HSE
Health & Safety Executive

OFFSHORE TECHNOLOGY REPORT - OTO 93 028

INTERIM JET FIRE TEST FOR DETERMINING THE EFFECTIVENESS OF PASSIVE FIRE PROTECTION MATERIALS

Date of Issue: 21 December 1993

Health and Safety Executive

Reports in the OTO series may be obtained from HSE Information Services, Information Centre, Broad Lane, Sheffield S3 7HQ
Tel: 0742 892345, Fax: 0742 892333, Telex: 54556.

DISCLAIMER FOR OTO 93 028

OTO REPORT NO OTO-93-028

Interim Jet Fire Test for Determining the Effectiveness of Passive Fire Protection Materials

Background to the Test Procedure

The explosion and fire on Piper Alpha in 1988 claimed the lives of 167 men in the worst industrial accident in Britain for over 50 years. In the report of the Public Enquiry under Lord Cullen, it was noted that a major misconception in the performance of fire protection is the belief that a fire rating indicates the time the assembly will survive in an actual fire. In addition, it was accepted that the time versus temperature curve method of fire testing is far from satisfactory. In summing up, Lord Cullen observed "It is clearly desirable that any [fire] test used be realistic. The essential problem is not that of a test per se, but of the information which the test provides to the designer about the probable behaviour of the fire barrier in real hydrocarbon fire conditions ...".

With increasing reliance being placed on passive fire protection materials offshore and the realisation that in many areas jet fires pose the most onerous threat, the need for a jet fire test is now widely accepted.

It is generally recognised that the conditions in the standard and hydrocarbon furnace tests do not represent the characteristics such as heat flux and erosion found in full scale high velocity jet fires. In the absence of any recognised test for jet fire resistance, ad hoc tests and demonstrations of performance have been used. The most reliable of these must be those that are essentially full scale demonstrations.

At present, routine testing at full scale is not a practical proposition, being both expensive and requiring access to a unique test facility. What is required is a test of the performance of passive fire protection at a moderate scale that can produce conditions found at the actual scale.

One test that has been used extensively in testing PFP materials was developed at the Norwegian test laboratory in Trondheim, SINTEF. At present, this is essentially a material test of planar specimens 1.5 m square. An ignited sonic jet of propane vapour is fired horizontally into a shallow box in which the test specimen forms the rear wall. This geometry is the key to simultaneously achieving a high radiative flux and high convective flux at this scale.

Unfortunately, this configuration does not lend itself to direct comparison with most of the protected specimens that have been tested at large scale, these being mainly structural sections or enclosures. Thus, whilst a small number of fire protection products have been tested at both scales, the results tell us very little about the validity of medium scale testing.

In March 1992, the Health and Safety Executive (HSE), in conjunction with the Norwegian Petroleum Directorate, convened a working group with members from UKOOA, Shell, British Gas and SINTEF in Norway. More recently the working group has been joined by the

Southwest Research Institute in the USA. The primary objective of this Jet Fire Test Working Group was to explore the possibilities of agreeing a jet fire test.

One of the first actions of the working group was to agree a programme of work to carry out a comparative review of jet fire data from the British Gas and Shell work at the British Gas Spadeadam test facility and the SINTEF work in Norway. Funded by the HSE in June 1992, a total of 53 documents were reviewed. Some of the documents consisted of material available in the open literature; many items, however, were of a confidential nature. Most of the documents were provided by British Gas, Shell and SINTEF, although 3 additional items were supplied from alternative sources.

The review concluded that a medium scale jet fire test based on the test developed by SINTEF and evaluated jointly by Shell Research, can produce conditions which are currently considered to be important to the performance of passive fire protection materials. Therefore, it was concluded that the interim jet fire test should be based on this test. However, although the conditions which exist in the medium and full scale tests are similar, the effects of the fires on materials has not been compared due to insufficient data.

In order to progress the development of an interim test, the working group proposed a Joint Industry project. The proposal was issued to the manufacturers of passive fire protection materials in June 1993. The proposal outlined a test programme to subject specimens of the same configuration and protected to the same degree to jet fires at both scales, ie. Spadeadam and SINTEF. In addition, it was proposed to repeat some of the SINTEF tests at the HSE's RLSD test site at Buxton.

The main objective of the programme was to provide validation to cover reproducibility of results between test houses and comparison of the results of tests at the medium scale with the results of the large scale tests to prove the suitability of the proposed test method.

The industry response to the proposal was generally favourable but, unfortunately, companies tended to offer access to their test data rather than the finance to carry out the necessary test programme. A review of the data available indicated that no passive fire protection materials had been tested with similar configurations at both scales, a requirement for validating the proposed test method.

While industry was considering the JIP proposal, the working group - who were increasingly aware of the urgent need for a jet fire test now - began the work of compiling an interim jet fire test procedure.

The working group decided to adopt the SINTEF test as the basis for the interim jet fire test. As has already been mentioned, this test is essentially a material test for planar test specimens.

During the various discussions on the interim test, a variation to the test was developed which enables the procedure to cover up to 3 different configurations of test specimens. For coatings applied to flat substrates, the procedure is similar to the SINTEF type test. However, the addition of a central vertical web enables coatings on edges to be tested. For panel materials, a joint may be incorporated into the specimen to evaluate the effect of a jet fire across the front face of the panel joint.

The Procedure

The working group has now finished drafting its version of the SINTEF test which is presented in this report. Entitled "Interim Jet Fire Test for Determining the Effectiveness of Passive Fire Protection Materials", the procedure is offered by the working group as an **interim** measure, pending validation which must be carried out by the end of 1994.

Validation of the procedure will hopefully result in a generally agreed standard with clear benefits to all in the industry. This includes limiting the need for demonstration tests at full-scale to type testing of prototype assemblies not covered in the procedure, assisting designers in the selection of appropriate passive fire protection materials and aiding the development of new and more effective passive fire protection systems.

Failure to validate the procedure will result in the possibility of potentially suitable candidate systems being overlooked, a reliance on ad-hoc full scale testing of systems for each configuration and the need to demonstrate that individual fire scenarios have been taken into consideration on a case by case basis.

Under the auspices of the working group, British Gas are currently preparing a proposal for a Joint Industry Project to carry out the experimental work and analysis necessary to validate the procedure.

It is recognised that this proposed interim procedure does **not** fully represent the severe conditions of phenomena such as multiphase jets (with high momentum liquid droplets or solid particles). However, it is considered to offer significant advantages over the hydrocarbon furnace test by representing more closely conditions where jet fire impingement poses a significant threat. The interim procedure is seen as a complimentary test to the hydrocarbon furnace test, and not as a replacement.

Interim jet-fire test for determining the effectiveness of passive fire protection materials

Produced by the Jet-fire Test Working Group

1 Scope

1.1 The test described in this procedure is an example showing one way in which some of the properties of passive fire protection materials may be determined. This test is designed to give an indication of how well passive fire protection materials could withstand an actual jet fire. However, it is a test of the material and not a test of assemblies, so large scale testing may still be needed to determine the effectiveness of the material in protecting a particular assembly or fabrication.

1.2 This test is not intended to replace the "Hydrocarbon fire resistance test for elements of construction for offshore installations" but is seen as a test complimentary to it.

1.3 The test involves hazardous materials and operations. The procedure does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of the procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.4 Although the method specified has been designed to simulate some of the conditions which would occur in an actual jet fire, it cannot reproduce them exactly. The results of this test are not in themselves a guarantee of safety, but may be used as elements of a fire risk assessment for structures or plant. This should also take into account all the other factors which are pertinent to an assessment of the fire hazard for a particular end use.

1.5 This test offers no assessment of other properties of the passive fire protection material such as weathering, ageing, shock resistance, impact or explosion resistance or smoke production.

1.6 Data on repeatability and reproducibility will be added to Section 8 when it becomes available.

2 Informative references

The following standards and test specification are relevant to this procedure:

ISO 834 'Fire resistance tests - elements of building construction'.

BS 476 'Fire tests on building materials and structures' Part 20 Appendix D

Test specification - Issue 1 : January 1990, Hydrocarbon fire resistance test for elements of construction for offshore installations.

3 Definitions

For the purposes of this procedure, the following definitions apply.

jet flame : A discharge of ignited, flammable material (in this case propane vapour) under pressure.

jet nozzle : The assembly from which the jet flame issues, see Figure 7.

test specimen : An open fronted box with passive fire protection material applied or fitted to it as shown in Figures 1, 2 or 3.

rear box : A mild steel box, open at the front and back, which is designed to be attached onto the rear of the test specimen to shield it from environmental influences, see Figure 8.

passive fire protection : There are two distinct types:

> **coating materials** : A material which is applied to a substrate, and is designed to protect it from thermal effects.
>
> **panel materials** : An insulation material in the form of a panel or sheet, including pre-formed sections, which can stand alone or protect a substrate.

4 Test specimen

4.1 Construction of test specimen

4.1.1 Coating materials

The test specimen for use with coating materials is constructed in the form of an open fronted box, generally using mild steel 10 mm in thickness. The internal dimensions prior to coating are: 1500 mm wide x 1500 mm high x 500 mm deep. The test specimen has a central 20 mm thick vertical web running its entire height, 0.25 m deep; this is to simulate edge details such as stiffening webs or edges of 'I' beams. The web is made up of two 10 mm thick steel plates which are slotted to have thermocouples inserted and fixed by a method in Annex A before being welded together. It can be seen in Figure 1. The joints may be of a welded construction and must be gas tight.

4.1.2 Coating materials - planar applications

If a coating material is only required to be applied to planar surfaces, the following variation of the test specimen may be used. The test specimen is of the same dimensions and construction as the one detailed above, but without the vertical web. It is normally made from mild steel, except when testing materials for protecting substrates other than steel, when that other material may be used. The rear wall may be made of material of a thickness other than 10 mm, if this is appropriate to the application. Any departures from the specification in this test procedure must be stated in the test report. This test specimen is shown in Figure 2.

4.1.3 Panel materials

The test specimen for use with wall or panel sections is the same basic shape as that used for coating materials, but the rear wall of the test specimen is replaced by the panel assembly. This is shown in Figure 3. At least one joint in the panel material should be included, and this should be positioned vertically, offset from the centre by 250 mm. If the joint is not symmetrically resistant to jet-fire across the front face, eg a lap joint, the joint should be orientated to give the most severe exposure to the jet.

4.2 Passive fire protection material

4.2.1 For testing passive fire protection materials applied as coatings, the test specimen shall have passive fire protection material applied directly to all inside surfaces of the test specimen facing the jet flame. The outside surfaces of the sides, top and bottom of the test specimen shall also be coated to a distance of 50 mm from the front edge. The manufacturer's assembly, curing, and fabrication procedures shall be utilised, including procedures for surface preparation.

4.2.2 If the passive fire protection material is in the form of a panel designed to be used as a wall, the rear wall of the test specimen shall be replaced by the material and held in position as shown in Figure 3. The jointing between the panel and the box should be sealed to prevent passage of hot gases, for example using soft mastic or ceramic fibre. This should be left to the discretion of the manufacturer of the material. The internal walls of the test specimen should be protected by a board insulation material, selected at the discretion of the test house, in a similar way to the test specimen for coating materials.

4.2.3 Documentation of the method of preparation of the test specimen should be included in the test report and provided to the test house in advance of the test.

4.3 Instrumentation

The test specimen is instrumented with thermocouples on the rear face. Figures 4, 5 and 6 show the thermocouple positions to be used. They are fixed by one of the methods given in Annex A (normative). Provision shall be made to record the readings at intervals of not more than 30 seconds. The thickness of the thermal insulation material at each thermocouple position shall be measured and recorded.

5 The jet flame

5.1 Nozzle geometry and position

The jet flame issues from a tapered, converging nozzle of length 200 mm, inlet diameter 52 mm and outlet diameter 17.8 mm. There is a tapping for a pressure transducer and a hole drilled half way through the nozzle wall for a thermocouple, see Figure 7. The tip of the nozzle is located 1.00 m from the surface of the passive fire protection material and with its centre 1/4 of the height of the test specimen above the inner surface of the test specimen's base (excluding the coating). The jet flame impinges the test specimen normal to its rear wall.

5.2 Fuel

The fuel is commercial propane, delivered as vapour without a liquid fraction at a steady rate of 0.30 ± 0.05 kg/s. There shall be a means of monitoring the mass flow rate during the test. There shall also be a means of recording the total amount (kg) of propane used; for the test to be valid, this shall be (0.3 x duration of test in seconds) ± 5 %. The temperature and pressure shall be monitored at the nozzle.

6 Test location

The test shall be carried out indoors, or in a sufficiently sheltered environment that the effects of the weather, e.g. wind and rain, can be excluded. The ambient air temperature shall be measured, and the test may be carried out if it is between -10°C and +40°C.

7 Conduct of the test

7.1 This test can be used in two ways: either to determine the maximum temperature above ambient reached after a defined period of exposure to the jet flame; or to determine the length of time taken to reach a specified maximum temperature, which will define the duration of the test. The method to be employed shall be decided before the test commences.

7.2 The test specimen is fixed to the rear box and the assembly is mounted on lightweight concrete blocks (or similar) approximately 1.0 m from the ground. Blocks (or similar) should also be placed around the test specimen to prevent the flame from impinging the sides of the test specimen. Figure 8 shows the layout of the test facility. Photographs shall be taken of the test specimen before the test.

7.3 Weather conditions shall be measured immediately before the test, and any significant changes during the test noted. Measurements taken shall include ambient temperature and relative humidity, and for tests conducted outdoors, wind speed and direction, whether sunny/cloudy and any precipitation.

7.4 When the jet of propane vapour is ignited, a timer shall be started and the flow rate, temperatures and pressures monitored. Readings of the instruments shall be taken at least once every 30 seconds. The test shall continue until either the time or temperature selected prior to the test is reached.

7.5 Observations shall be recorded of significant details of the behaviour and appearance of the test specimen during the test and after the jet flame is extinguished. Information on deformation, spalling, cracking, burning of the test specimen, continuance of flaming and the production of smoke shall be noted.

7.6 Photographs of the test specimen shall be taken at times of 1 minute and 1 hour after the jet has been turned off. These shall be included in the test report.

8 Repeatability and reproducibility

Data on repeatability (within-laboratory variability) and reproducibility (among-laboratory variability) will be added here when it becomes available.

9 Presentation and interpretation of results

The test report shall include the following information:

a) Name of the testing laboratory and the test date.

b) Names of the sponsor/customer, the manufacturer and the product.

c) Documentation on how and when the test specimen was prepared.

d) A description of the test specimen, including measurements of the thickness of thermal insulation material at each thermocouple position.

e) Record of test details:

   (i) Ambient conditions.

   (ii) Record of fuel mass flow rate, temperature, pressure every 30 seconds throughout the test, and total mass of fuel used.

   (iii) For reacting materials, the thickness of unreacted material left at the end of the test.

f) The test result, in the format given below:

   (i) The behaviour and appearance of the test specimen during and after the test and photographs, as mentioned in the 'Conduct of test' section.

(ii) Time/temperature plot for each thermocouple.

(iii) Record of the maximum temperature rise above ambient and the time taken to reach it.

Figure 1 - TEST SPECIMEN FOR COATING MATERIALS

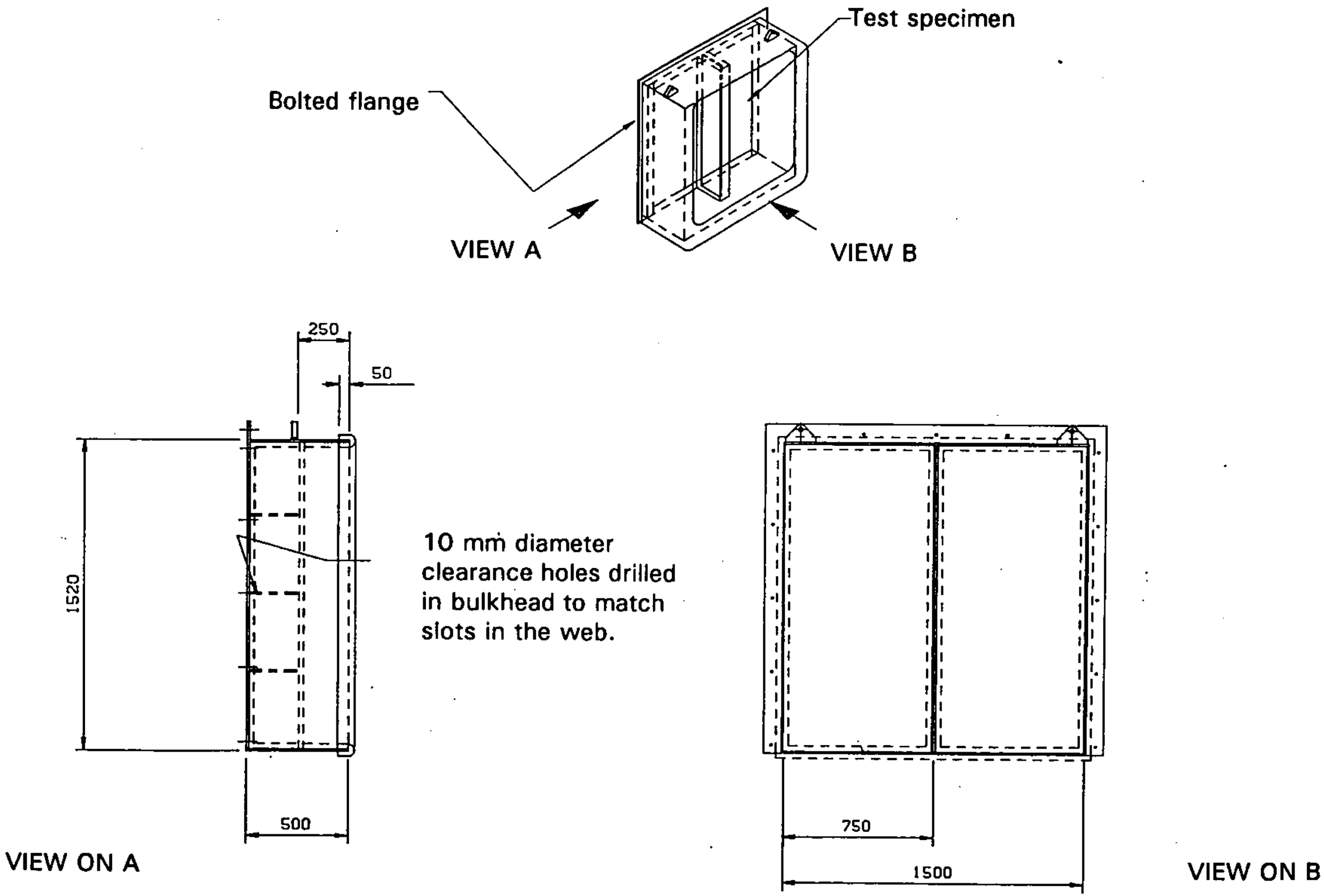


Figure 2 - TEST SPECIMEN FOR COATING MATERIALS IN PLANAR APPLICATIONS

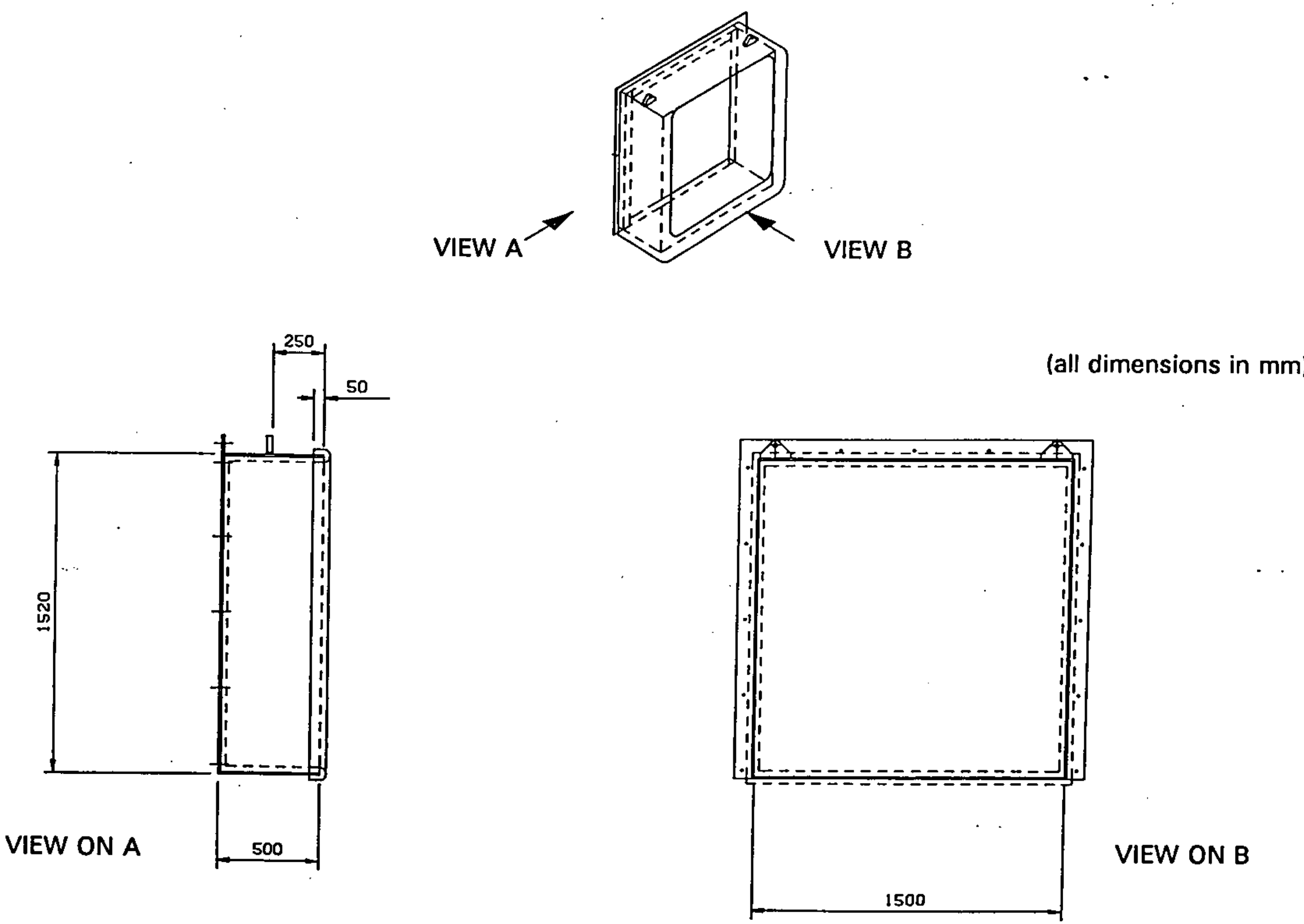


Figure 3 - TEST SPECIMEN FOR PANEL MATERIALS

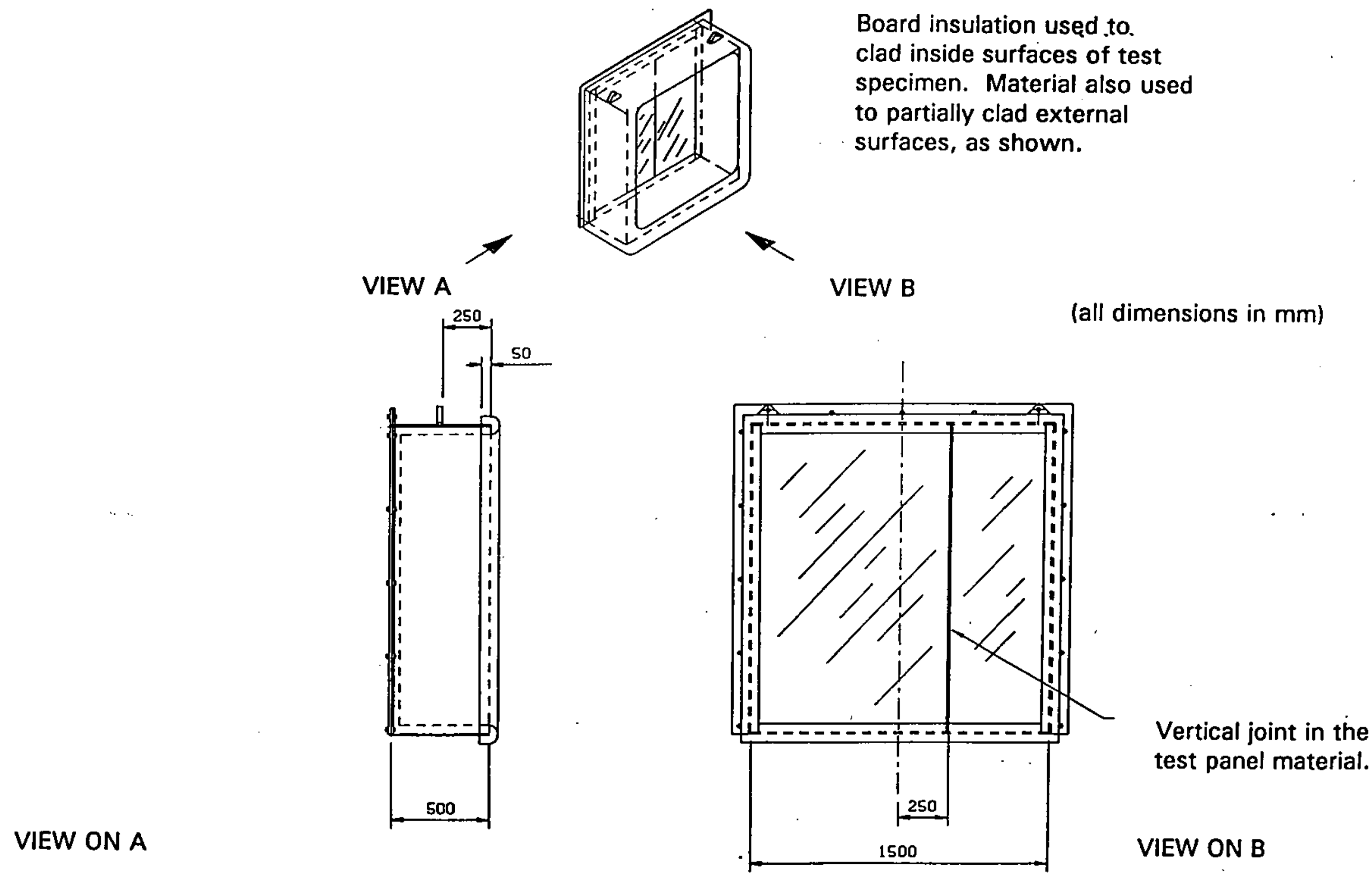
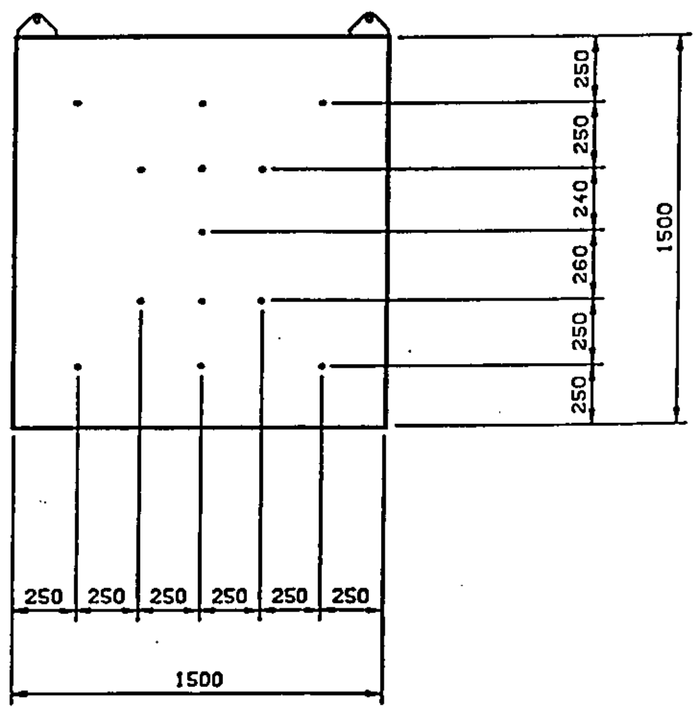
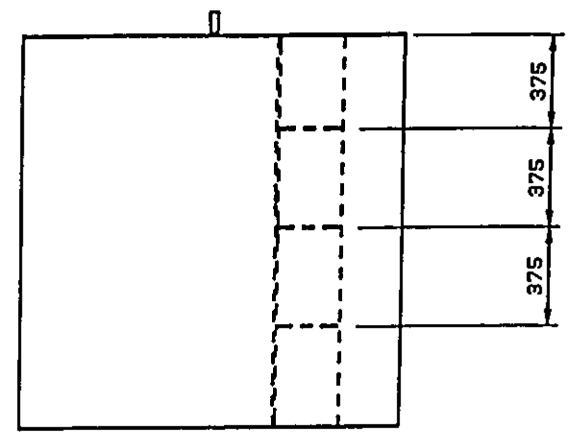


Figure 4 - THERMOCOUPLE LAYOUT FOR COATING MATERIALS

(all dimensions in mm)



VIEW B
(REAR)

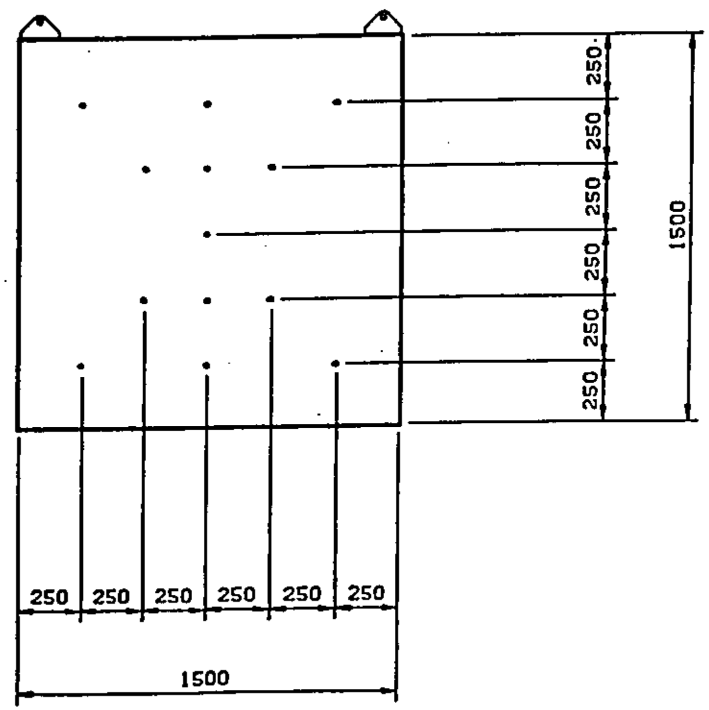


Thermocouples attached inside slots by chosen method from Annex A before halves of web are welded together.

VIEW A
(SIDE ELEVATION)

Figure 5 - THERMOCOUPLE LAYOUT FOR COATING MATERIALS IN PLANAR APPLICATIONS

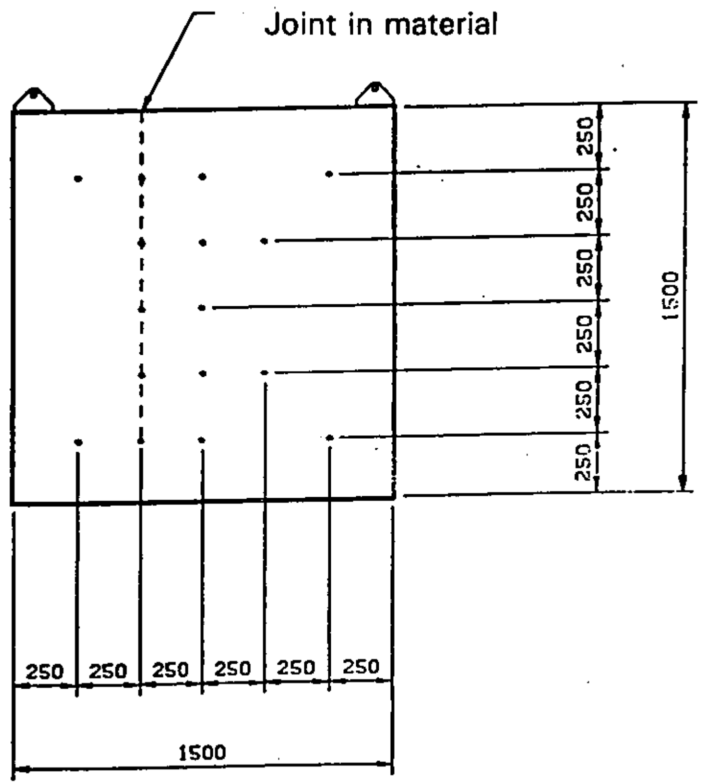
(all dimensions in mm)



VIEW B
(REAR)

Figure 6 - THERMOCOUPLE LAYOUT FOR PANEL MATERIALS

(all dimensions in mm)



VIEW B
(REAR)

Figure 7 - JET FIRE NOZZLE

(all dimensions in mm)

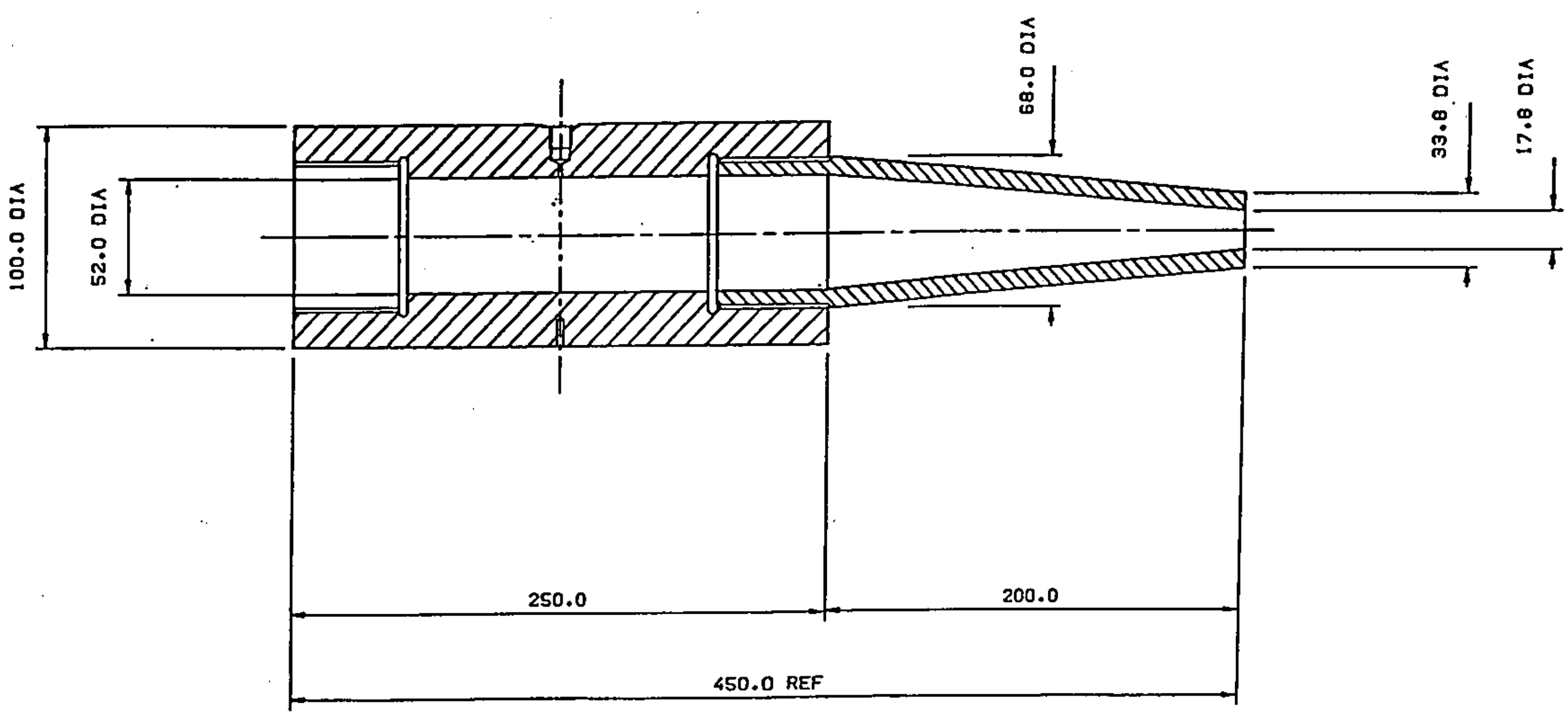
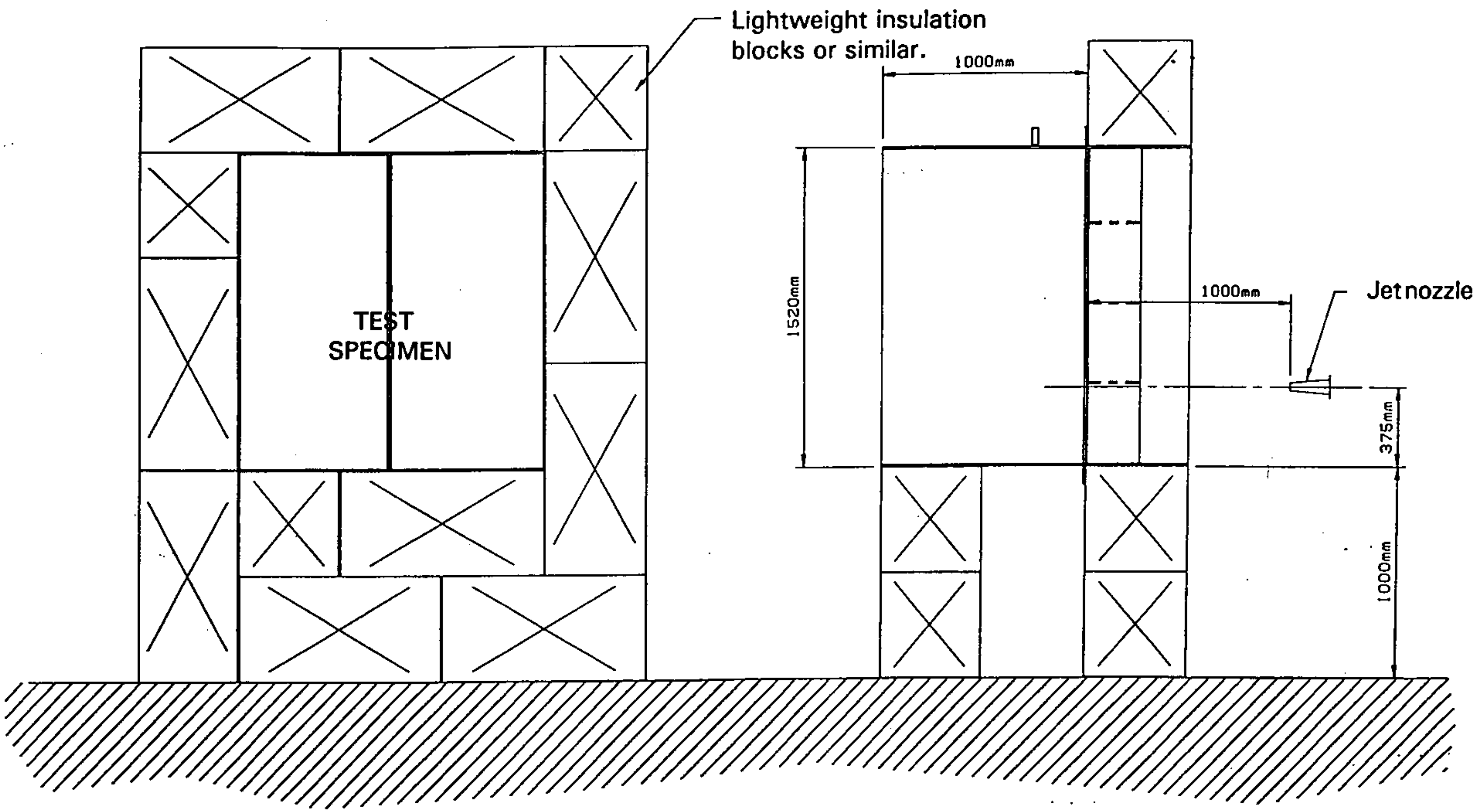


Figure 8 - JET FIRE TEST LAYOUT



FRONT ELEVATION

SIDE ELEVATION (SECTION)

Annex A
(normative)

Methods of fixing thermocouples

The type of thermocouples used are Chromel/Alumel (type K), with conductors of a diameter appropriate to the method of fixing. Some of the alternative methods for fixing the thermocouples are given below. Other methods could by used if they are shown to be equivalent.

- **'Quick Tip' attachment**

(i) The two 0.3 mm diameter thermocouple wires are put into a metal piece with pre-drilled holes for the wires.

(ii) The metal piece is then squeezed in a special tool into a cylindrical shape, 1.5 mm long and 1.5 mm in diameter, firmly gripping both wires in the process.

(iii) A 2 mm hole, 2 mm deep, is drilled in the position where the thermocouple is to be fixed. The joint piece is placed in the hole and a drift is used to peen over the metal.

- **Capacitive discharge welding**

This uses a proprietary piece of equipment such as the Cooperheat T.A.U. (Thermocouple Attachment Unit) and is a suitable method for attaching thermocouples to a metal substrate. Always follow the manufacturer's operating instructions.

(i) Clean loose scale or rust from the selected attachment area (do not clean to bright metal).

(ii) Attach the earth return, ensuring a good electrical connection.

(iii) Strip back 10 mm of insulation on each 0.7 mm diameter thermocouple wire.

(iv) Attach electrode to one wire, position it correctly on substrate, discharge current.

(v) Repeat with other wire a maximum distance of 6 mm away from the first one.

- **Drilling and peening**

This method is also suitable for attaching thermocouples to a metal substrate.

(i) Weld the two thermocouple wires together.

(ii) Drill a hole of appropriate diameter in the position in which the thermocouple is to be attached.

(iii) Insert the thermocouple and peen over the edges of the hole with a centre punch.

- **Adhesive**

This method is suitable for fixing thermocouples to non-metal substrates.

(i) Weld the two thermocouple wires together.

ii) Fix the thermocouple to the substrate with an epoxy adhesive suitable for high temperature duty.
