was weak and easily damaged. The underlying steel mesh was visible, showing through the char in many locations. The steel mesh appeared intact, Photograph D10.

c) The upper 1/3 of both the left and right halves of the rear wall was covered in a thick black char, which was weakly attached to the underlying material. The steel mesh was fully enclosed in the char and was not visible, Photograph D10.

d) The upper area on the central web, above the area directly impinged by the jet fire, had been stripped clean of pfp material and char and the steel substrate was visible over a length of 450 mm, Photograph D12.

Thickness Measurements

The thickness of the char on the rear wall and the central web was measured at a number of locations. A metal probe was pushed firmly into the char until it contacted the steel substrate of the test specimen, Photograph D13. The depth was marked on the metal probe and measured using a steel ruler after the metal probe had been withdrawn. The measurements are summarised in Figures E1 and E3.

Destructive Examination

Following the visual inspection and thickness measurements, an examination was made on selected areas of the test specimen. The examination involved removing the overlying char, cutting through the retaining meshes and removing the underlying char or un-reacted pfp material, Photograph D14. The observations made in carrying out this examination are detailed below. The locations referred to in the text are shown in Figure E6.

b) The lower 2/3 of both the left and right halves of the rear wall was covered in a light grey char which was weak and easily damaged. The underlying steel mesh was visible, showing through the char in many locations. The steel mesh appeared intact, Photograph D2.

c) The upper 1/3 of both the left and right halves of the rear wall was covered in a thick black char, which was weakly attached to the underlying material. The steel mesh was fully enclosed in the char and was not visible, Photograph D2.

d) The upper area on the central web, above the area directly impinged by the jet fire was covered in a grey char which was strongly attached to the underlying material, Photograph D4. The underlying steel mesh was fully enclosed in the char and was not visible. A large fissure ran vertically down the front edge of the char for a distance of 490 mm. The fissure did not penetrate to the steel mesh.

Thickness Measurements

The thickness of the char on the rear wall and the central web was measured at a number of locations. A metal probe was pushed firmly into the char until it contacted the steel substrate of the test specimen. The depth was marked on the metal probe and measured using a steel ruler after the metal probe had been withdrawn. The measurements are presented in Figures E1 and E2.

Destructive Examination

Following the visual inspection and thickness measurements, an examination was made on selected areas of the test specimen. The examination involved removing the overlying char, cutting through the retaining meshes and removing the underlying char or un-reacted pfp material, Photograph D5. The observations made in carrying out this examination are detailed below. The locations referred to in the text are shown in Figure E5.

Location	Observation
1. Central web impinged by jet fire	Black char with a solid surface, firmly attached to underlying material. Steel mesh was intact and strong, no evidence of damage. No un-reacted pfp material, Photograph D6.
2. Left rear wall, mid height	Weak grey/white char, easily damaged with steel mesh visible. Steel mesh was intact and strong, no evidence of damage. No un-reacted pfp material, Photograph D7.
3. Left rear wall, upper height	Black char, weakly attached to underlying material. Steel mesh was intact and strong, no evidence of damage. No un-reacted pfp material.
4. Central web, above impinged area	Strong grey char, firmly attached to underlying material. Large fissure ran along edge of web. Steel mesh was intact and strong, no evidence of damage. No un-reacted pfp material, Photograph D8.

Location	Observation
1. Central web impinged by jet fire	Black char with a solid surface, firmly attached to underlying material. Steel mesh was intact and strong, no evidence of damage. No un-reacted pfp material on front edge, but partially reacted pfp material visible on sides of central web.
2. Left rear wall, mid height	Weak grey/white char, easily damaged with steel mesh visible. Steel mesh was intact and strong, no evidence of damage. No un-reacted pfp material, Photograph D15.
3. Left rear wall, upper height	Black char, weakly attached to underlying material. Steel mesh was intact and strong, no evidence of damage. No un-reacted pfp material, Photograph D15.
4. Central web, above impinged area	Steel substrate uncovered for 450 mm. No char or un-reacted material visible. Steel mesh was badly damaged, Photograph D16.

4.4.1.3 Buxton

Visual Inspection

A visual inspection was undertaken on the test specimen C1 one hour and 40 minutes after the test had been terminated, Photographs D17 and D18. Figure 11 shows the locations a) to d) referred to below.

a) Black char was observed on the central web and on the rear wall of the area directly impinged by the jet fire. The char was strong and firmly bonded to the underlying material. The steel retaining mesh was fully enclosed in the char and was not visible, Photograph D19.

b) The lower 2/3 of both the left and right halves of the rear wall was covered in a light grey char which was weak and easily damaged. The underlying steel mesh was visible, showing through the char in many locations. The steel mesh appeared intact, Photograph D17.

c) The upper 1/3 of both the left and right halves of the rear wall was covered in a thick black char, which was weakly attached to the underlying material. The steel mesh was fully enclosed in the char and was not visible, Photograph D17.

d) The upper area on the central web, above the area directly impinged by the jet fire, had been stripped clean of pfp material and char and the steel substrate was visible over a length of 330 mm, Photograph D20.

Thickness Measurements

The thickness of the char on the rear wall and the central web was measured at a number of locations. A metal probe was pushed firmly into the char until it contacted the steel substrate of the test specimen. The depth was marked on the metal probe and measured using a steel ruler after the metal probe had been withdrawn. The measurements are presented in Figures E1 and E4.

Destructive Examination

Following the visual inspection and thickness measurements, an examination was made on selected areas of the test specimen. The examination involved removing the overlying char, cutting through the retaining meshes and removing the underlying char or un-reacted pfp material, Photograph D21. The observations made in carrying out this examination are detailed below. The locations referred to in the text are shown in Figure E7.

Location	**Observation**
1. Central web impinged by jet fire	Black char with a solid surface, firmly attached to underlying material. Steel mesh was intact and strong, no evidence of damage. No un-reacted pfp material on front edge, but partially reacted pfp material visible on sides of central web, photograph D22..
2. Left rear wall, mid height	Weak grey/white char, easily damaged with steel mesh visible. Steel mesh was intact and strong, no evidence of damage. No un-reacted pfp material, Photograph D24.
3. Left rear wall, upper height	Black char, weakly attached to underlying material. Steel mesh was intact and strong, no evidence of damage. No un-reacted pfp material.
4. Central web, above impinged area	Steel substrate uncovered for 530 mm. No char or un-reacted material visible. Steel mesh was badly damaged.
5. Right rear wall, mid height	Weak grey/white char, easily damaged. Steel mesh was intact strong, no evidence of damage. No un-reacted pfp material, Photograph D23.

4.4.2 Type 2 pfp Material

The results from the post test inspections carried out on the test specimens protected by Type 2 pfp material are presented in Appendices F and G. Appendix F contains photographs of the test specimens taken after the end of each test and Appendix G contains the results from detailed thickness measurements and sketches showing the locations of areas on the test specimens subjected to detailed destructive examination.

4.4.2.1 SwRI

Visual Inspection

A visual inspection was undertaken on the test specimen A2 one hour after the test had been terminated, Photographs F1 and F2. Figure 11 shows the locations a) to d) referred to below.

a) Black char was observed on the central web and on the rear wall of the area directly impinged by the jet fire. The char was strong and firmly bonded to the underlying material. The fabric and steel retaining meshes were not visible, Photograph F3.

b) The lower 2/3 of both the left and right halves of the rear wall was covered in a dark grey char which was weak and easily damaged. The underlying fabric mesh was visible, showing through the char in many locations. The steel mesh was not visible, Photograph F2.

c) The upper 1/3 of both the left and right halves of the rear wall was covered in a thick, dark grey char, which was weakly attached to the underlying material. The fabric and steel meshes were not visible, Photograph F2.

d) The upper area on the central web, above the area directly impinged by the jet fire was covered in a grey char. The underlying fabric mesh was not visible. A few glassy droplets were observed in the area, Photograph F4. Following discussions with the manufacturer, this was identified as borate glass originating from the Type 2 pfp material.

Thickness Measurements

The thickness of the char on the rear wall and the central web was measured at a number of locations. A metal probe was pushed firmly into the char until it contacted the steel substrate of the test specimen. The depth was marked on the metal probe and measured using a steel ruler after the metal probe had been withdrawn. The measurements are presented in Figures G1 and G2.

Destructive Examination

Following the visual inspection and thickness measurements, an examination was made on selected areas of the test specimen. The examination involved removing the overlying char, cutting through the retaining meshes and removing the underlying char or un-reacted pfp material. The observations made in carrying out this examination are detailed below. The locations referred to in the text are shown in Figure G5.

Location	Observation
1. Left rear wall, mid height	Dark grey/black char with fabric mesh exposed. Fabric mesh was intact but weak and brittle. Steel mesh was enclosed in char and was intact and strong. There was 0.5 mm of un-reacted pfp material, Photograph F7.
2. Central web, impinged by jet fire	Black char, strong and firmly attached to the underlying material. No mesh was visible. Fabric and steel meshes were strong and intact. There was 2.5 mm of un-reacted pfp material and 4.5 mm of partially reacted pfp material, Photograph F6.
3. Right rear wall, mid height	Dark grey/black char with fabric mesh exposed. Fabric mesh was intact but weak and brittle. Steel mesh was enclosed in char and was intact and strong.

	There was 1.0 mm of un-reacted pfp material, Photograph F8.
4. Central web, above impinged area	Grey char, strong and firmly attached to underlying material. Fabric mesh was not visible, but glassy droplets were visible. Steel mesh was enclosed in char and was intact and strong. There was no un-reacted pfp material, Photograph F5.

4.4.2.2 SINTEF

Visual Inspection

A visual inspection was undertaken on the test specimen B2 one hour after the test had been terminated, Photographs F9 and F10. Figure 11 shows the locations a) to d) referred to below.

a) Black char was observed on the central web and on the rear wall of the area directly impinged by the jet fire. The char was strong and firmly bonded to the underlying material. The fabric and steel retaining meshes were not visible, Photograph F11.

b) The lower 2/3 of both the left and right halves of the rear wall was covered in a dark grey char which was weak and easily damaged. The underlying fabric mesh was visible, showing through the char in many locations. The steel mesh was not visible, Photograph F10.

c) The upper 1/3 of both the left and right halves of the rear wall was covered in a thick black char, which was weakly attached to the underlying material. The fabric and steel meshes were not visible, Photograph F10.

d) The upper area on the central web, above the area directly impinged by the jet fire was covered in a grey char. The underlying fabric mesh was visible and glassy droplets covered the area, Photograph F12.

Thickness Measurements

The thickness of the char on the rear wall and the central web was measured at a number of locations. A metal probe was pushed firmly into the char until it contacted the steel substrate of the test specimen. The depth was marked on the metal probe and measured using a steel ruler after the metal probe had been withdrawn. The measurements are summarised in Figures G1 and G3.

Destructive Examination

Following the visual inspection and thickness measurements, an examination was made on selected areas of the test specimen. The examination involved removing the overlying char, cutting through the retaining meshes and removing the underlying char or un-reacted pfp material, Photograph F13. The observations made in carrying out this examination are detailed below. The locations referred to in the text are shown in Figure G6.

Location	Observation
1. Left rear wall, mid height	Dark grey/black char with fabric mesh exposed. Fabric mesh was intact but weak and brittle. Steel mesh was enclosed in char and was intact and strong. There was approximately 2 to 3 mm of un-reacted pfp material, Photograph F15.
2. Central web, impinged by jet fire	Black char, strong and firmly attached to the underlying material. No mesh was visible. Fabric and steel meshes were strong and intact. There was 8 mm of un-reacted pfp material and partially reacted pfp material.
3. Right rear wall, mid height	Dark grey/black char with fabric mesh exposed. Fabric mesh was intact but weak and brittle. Steel mesh was enclosed in char and was intact and strong. There was no un-reacted pfp material, Photograph F16.
4. Central web, above impinged area	Grey char, strong and firmly attached to underlying material. Fabric mesh was visible and damaged. Glassy droplets were visible. Steel mesh was enclosed in char and was intact and strong. There was no un-reacted material, Photograph F14.

4.4.2.3 Buxton

Visual Inspection

A visual inspection was undertaken on the test specimen C2 eighteen hours after the test had been terminated, Photographs F17 and F19. Figure 11 shows the locations a) to d) referred to below.

a) Black char was observed on the central web and on the rear wall of the area directly impinged by the jet fire. The char was strong and firmly bonded to the underlying material. The fabric and steel retaining meshes were not visible.

b) The lower 2/3 of both the left and right halves of the rear wall was covered in a dark grey char which was weak and easily damaged. The underlying fabric mesh was visible, showing through the char in many locations. The steel mesh was not visible, Photograph F19.

c) The upper 1/3 of both the left and right halves of the rear wall was covered in a thick black char, which was weakly attached to the underlying material. The fabric and steel meshes were not visible, Photograph F19.

d) The upper area on the central web, above the area directly impinged by the jet fire was covered in a grey char. The underlying fabric mesh was visible and glassy droplets covered the area, photograph F18.

Thickness Measurements

The thickness of the char on the rear wall and the central web was measured at a number of locations. A metal probe was pushed firmly into the char until it contacted the steel substrate of the test specimen. The depth was marked on the metal probe and measured using a steel ruler after the metal probe had been withdrawn. The measurements are presented in Figures G1 and G4.

Destructive Examination

Following the visual inspection and thickness measurements, an examination was made on selected areas of the test specimen. The examination involved removing the overlying char, cutting through the retaining meshes and removing the underlying char or un-reacted pfp material, Photograph F20. The observations made in carrying out this examination are detailed below. The locations referred to in the text are shown in Figure G7.

Location	Observation
1. Left rear wall, mid height	Dark grey/black char with fabric mesh exposed. Fabric mesh was intact but weak and brittle. Steel mesh was enclosed in char and was intact and strong. There was approximately 2 mm of un-reacted pfp material, Photograph F22.
2. Central web, impinged by jet fire	Black char, strong and firmly attached to the underlying material. No mesh was visible. Fabric and steel meshes were strong and intact. There was no un-reacted pfp material.
3. Right rear wall, mid height	Dark grey/black char with fabric mesh exposed. Fabric mesh was intact but weak and brittle. Steel mesh was enclosed in char and was intact and strong. There was 0.5 mm of un-reacted pfp material, Photograph F23.
4. Central web, above impinged area	Grey char, strong and firmly attached to underlying material. Fabric mesh was visible and damaged. Glassy droplets were visible. Steel mesh was enclosed in char and was intact and strong. There was no un-reacted pfp material, Photograph F21.

4.5 FLOW MEASUREMENT

4.5.1 SwRI

Graphs of the propane mass flow rate versus time for the tests on specimens A1 and A2 are shown in Figure H1 in Appendix H.

For the test on A1, the target flow rate of 0.3 kg/s was quickly achieved and maintained throughout the test. Very little adjustment was required.

For the test on A2, the initial flow rate for the first few minutes was greater the 0.3 kg/s, during the next ten minutes the flow rate was slightly less than 0.3 kg/s. Following this, the flow rate oscillated about 0.3 kg/s by approximately +/-0.005 kg/s with a period of 3 minutes.

The total quantity of propane consumed in the tests was not measured.

4.5.2 SINTEF

Graphs of the mass flow rate versus time for the tests on specimens B1 and B2 are shown in Figure H2 in Appendix H.

For the test on specimen B1, the flow quickly achieved 0.28 kg/s but then fell back to 0.24 kg/s for an instant before increasing again. After 3 minutes, the flow rate stabilised at 0.3 kg/s and remained fairly constant for the remainder of the test. An adjustment made after 40 minutes caused some oscillations in the flow rate for approximately 12 minutes. The oscillations varied between 0.315 kg/s and 0.285 kg/s.

For the test on B2, the target flow rate of 0.3 kg/s was achieved within 2 minutes. However, the flow varied between 0.32 kg/s and 0.28 kg/s for a further 4 minutes when the flow rate stabilised. From 6 minutes to 40 minutes the flow rate was slightly greater than 0.3 kg/s and an adjustment was made at 40 minutes to reduce the flow rate below 0.3 kg/s for the remaining 20 minutes of the test.

The total quantity of propane consumed in the tests was 1259.3 kg for the test on B1 and 1085.7 kg for the test on B2. This gave an average flow rate of 0.30 kg/s for B1 and 0.30 kg/s for B2.

4.5.3 Buxton

Graphs of the mass flow rate versus time for the tests on specimens C1 and C2 are shown in Figure H3 in Appendix H.

For the test on specimen C1, the flow rate of 0.3 kg/s was achieved very quickly. However, the flow rate oscillated between 0.34 kg/s and 0.27 kg/s for the first 35 minutes of the test. After this time, the flow rate stabilised and the maximum difference from the required 0.3 kg/s was less than 0.01 kg/s. However, a linear regression analysis (carried out by Buxton) of the data from the load cell measurements shows the average flow rate to be 0.3285 kg/s. It is therefore believed that the graph of mass flow against time for specimen C1, Figure H3, is in error.

The error in the control of the mass flow rate was realised following the test on specimen C1. The mass flow rate controller was therefore set to provide 0.29 kg/s for the test on specimen C2 in the belief that this would yield a true flow rate close to 0.3 kg/s.

For the test on specimen C2, the flow rate of 0.29 kg/s was quickly achieved, however, in the first 5 minutes it dropped to 0.1 kg/s, 0.25 kg/s and 0.23 kg/s for short periods, before stabilising on 0.29 kg/s. The flow rate remained on 0.29 kg/s for the remainder of the test. A linear regression analysis (carried out by Buxton), of the data from the load cell measurements shows the average flow rate to be 0.290 kg/s. Therefore the graph of mass flow rate against time for specimen C2, Figure H3, is believed to be correct.

The total quantity of propane consumed in the tests was 1388 kg for the test on C1 and 1035 kg for the test on C2.

4.6 TEMPERATURE MEASUREMENTS

4.6.1 Type 1 pfp Material

The measurements from the thermocouples attached to the test specimens coated with Type 1 pfp material are presented in Figures I1 to I18 in Appendix I. Each figure contains the temperature versus time profile for one thermocouple location from all three test laboratories. In addition Figure I19 and Table I1 contain a summary of the temperatures reached on each thermocouple at the end of the test.

Rear Wall Temperatures

Figures I1 to I13 contain the results from the thermocouples attached to the rear wall, thermocouple positions 1 to 13 (see Figure 1).
In general there was good agreement between the results from the test laboratories, for example Figure I7, thermocouple at position 7. In the majority of these graphs, the temperatures measured during the test carried out at the SINTEF test laboratory were slightly lower than the results from the other two laboratories.

In addition, there was good agreement between the results from the thermocouples placed symmetrically about the central web, thermocouples at positions 1 and 3, 4 and 6, 8 and 10, and 11 and 13.

Central Web Temperatures

Figures I14 to I18 contain the results from the thermocouples attached to the central web, thermocouple positions 14 to 18, (see Figure 1).

There was a major difference in the response of the central web between the test laboratories, Figure I15, thermocouple at position 15. At this location, similar temperatures were measured at the three laboratories for the first 35 minutes, however, the temperatures measured from 35 to 70 minutes in the test carried out at SwRI were significantly lower than the temperatures measured during the same period at SINTEF and Buxton.

The temperatures measured on the other thermocouples in the central web showed reasonable agreement between the test laboratories, the best agreement was shown by the results from the thermocouple at position 18, located at the bottom of the web.

(Note: The measurements made by thermocouples at positions 14 and 16 during the test on test specimen C1 at Buxton recorded temperatures which decreased monotonically as the test progressed. This was clearly an error. Subsequent correction of the data from these two thermocouples, by the supplier of the data logging system, produced the results shown in Figures I14 and I16. The reason for recording decreasing temperatures was not discovered. The same thermocouples were used, and connected in the same way, for the test on specimen C2, in which they behaved as expected giving temperatures which increased with time).

The table shows that the temperatures measured on the test specimen tested at Buxton are generally higher than the average temperatures and the temperatures measured on the test specimen tested at SINTEF are generally lower than the average temperatures.

End of Test Temperatures

The temperature rise above the initial temperature, measured by each thermocouple at the end of the test, is shown in Figure I19 and Table I1. The table also shows the average temperature over the three tests carried out at the three test laboratories calculated for each thermocouple location and the difference from the average expressed as a percentage of the average.

The table shows that the temperatures measured on the test specimen tested at Buxton are generally higher than the average temperatures.

4.6.2 Type 2 pfp Material

The measurements from the thermocouples attached to the test specimens coated with Type 2 pfp material are presented in Figures J1 to J18 in Appendix J. Each figure contains the temperature versus time profile for one thermocouple location from all three test laboratories. In addition Figure J19 and Table J1 contain a summary of the temperatures reached on each thermocouple at the end of the test.

Rear Wall Temperatures

Figures J1 to J13 contain the results from the thermocouples attached to the rear wall, thermocouple positions 1 to 13 (see Figure 1).

In general there was reasonable agreement between the results from the test laboratories. In the majority of these graphs, the results from SINTEF were slightly lower than the results from the other two laboratories.

In addition, there was good agreement between the results from the thermocouples placed symmetrically about the central web, thermocouples at positions 1 and 3, 4 and 6, 8 and 10, and 11 and 13.

Central Web Temperatures

Figures J14 to J18 contain the results from the thermocouples attached to the central web, thermocouple positions 14 to 18 (see Figure 1).

There was a difference in the response of the central web between the test laboratories which is most noticeable in Figures J15 and J16, thermocouples at positions 15 and 16.. At these locations, the temperatures measured in the test carried out at Buxton were significantly higher than the temperatures measured at SINTEF and SwRI.

End of Test Temperatures

The temperature rise above the initial temperature, measured by each thermocouple at the end of the test, is shown in Figure J19 and Table J1. The table also shows the average temperature over the three tests carried out at the three test laboratories calculated for each thermocouple location and the difference from the average expressed as a percentage of the average.

in areas of overlap between adjacent applications and up to 100 microns is acceptable. For this reason it is considered that the thickness of the primer on the specimens protected by Type 1 pfp material is acceptable.

The thickness measurements made of pfp material on each test specimen is discussed in 5.6 below.

The amount of time the coating of pfp material on each test specimen was allowed to cure before testing was determined by the testing schedule at each of the test laboratories. These times are quoted below:-

Test Specimen	Time (days)	Test Specimen	Time (days)
A1	48	A2	54
B1	34	B2	40
C1	48	C2	54

The differences in time allowed for curing is not considered significant in terms of the performance of the test specimens in the tests.

5.4 TEST SPECIMEN SET-UP

The test specimens were mounted differently at each test laboratory. At SwRI, they were mounted on a steel frame, at SINTEF on aerated concrete blocks and at Buxton on steel scaffolding. This did not appear to have any effect on the jet fire or on the test.

The protection around the test specimens differed at each laboratory. At SwRI no protection was installed around the sides or across the top of the specimen and rear box. At SINTEF and Buxton, blocks were mounted around the sides and across the top of the specimen with the intention of preventing the rear box and consequently the back of the rear wall from receiving heat. At SwRI there was no evidence of the flames passing around the sides or across the top of the test specimen and the rear box. It was not possible to determine whether or not radiation from the flames incident upon the rear box was significant since appropriate measurements were not made.

The attachment of the test specimen to the rear box at SwRI was achieved using four clamps, whereas at SINTEF and Buxton a number of bolts were used. Both methods proved capable of holding the test specimen onto the rear box.

5.5 AMBIENT CONDITIONS

The ambient temperature and relative humidity were measured at SINTEF and Buxton and the ambient temperature was measured at SwRI. The ambient temperature was a minimum of 8 C measured at SINTEF and a maximum of 23 C measured at SwRI. The differences in ambient temperature were not considered to be significant.

A high relative humidity was measured at Buxton on both test days.

It should be noted that during the tests at SwRI and also at SINTEF, the floor of the test hall was sprayed with water to keep it cool and prevent damage to the concrete. The thermal radiation from the jet fire caused the water on the floor to be evaporated

5. DISCUSSION

5.1 TEST SPECIMEN DESIGN AND MANUFACTURE

The design of the test specimens was based on the design described in the IJFT procedure [1]. The design was modified to accommodate the insertion of 3 mm diameter stainless steel sheathed thermocouples in the central web, which were installed shortly before testing. The design required an accurate matching of the slots machined in the central web with the drilled and tapped holes in the rear wall. The manufacturers reported no problems in fabricating the test specimens in accordance with the modified design and achieving the matching of the slots and tapped holes. They commented that the test specimens were constructed using normal working practice with no special precautions or techniques.

Full engineering drawings of the test specimen with the central web have been produced and are enclosed at the rear of this report.

5.2 TEST SPECIMEN INSTRUMENTATION

The thermocouples attached to the rear wall of the test specimen were installed prior to application of the pfp material. Therefore they were vulnerable to damage during transportation, application of the pfp material and test set-up. The use of small steel shims, spot welded over the thermocouple junctions and also spot welded over the thermocouple leads onto the rear wall provided protection for the thermocouples during handling of the test specimen. No damage was observed to these thermocouples.

The 3 mm diameter stainless steel sheathed thermocouples were inserted in the slots in the central web via the tapped holes in the rear wall, shortly before the tests. The installation of these thermocouples was relatively simple, although care had to be taken to avoid damage to the threads on the tapped hole and the thin steel sheath as the compression fitting was being fitted. In addition, it was important to ensure that the thermocouple was pushed fully into the slot when the compression fitting was being tightened. These thermocouples were re-used on a number of occasions without difficulty.

5.3 APPLICATION OF PFP MATERIAL

The application of the two pfp materials to the test specimens was undertaken such that the respective test specimens were coated virtually simultaneously. Thus, they were coated under the same conditions with the same material by the same people at the same time. This ensured a consistent and uniform application of pfp materials to the specimens. From the observations and measurements made during the application and presented in this report, it is concluded that this was achieved.

The thickness of the primer on the specimens protected by Type 1 pfp material was measured to be between 40 and 70 microns. The maximum allowable thickness was specified to be 50 microns. It is important that the thickness of the primer is not too large since it may become a layer of weakness which could fail prematurely and hence cause the pfp material to become disbonded from the steel substrate. However, the manufacturer of Type 1 pfp material does allow the primer to exceed 50 microns and hence the relative humidity in the test halls during these tests would have been significantly higher than that measured at the start of the tests.

5.6 PRE-TEST MEASUREMENTS

The test specimens were transported to the test laboratories in specially designed wooden crates to avoid damage to the pfp material on the specimens. This was successful in that only one test specimen showed any evidence of slight damage during the pre-test inspections. A small abrasion over a length of 100 mm was observed on the outside edge of specimen A2. This was not considered to be significant.

The measurements made by the digital thermometers during transportation showed that the maximum temperatures reached by the test specimens shipped to SwRI, SINTEF and Buxton were 27 C, 20 C and 25 C respectively. The corresponding minimum temperatures were 5 C, 1 C and 11 C respectively. The difference in these values was not considered to be significant.

(Note: The maximum temperature of 34 C measured by the thermometer probe attached to test specimen C2 was thought to be in error. It is thought that the probe was handled at some time during the removal of the test specimen from the transportation crate).

The hardness measurements made on the pfp material coating the test specimens were in reasonable agreement with each other. The maximum and minimum values for the two types of pfp material were 75 and 69 for Type 1 and 77 and 64 for Type 2. The differences for each type of pfp material were not considered to be significant.

The average thickness of the pfp material on the rear wall and central web of the test specimens coated with Type 2 pfp material was reasonably consistent, the variation about the nominal depth of 13 mm, (which was also the specified depth), was +8% (14 mm) and -5% (12.6 mm). The range of individual thickness measurements was much larger, from a minimum thickness of 8.5 mm to a maximum thickness of 17.0 mm.

The average thickness of the pfp material on the rear wall and central web of the test specimens coated with Type 1 pfp material was also reasonably consistent. In this case however, the thickness of material applied was slightly different to that specified by the manufacturer (which was 10.0 mm on the central web and 6 mm on the rear wall) and a nominal thickness has therefore been calculated as the average thickness across the three test specimens. This gave values of 9.3 mm on the central web and 6.9 mm on the rear wall. The variation about these nominal depths was +8% (10 mm) and -6%(8.7 mm) for the web and +2% (7.0 mm) and -4% (6.6 mm) for the rear wall. The range of individual thickness measurements was much larger, from a minimum thickness of 7.0 mm to a maximum thickness of 11.5 mm on the central web and from a minimum thickness of 4.5 mm to a maximum thickness of 10.0 mm on the rear wall.

In those locations where both initial thickness and temperature measurements have been made, the results from the tests have failed to show a consistent relationship between pfp material thickness and measured temperature rise. Individual spot measurements of thickness may therefore not be of major significance in determining the temperature rise with time. During a fire, the epoxy intumescent pfp material continually reacts and forms a char, the initial thickness of pfp material will therefore determine the length of time it is available to react and form the char.

5.7 FLOW MEASUREMENT AND CONTROL

The measurement of the flow rate at all three test laboratories involved the measurement of a differential pressure across some component in the delivery pipework, either an orifice, a nozzle or a pitot tube. The static pressure in the pipework was also measured at all three laboratories, however the temperature of the flowing propane was only measured at SINTEF and SwRI. At Buxton a temperature was assumed. This may have led to errors in the calculation of the flow rate if the temperature of the propane in the pipework differed from the assumed value, although if the temperature differences were small then the errors were also likely to be small.

The flow rate of 0.3 kg/s of propane to the jet fire was quickly achieved by all test laboratories. SwRI and SINTEF also managed to achieve a stable flow rate for the duration of the tests. Buxton, however, had some problems in ensuring a stable flow rate and achieving the desired 0.3 kg/s for the whole duration of the tests. This was thought to be due to the recent installation of a new flow control system which had not been fully commissioned. It was also thought that the flow through the vaporiser used at Buxton took some time to stabilise and this contributed to the unstable flow. However, the oscillations in the flow rate seen at Buxton did not appear to have an effect on the visual characteristics of the flame, Section 5.8.

Both SwRI and SINTEF used manual control of the flow and this proved very effective in achieving the desired flow rate.

All the tests met the flow criteria specified in the IJFT procedure [1] except one. This was the test on test specimen C1 at Buxton where the total quantity of propane consumed was 1388 kg which was 10% greater than the specified nominal total consumption of 1260 kg. The upper limit specified in the IJFT procedure is +5%.

From the tests at SwRI and SINTEF, it was apparent that the flow rate criteria specified in the IJFT procedure were achievable and that the problems experienced at Buxton were due to the lack of commissioning of the flow control system and their relatively limited experience in operating the test arrangement. Since these problems are relatively easy to overcome, it is not considered necessary to modify the flow rate criteria in the IJFT procedure.

5.8 VISUAL APPEARANCE OF JET FIRE

The characteristics of the jet fires seen at SwRI and SINTEF were very similar, both were bright yellow flames approximately 1.5 m wide, 2 m deep and 4 m high directly in front of the test specimen. The base of the flames did not appear to extend below the base of the test specimens. The flames did not produce much smoke or soot. They were symmetric about the vertical plane through the centre of the test specimen.

The jet fire at Buxton was different from the above description, and was seen to switch between:

During one test at SwRI, where there was a strong wind blowing in through the open door of the test hall. The door was closed and this eliminated the effect of the wind completely.

The walls of the test enclosure at Buxton formed a fairly narrow channel and this may have had an effect which limited the amount of air available for combustion. This in turn may have produced a condition where the combustion process in the jet fire became ventilation limited and the flame characteristics changed with more soot being produced. A billowing sooty flame, (blooming), was observed in the Buxton tests. If this was due to a reduction in the air supply, then it may be that the size of the enclosure was too small.

It has also been suggested that the pfp material itself may produce blooming, by suddenly releasing large quantities of gas, from the reacting pfp material, into the jet fire, thereby altering the characteristics of the flame. This may have happened, however it is likely that it would also have been observed during the tests at the other test laboratories.

It is significant that the temperatures measured on the test specimens tested at Buxton were generally higher than at the other test laboratories. This may be due to the close proximity of the walls of the U shaped test enclosure to the test specimen. The thermal radiation from the jet fire and contact from the flame would have caused the brick walls of the enclosure to become very hot. As the walls increased in temperature, the enclosure may behave like a furnace thereby increasing the incident heat flux on the test specimen.

5.11 VISUAL APPEARANCE OF TESTED SPECIMENS

Type 1 pfp Material

A visual inspection of the specimens tested at the three laboratories was undertaken at the end of each test. This showed that there was a very strong similarity in the appearance of the char on the specimens, except for the central web above the area impinged by the jet fire. On test specimen A1 this area remained protected by a well attached char, also the steel retaining mesh was still embedded in the char; however on test specimens B1 and C1 this area was completely free of char and the bare steel substrate of the test specimen was visible.

Type 2 pfp Material

A visual inspection of the specimens tested at the three laboratories was undertaken at the end of the tests. This showed that there was a very strong similarity in the appearance of the char on the three test specimens.

5.12 CHAR THICKNESS AND DESTRUCTIVE EXAMINATION

The thickness of the char formed on the test specimens was measured at the end of each test. Apart from the area on the central web of test specimen A1, identified in Section 5.11 above; the measured thicknesses of the char on the specimens from each laboratory showed that there was good agreement between the respective test specimens.

i) a bright yellow flame, close to the test specimen, similar in size to the SwRI and SINTEF flames but skewed to the left. The flame actually impinged on the left hand wall of the U shaped test enclosure.

and

ii) an orange, swirling, sooty flame which filled the whole of the U shaped test enclosure, this effect was termed blooming. The blooming was observed on many occasions throughout the tests at Buxton. It was not observed in any of the tests at SwRI and SINTEF.

It is not known what effect this phenomena has on the performance of the pfp material on the test specimens.

It is not thought that the problems that were experienced by Buxton in achieving a stable flow rate had a significant effect on the characteristics of the flame that were observed.

A discussion of the possible causes of blooming is presented in 5.10 below.

5.9 OBSERVED BEHAVIOUR OF PFP MATERIAL

It was very difficult to observe the pfp material during the tests due to the intensity of the flames which masked the test specimen. What was observed however was the size and quantity of fragments of char which were blown off the test specimen during the test.

In all tests, there was an initial period where large pieces of char were blown off. The quantity and size of the fragments gradually reduced such that after a period of time, very little char was blown off and there appeared to be little change in the pfp material on the test specimens.

Therefore it was concluded that there were no significant differences in the observed performance of the pfp material during the tests.

5.10 TEST HALL / ENCLOSURE

The tests which were undertaken at SwRI and SINTEF were carried out inside large test halls whereas the tests at Buxton were carried out in a U shaped test enclosure, outdoors. Therefore the tests at SwRI and SINTEF were protected from the wind very effectively but the tests at Buxton relied on the walls of the enclosure to provide wind protection.

During the two test at Buxton the wind was blowing generally from left to right and from the closed end of the enclosure. This may have resulted in a complex pattern of airflow into the enclosure which may have affected the flame. The flame was in fact observed hugging the left hand side of the enclosure. If the wind was the cause of the flame being skewed to the left, then it may be that the walls of the enclosure were not sufficiently large to effectively protect the test specimens from the wind. In future tests with a different wind conditions, it would be useful to note the behaviour of the flame.

Selected areas on the test specimens from each laboratory were examined in detail by excavating the char down to the steel substrate. This examination showed that there was a close similarity in the condition of the char, condition of the fabric and steel meshes and the amount of un-reacted pfp material remaining on the respective test specimens.

5.13 TEMPERATURE MEASUREMENTS

In general, the results of the temperature measurements on the rear wall of the test specimens showed that there was reasonable agreement between the three test laboratories.

For the test on specimens coated with Type 1 pfp material, the results from Buxton were slightly higher than the average.

For the test on specimens coated with Type 2 pfp material, the results from Buxton were slightly higher and the results from SINTEF were slightly lower that the average.

The results of the temperature measurements in the central web of the test specimens showed poor agreement between the three test laboratories for both types of pfp material. This can be explained for Type 1 pfp material by the failure of this material on specimens B1 and C1 and the non failure on specimen A1. The difference in the measurements made in the test specimens protected by Type 2 pfp material may be due to the postulated higher incident heat fluxes thought to occur in the Buxton tests. These higher heat fluxes may be due to the proximity of the walls of the enclosure to the test specimen.

5.14 PERFORMANCE OF PFP MATERIAL ON THE CENTRAL WEB

The central web on the IJFT test specimen is intended to represent a particularly vulnerable aspect of the application of pfp material on structural sections, for example the edge features of I-section beams and columns. Therefore the central web may be particularly sensitive to minor differences in the test specimen, pfp material or jet fire. This may account for the difference in behaviour of the pfp material applied to the central web of the test specimen A1, tested at SwRI and the pfp material applied to the central webs of the test specimens B1 and C1, tested at SINTEF and Buxton. That is, the effect of minor differences in the test specimen, pfp material or jet fire may be exaggerated on this particular feature.

Alternatively, this difference seen in behaviour of the pfp material may be a reflection of the inherent variability in the performance of pfp materials of this type in jet fires. Although it must be noted that the results from the test specimens B1 and C1 did show good agreement.

It should also be noted that this difference in behaviour of the pfp material was in the upper half of the central web, away from that part of the web impinged by the jet fire. In the area impinged by the jet fire, the performance of the pfp material was remarkably uniform.

6. CONCLUSIONS

6.1 TEST SPECIMENS

The test specimens were manufactured in accordance with the engineering drawing provided at the rear of this report. They were coated with pfp material in accordance with the manufacturer's specification or where the application of the pfp material differed from the specification, the difference was approved by the manufacturer's representative who was present during the application. The application was undertaken in a manner which ensured that the pfp material on the test specimens was as uniform as reasonably practical. It is therefore concluded that the test specimens and pfp material were as uniform as could be reasonably expected.

6.2 TEST PROCEDURE

The three test laboratories carried out the tests on the test specimens generally in accordance with the IJFT procedure. At SwRI no protection was installed around the sides or across the top of the specimen and rear box. There was no evidence of the flames passing around the sides or top of the specimen, however it was not possible to determine whether or not incident radiation from the flames upon the rear box was significant since appropriate measurements were not made.

Some minor changes and additions were made to the IJFT procedure, namely:

a) the method of installing thermocouples in the central web,

b) the attachment of thermocouple to the rear wall, and

c) the provision of engineering drawings.

These changes and additions are considered to have improved the IJFT procedure. It is concluded that the IJFT procedure is a workable procedure which can be used by test laboratories to carry out jet fire testing.

The test reports issued by the test laboratories vary in content and presentation and consideration should be given to ensuring more uniformity in the reporting of the results.

6.3 TESTING INDOORS V OUTDOORS

From the testing carried out at Buxton, it would appear that there are particular problems in undertaking IJFT tests outdoors which are not present when the IJFT's are carried out indoors. A number of suggestions have been made in an attempt to account for the differences in the jet fire witnessed at Buxton. It is concluded that further work is necessary to investigate the design of test enclosures used for IJFT's undertaken outdoors.

6.4 PERFORMANCE OF PFP MATERIAL ON REAR WALL

The condition of the char and the temperatures measured on the rear wall of the test specimens showed that there was a high level of uniformity in the results from the three test laboratories. It is therefore concluded that the IJFT procedure provides a uniform test for the rear wall of test specimens.

6.5 PERFORMANCE OF THE PFP MATERIAL ON THE CENTRAL WEB

The condition of the char and the temperatures measured on the central web of the test specimens showed that there was not a high level of uniformity in the results from the three test laboratories. Therefore, from these tests, it cannot be concluded that the IJFT procedure provides a uniform test for the central web of the test specimens.

7. RECOMMENDATIONS

7.1 IJFT PROCEDURE

It is recommended that the following changes be made to the IJFT procedure:

a) full engineering drawings should replace the diagrams in the procedure

b) the methods outlined in this report to attach the thermocouples to the rear wall should be adopted

c) stainless steel sheathed thermocouples should be used in the central web

d) a report format should be included

e) the IJFT procedure should insist that the report from the test laboratory should contain a section on the measurement and control of the propane flow rate.

7.2 OUTDOOR TESTING

It is recommended that further work be undertaken to investigate the design of test enclosures to be used outdoors. This work should determine an optimum size, shape, orientation, construction material and ventilation procedure for the test enclosure.

7.3 APPLICATION OF PFP MATERIAL TO THE REAR WALL

From the observations made during the IJFT's carried out at the three test laboratories, the pfp material applied to the rear wall of the test specimens responded uniformly. Therefore it appears that the IJFT procedure may be appropriate for the testing of pfp materials in such a configuration. However, further consideration should be given to the performance of the pfp material during an IJFT compared to its performance in a jet fire representative of that which might occur in practice.

7.4 APPLICATION OF PFP MATERIAL TO THE CENTRAL WEB

From the observations made during the IJFT's carried out at the three test laboratories, the pfp material applied to the central web of the test specimens did not respond uniformly. Therefore further consideration needs to be given to the IJFT procedure which may include:

a) the design of the test specimen

b) the configuration of the test specimen and test set-up

c) the orientation and arrangement of the jet fire

8. REFERENCES

[1] Health and Safety Executive, "Interim Jet Fire Test for Determining the Effectiveness of Passive Fire Protection Materials", OTO Report No OTO-93-028, December 1993.

[2] Swedish Standard SIS 05 59 00-1967, "Pictorial Surface Preparation Standards for Painting Steel Surfaces".

[3] Letter from the manufacturer of Type 2 pfp material to British Gas, 28th March, 1995.

	Test Specimen A1 Temperature (Celsius)		Test Specimen B1 Temperature (Celsius)		Test Specimen C1 Temperature (Celsius)	
	Thermometer	Probe	Thermometer	Probe	Thermometer	Probe
Minimum	5	4.7	1.2	0.8	9.3	10.5
Maximum	26.9	26.9	18	19.5	22.2	20.4

Table 1a: Type 1 Specimen Temperatures Recorded During Transportation to Test Facilities

	Test Specimen A2 Temperature (Celsius)		Test Specimen B2 Temperature (Celsius)		Test Specimen C2 Temperature (Celsius)	
	Thermometer	Probe	Thermometer	Probe	Thermometer	Probe
Minimum	5.8	6	1.6	1.8	8.1	8.2
Maximum	26.8	26.2	17.8	20	24.7	34.2

Table 1b: Type 2 Specimen Temperatures Recorded During Transportation to Test Facilities

	Test Specimen B1 Temperature (Celsius)	Test Specimen B2 Temperature (Celsius)
	Probe	Probe
Minimum	11.4	11.4
Maximum	20.8	20.8

Table 1c: Temperatures Recorded during Storage at SINTEF Test Facility Prior to Testing

	Shore 'D' Hardness Values For Test Specimens					
	Type 1 PFP Material			Type 2 PFP Material		
Position	Test Specimen A1	Test Specimen B1	Test Specimen C1	Test Specimen A2	Test Specimen B2	Test Specimen C2
1	69	75	70	73	76	64
2	70	75	73	77	69	65
3	70	70	71	65	64	68

Table 2: Shore 'D' Hardness Values for the PFP Materials Coating the Test Specimens

		Average PFP Thickness (mm)							
		Type 1 PFP Material							
		Specified	Test Specimen A1	Test Specimen B1	Test Specimen C1	Specified	Test Specimen A2	Test Specimen B2	Test Specimen C2
Web	Mean	10	9.1	8.7	10	13	13.5	13.2	12.4
	St. Dev.		0.8	0.7	0.7		1.7	1.4	1.4
	Range		7.0-10.7	7.0-10.3	8.5-11.5		8.5-16.8	10.5-16.0	10.0-14.8
Rear Wall	Mean	6	7	6.6	7	13	13.2	14	12.6
	St. Dev.		0.9	0.5	1.3		1	1.2	1.1
	Range		5.5-10.0	5.5-7.8	4.5-10.0		11.0-16.0	11.5-17.0	11.0-15.0

Table 3: Average PFP Thickness Measurements on Test Specimens

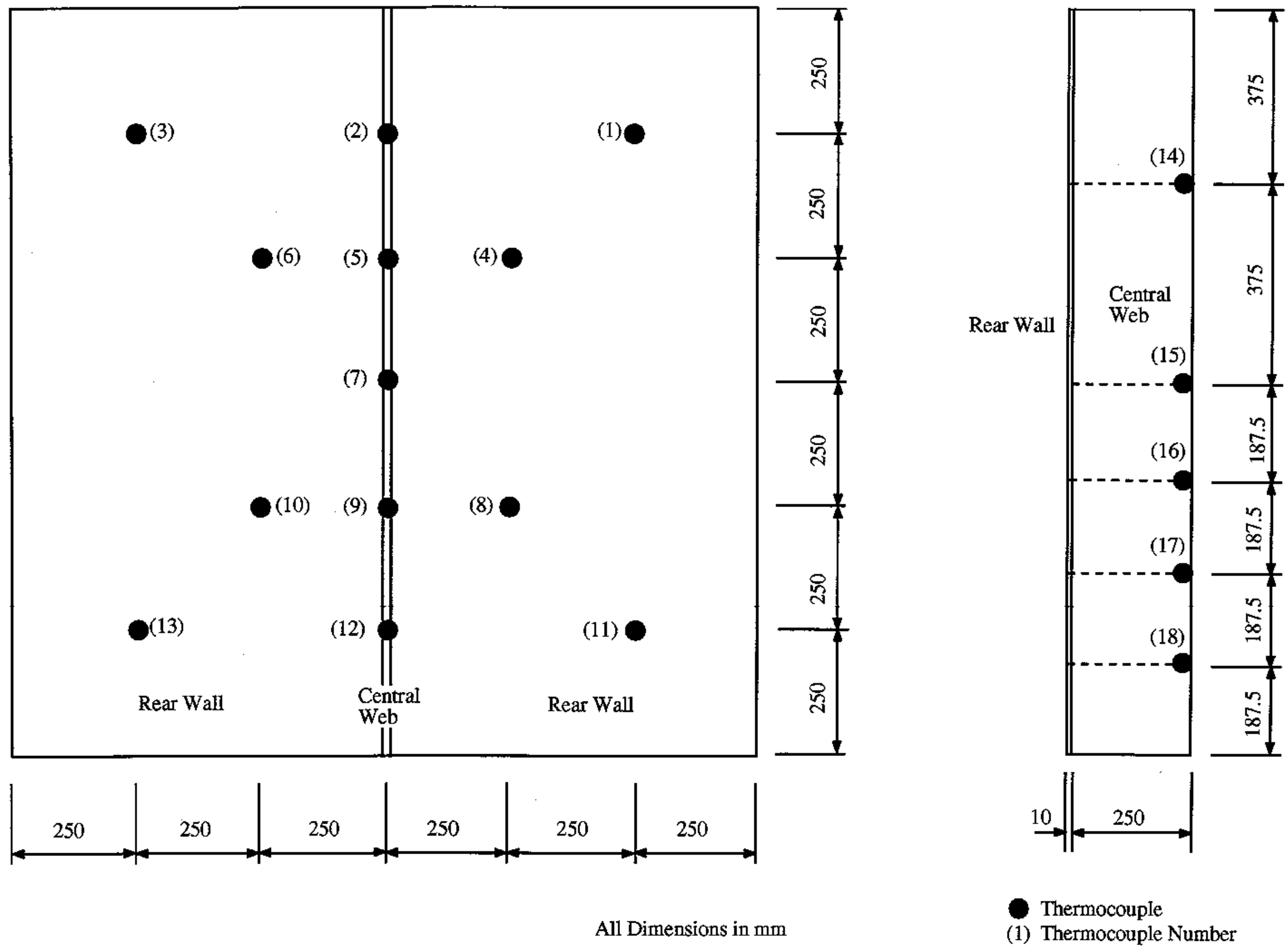


Figure 1: Thermocouple Locations on Test Specimens
View From the Front of the Test Specimen

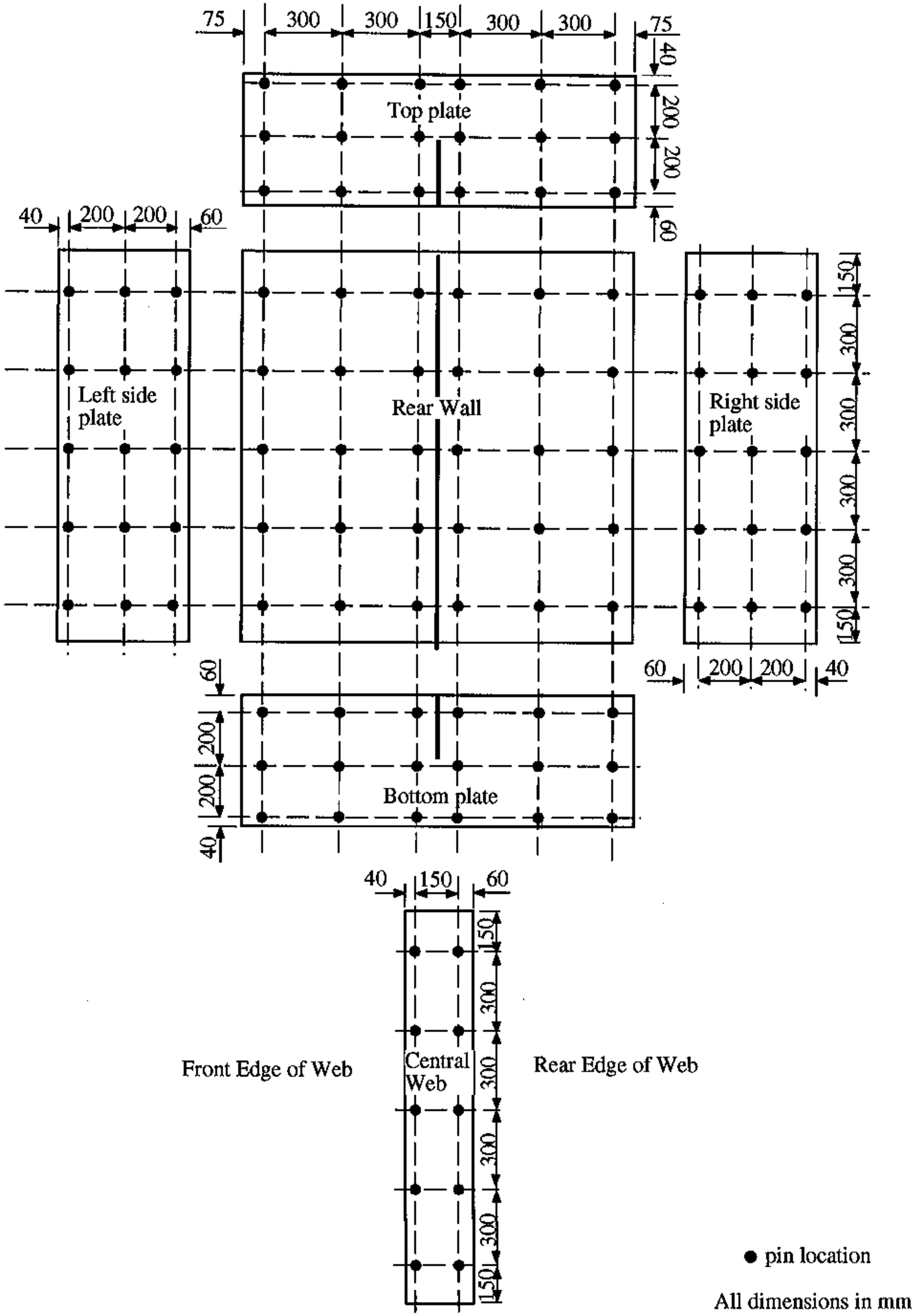
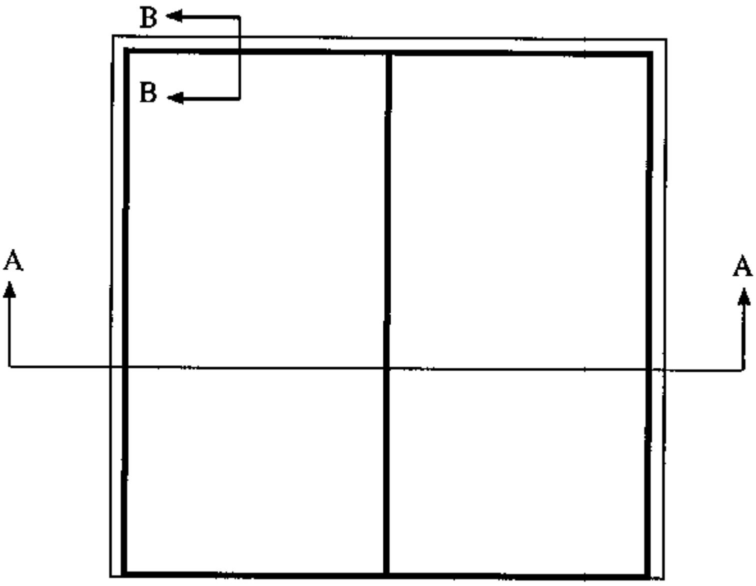
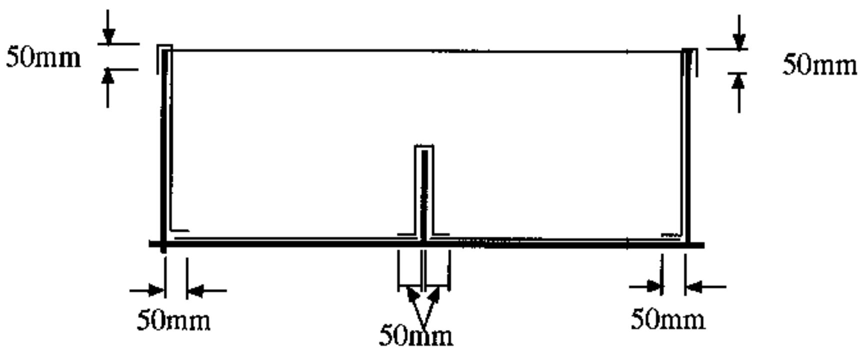


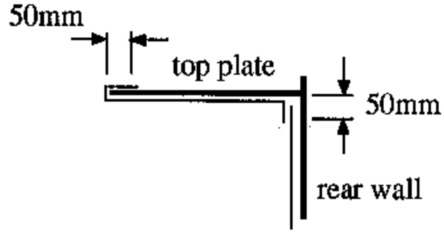
Figure 2: Exploded View of Test Specimen Showing Pinning Arrangement for Type 1 and 2 pfp Materials



Mesh tight to specimen on rear wall and sides
2mm stand off on mesh around web

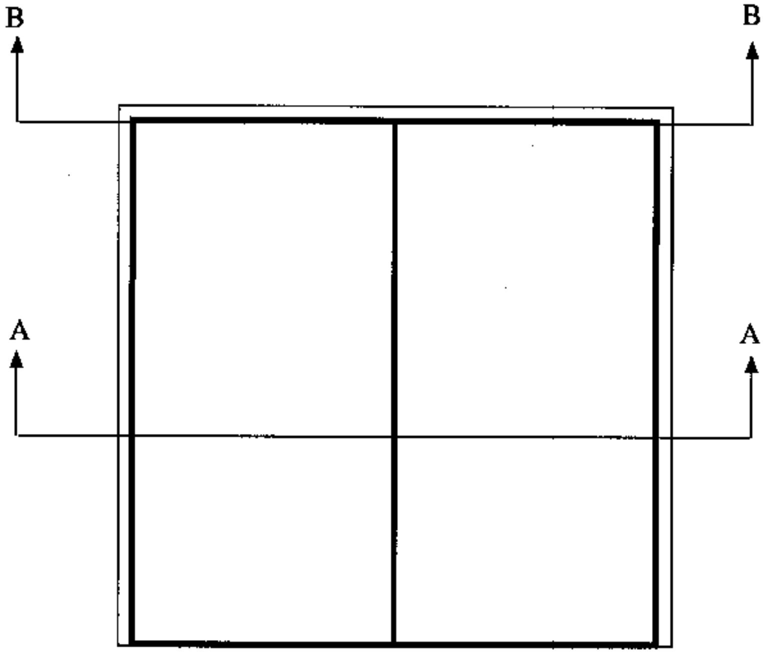


Cross–section view through AA showing mesh overlap on rear wall and side plates.

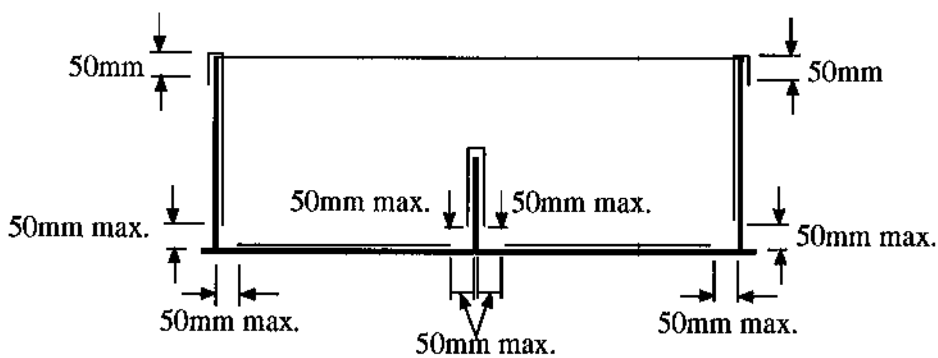


Cross–section view through BB showing mesh overlap on rear wall and top plate.

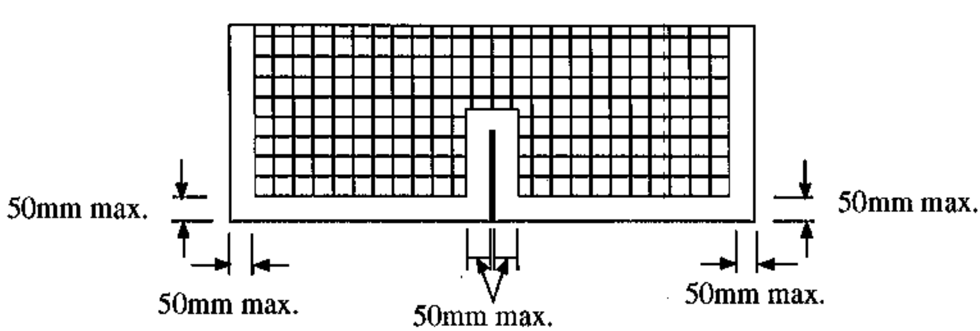
Figure 3 Metal Mesh layout for Test Specimens Coated with Type 1 pfp Material



5mm stand off of mesh over all of test specimen

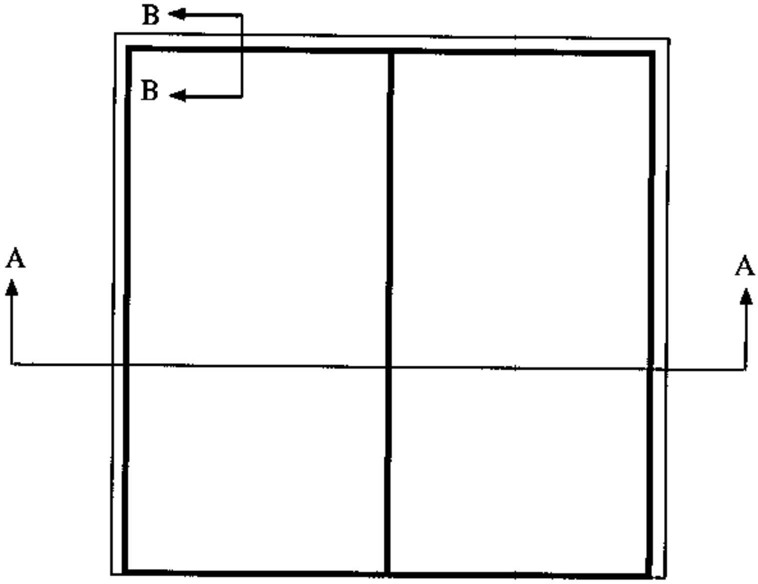


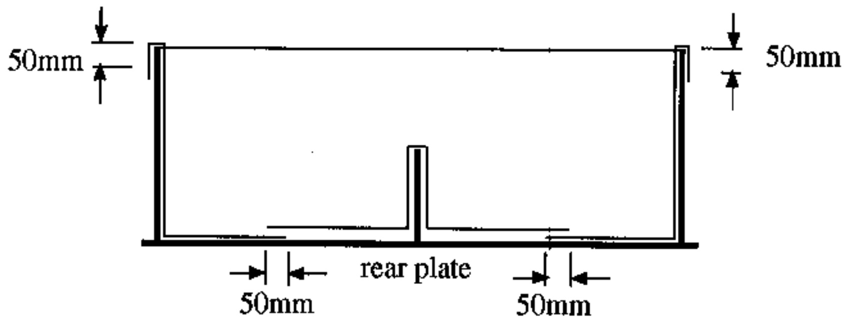
Cross–section view through AA showing mesh stand–off on sides, rear wall and central web.



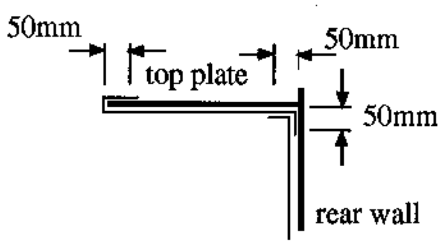
Cross–section view through BB showing mesh stand–off on top and bottom plates.

Figure 4 Metal Mesh layout for Test Specimens Coated with Type 2 pfp Material



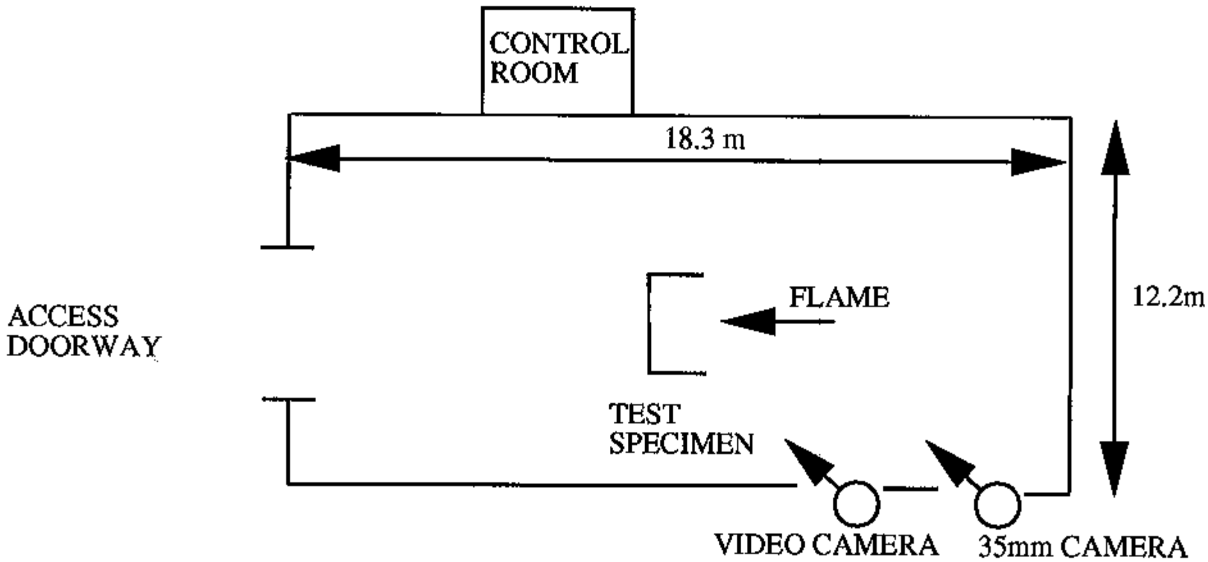


Cross–section view through AA showing mesh overlap on sides, rear wall and the central web.

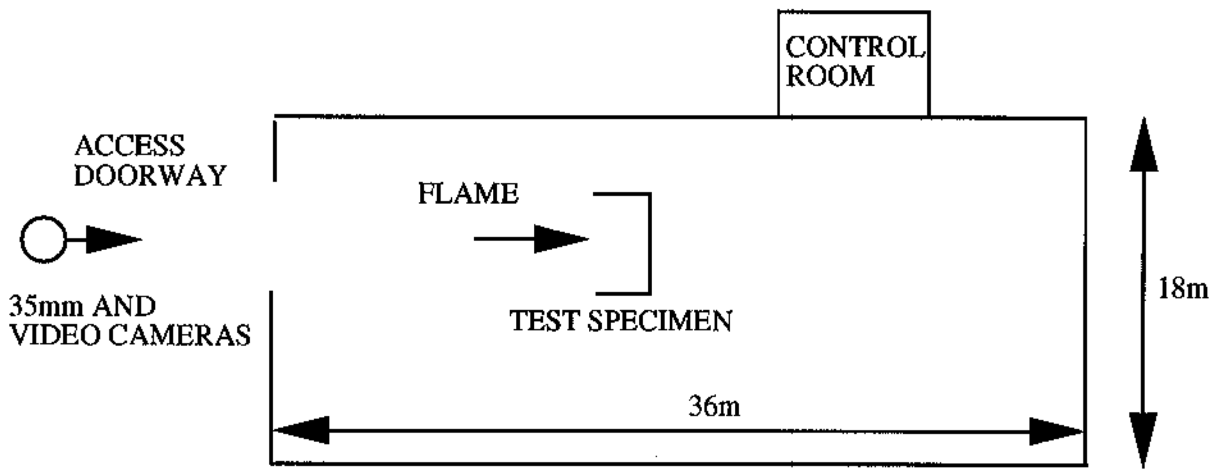


Cross–section view through BB showing mesh overlap on rear wall and top plate.

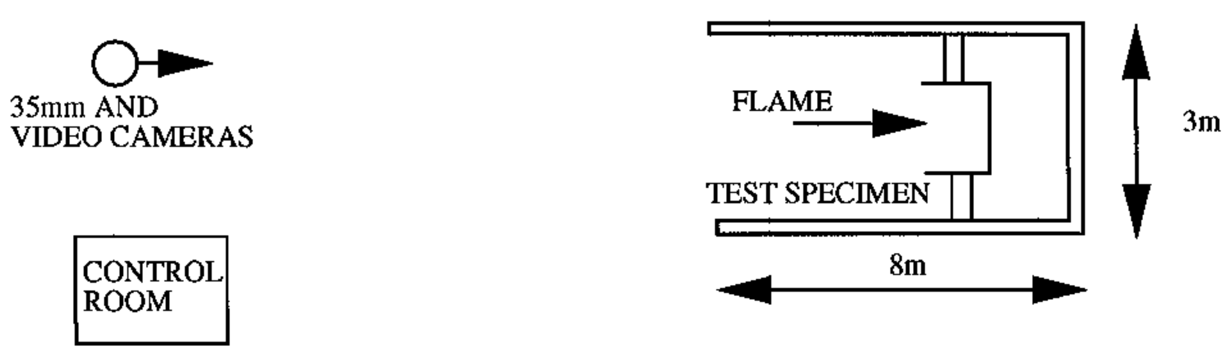
Figure 5: Fabric Mesh layout for Test Specimens Coated with Type 2 pfp Material



SwRI TEST HALL

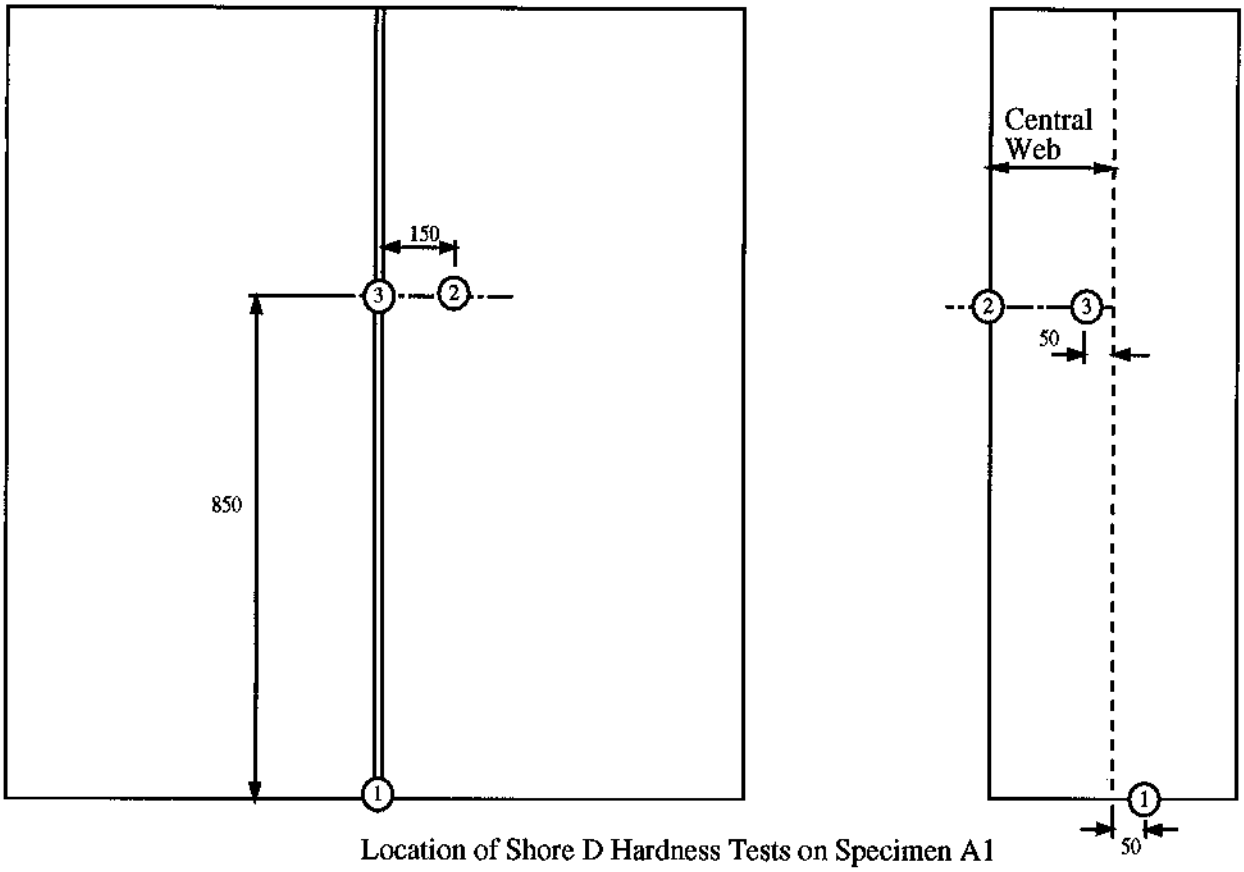


SINTEF TEST HALL

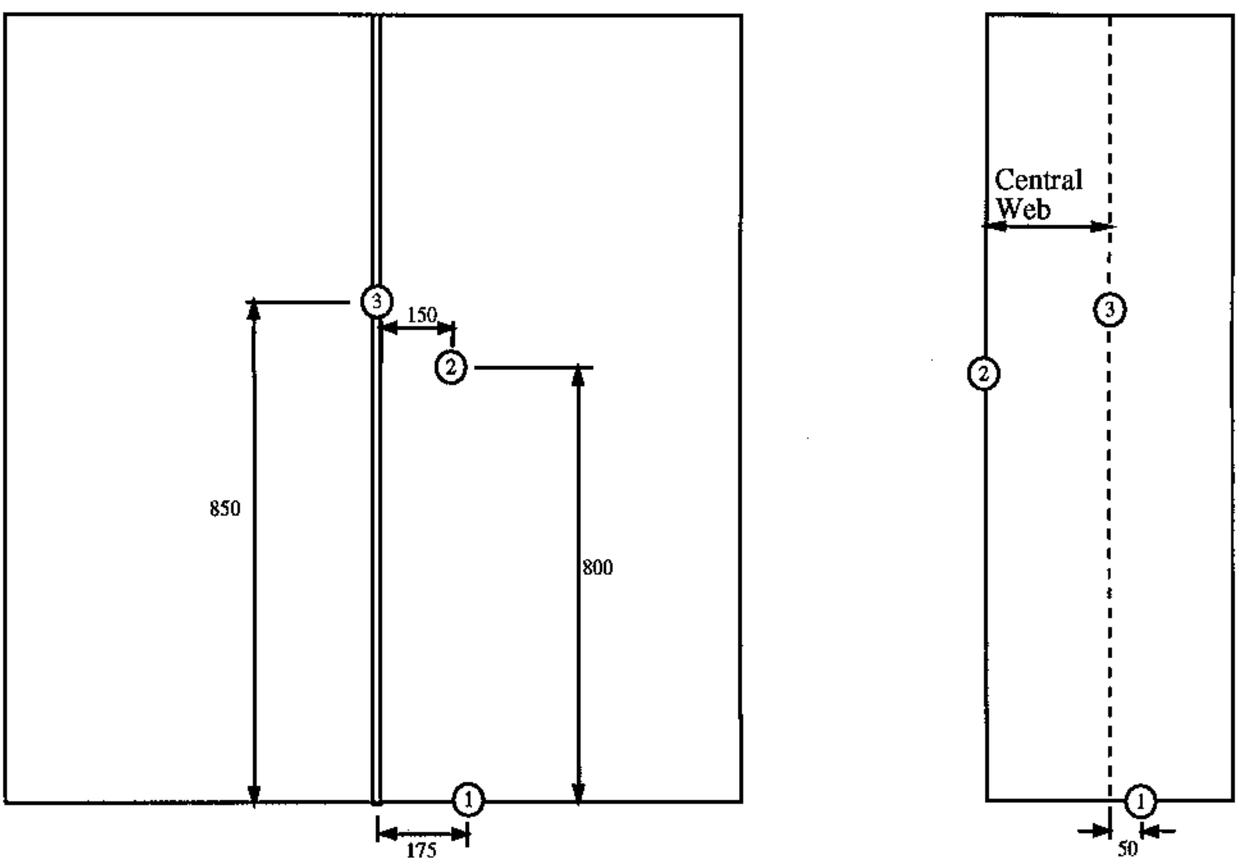


BUXTON TEST ENCLOSURE

Figure 6: Schematics of the Test Facilities



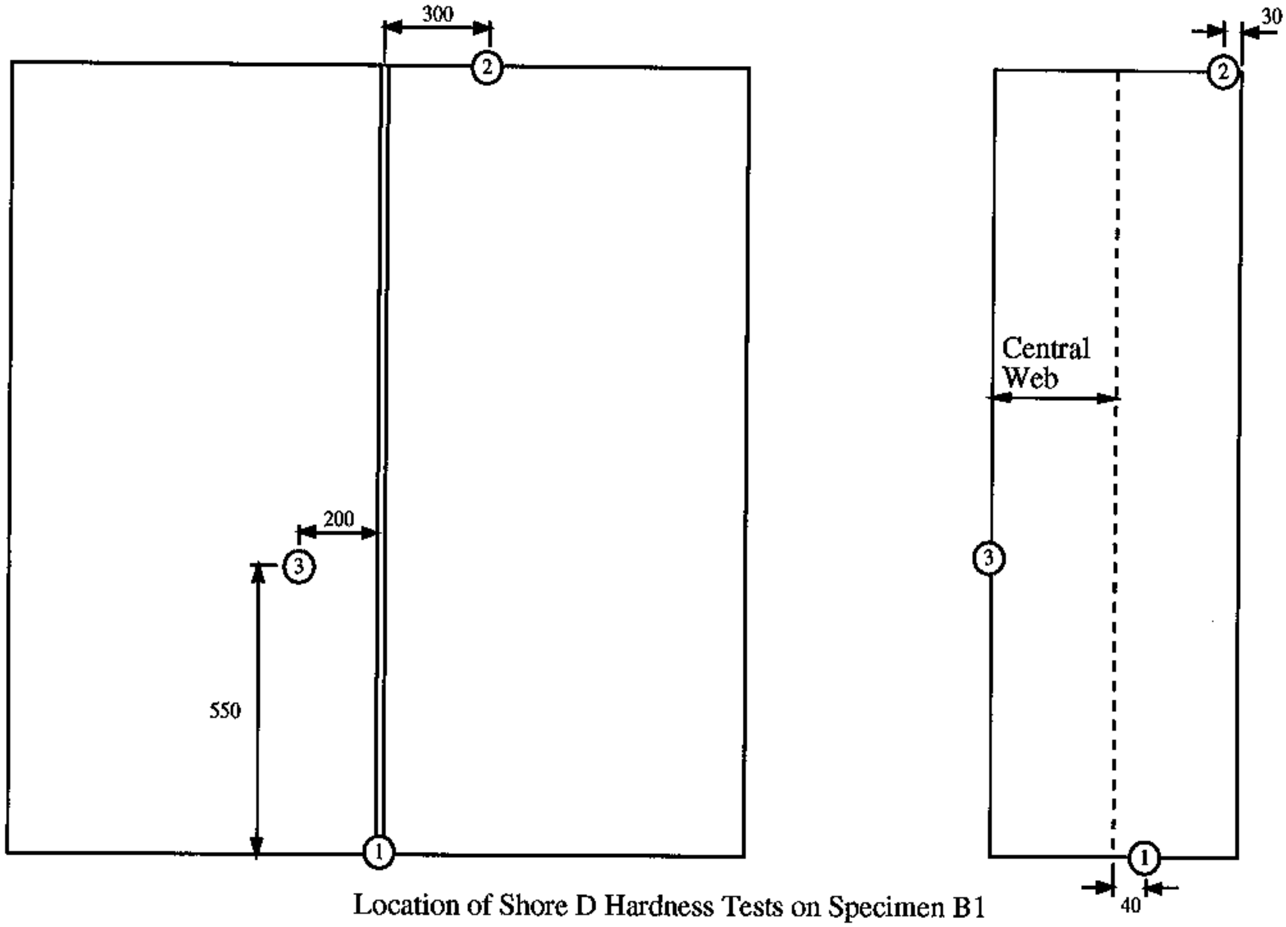
Location of Shore D Hardness Tests on Specimen A1



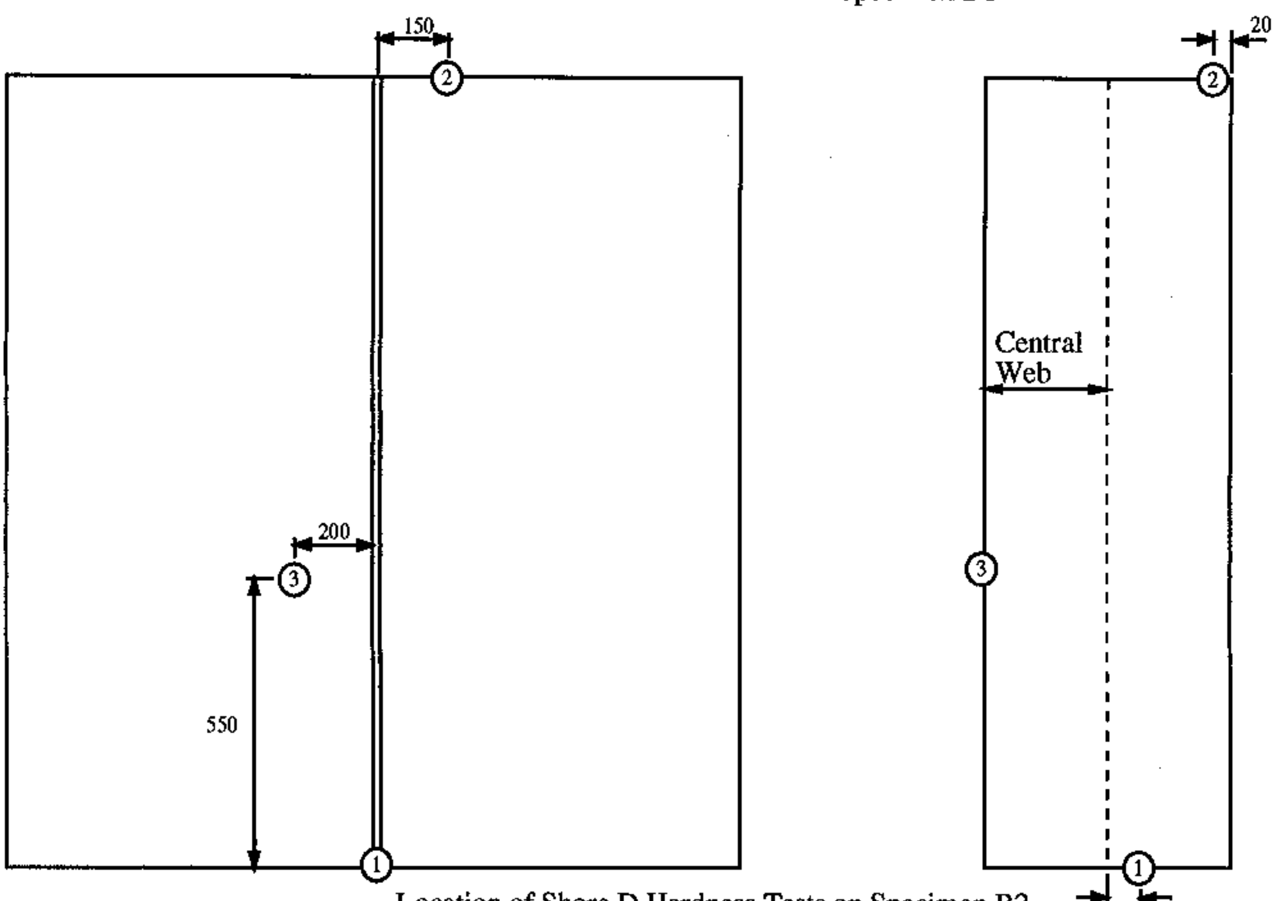
Location of Shore D Hardness Tests on Specimen A2

All Dimensions in mm

Figure 7: Position of Shore 'D' Hardness Measurements for Specimens Tested at SwRI



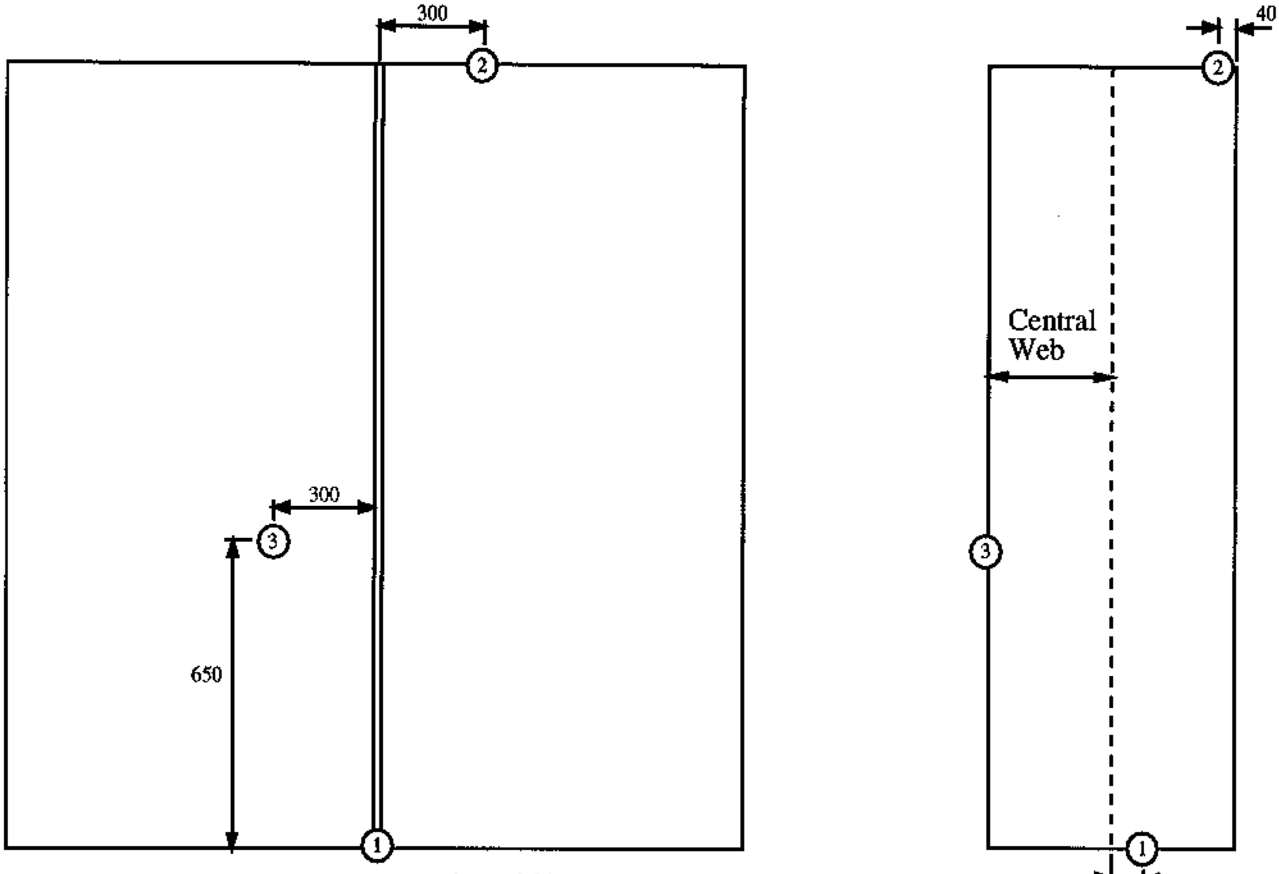
Location of Shore D Hardness Tests on Specimen B1



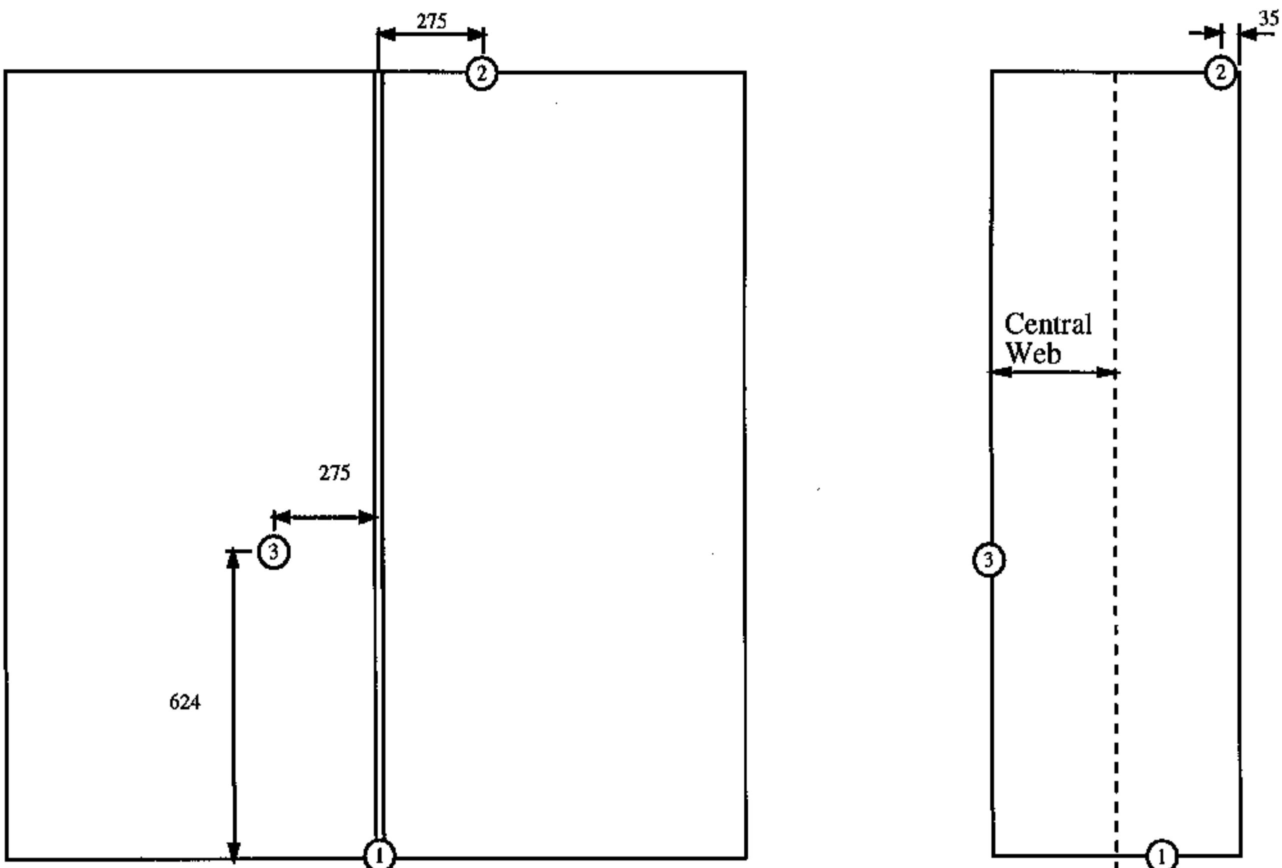
Location of Shore D Hardness Tests on Specimen B2

All Dimensions in mm

Figure 8: Position of Shore 'D' Hardness Measurements for Specimens Tested at SINTEF



Location of Shore D Hardness Tests on Specimen C1



Location of Shore D Hardness Tests on Specimen C2

All Dimensions in mm

Figure 9: Position of Shore 'D' Hardness Measurements for Specimens Tested at Buxton

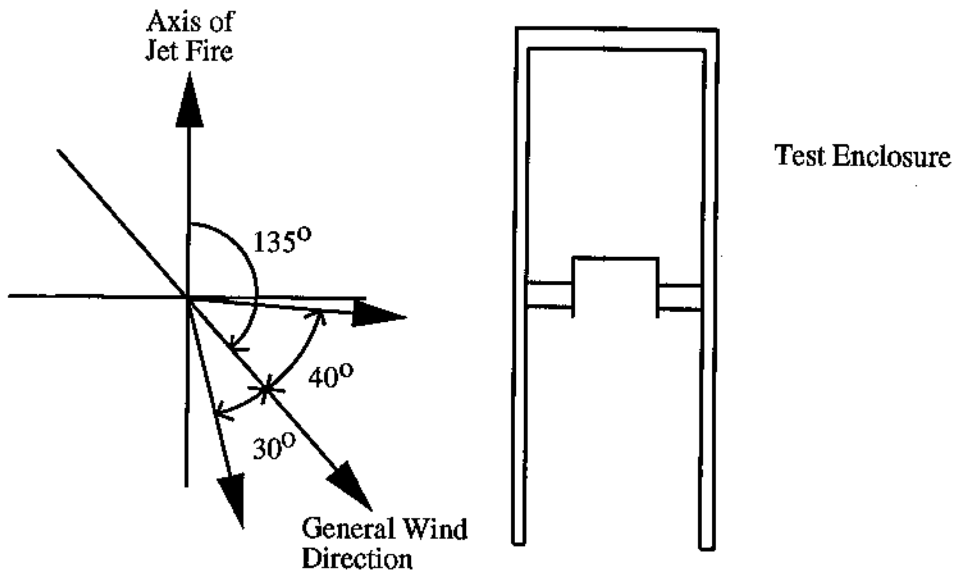


Figure 10a: Wind Direction During IJFT of Specimen C1 at Buxton

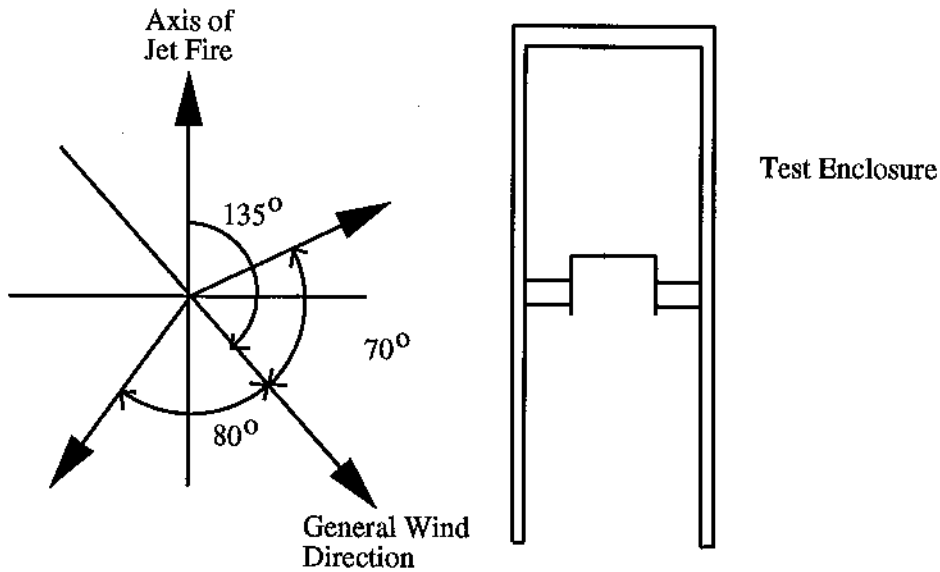


Figure 10b: Wind Direction During IJFT of Specimen C2 at Buxton

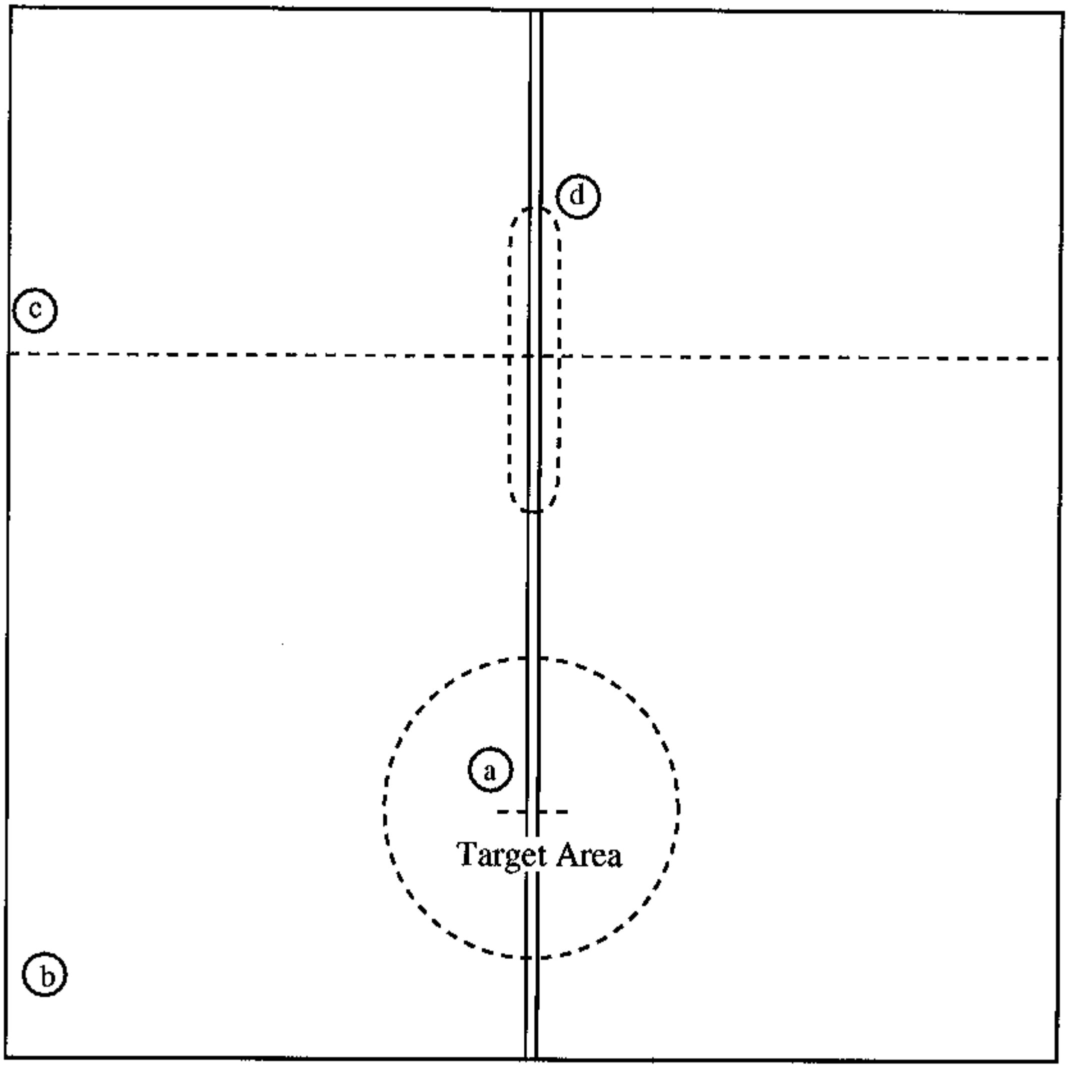


Figure 11: Schematic Showing Areas Described in Post Test Visual Inspections