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Test Method

# High temperature test method for polymer pipes

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ABSTRACT

Polymer pipes in walls can melt during a building fire, leaving an avenue for fire and smoke to spread. Firestop products aim to mitigate this, but their rapid development is impeded by the lack of appropriate, standardised laboratory tests for polymer pipes at elevated temperatures. We have created a suitable test protocol which can be easily implemented in the laboratory. We have carried out testing, using this protocol, on two common polymer pipes. The results show that PEX and PEX-Al-PEX pipes exhibit similar behaviour when tested at room temperature, but very different results at elevated temperatures. PEX-Al-PEX pipe, at elevated temperatures is observed to crush under a significantly lower load than PEX.

## 1. Introduction

The introduction of polymer pipes into the building industry over the past fifty years has changed fire protection fundamentally. Building fires, in “fireproof” rooms in particular, can result in a rapid increase in temperature [1]. Polymer pipes in walls, unlike metal pipes, typically melt away completely in these high temperature conditions; the resulting open pipe-installation sites can provide an avenue for fire and smoke to spread, thus compromising fire-resistance [2,3]. This has led to the development of firestop products that employ the thermal expansion properties of intumescent materials to close polymer-pipe-installation apertures under fire conditions [4,5]. *Hilti CP116A* sealant, for instance, is a firestop product containing graphite which undergoes a chemical change at elevated temperatures: expanding bubbles exert a compressive stress on the polymer pipes which they surround, crushing the pipe and finally hardening to a dense, heat-insulating multi-cellular char [5]. Such intumescent firestop products are commonly applied around the circumference of polymer pipes in walls during construction; in fire conditions these firestop products swell at elevated temperature and, coupled with the simultaneous softening of the polymer material, crush the pipe. This swelling and crushing results in plugging of the (potentially open) pipe-installation aperture during a building fire [4,5].

Although firestop products have been widely implemented, their development has been slow owing to the strict regulations surrounding fire safety [3]. Currently, approval of firestop products as sealants around polymer pipes, is only granted in Australia through exact situational replication, i.e. full fire tests, to demonstrate that the product meets Fire Resistance Level requirements. This requires exposure of firestop products and the associated polymer pipes to a full-scale controlled fire, which might produce results for only a few products at one time. If full fire testing is not carried out, the high-temperature behaviour of polymer pipes must be inferred from the room temperature properties of the polymers concerned. In order to accelerate the development of firestop products, several modelling and experimental investigations have been conducted, to better understand intumescent reactions together with the high-temperature behaviour of polymer pipes e.g. [4,5].

We have developed a standard protocol for laboratory testing of polymer pipes under the elevated temperatures experienced during a building fire. We have designed and built a test apparatus, carried out testing of two types of polymer pipes and evaluated their behaviour at ambient and elevated temperatures. Conventionally, testing of polymer pipes measures deformation under load only at ambient temperature: both external compression (usually due to soil, underground) and internal pressure (usually due to fluids or gas carried in the pipe) is measured [6–8]. Our elevated temperature testing protocol is designed to close a polymer pipe completely by external compression, i.e. to result in 100% deflection and zero internal diameter, in order to evaluate their performance with firestop products under fire conditions. We applied this protocol to two similar polymer pipes, crosslinked polyethylene (PEX) pipe and an aluminium-PEX composite (PEX-Al-PEX) pipe, in order to compare their performance. This is of particular interest in fire safety currently, because an intumescent sealant (*Hilti CP611A*) is approved for use with PEX but not yet with PEX-Al-PEX.

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## 2. Materials and methods

### 2.1. Materials

Two types of polymer pipes were tested: PEX and PEX-Al-PEX. PEX pipe consists of a thin black oxygen/UV barrier outer layer and an inner opaque layer of PEX. The PEX-Al-PEX composite pipe has an outer layer of PEX, a thin midlayer of overlap-welded aluminium and an inner layer of PEX. The PEX-Al-PEX pipes tested in the present work contained 10% Al by volume [9]. The addition of aluminium has the primary aim of increasing the internal burst pressure of the pipe, allowing for fluid or gas to be transported at higher internal pressure in PEX-Al-PEX pipe, than in PEX pipe.

### 2.1.1. Material preparation

Material preparation and testing was undertaken as per ASTM2412-11 "Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading" [6]. Each individual test piece was a length of pipe, with length equal to the outer diameter, 25.0 mm for both PEX pipe and PEX-Al-PEX pipe. The internal diameter of the PEX-Al-PEX test pipes was 20.0 mm. The internal diameter of the PEX pipe was initially 18.0 mm; but in the present work material was removed from the inner surface of PEX pipe by means of a lathe, to give an internal diameter of 20.0 mm and hence match the PEX-Al-PEX pipe dimensions.

### 2.2. Equipment

### 2.2.1. Compressive testing

An Instron Universal Tester (hereafter "Instron"), which meets the requirements of ASTM2412-11 [6], was used. The Instron was set up with a circular upper compression platen of diameter 50 mm and a square lower compression platen of 150 mm*150 mm.

### 2.2.2. Heating apparatus

The high temperature testing to be carried out requires (i) heating of the polymer pipe to temperatures similar to those experienced in building fires, and (ii) a diametral crush via external compression. The heating apparatus must accordingly provide rapid heating of the pipe to the intumescent activation temperature of the firestop material ($\approx 220\,^{\circ}\mathrm{C}$), while not impeding mechanical testing. The goal was a rate of heating equivalent to 220 °C in 220 s, as measured in the report by Zhao et al. [1].

*2.2.2.1. Heating plates*. To achieve both the desired heating rate and reproducibility, metal plates were selected to transfer heat to the test piece, by thermal conduction via two contact points: one above and one below the pipe, positioned in the Instron. Although thermal conduction does not completely replicate the radiant heating which occurs in fires, it can achieve the required heating rate and is reproducible. The metal selected for the heating plates was aluminium alloy 5025, which exhibits high thermal conductivity ($204\,\mathrm{Wm^{-1}K^{-1}}$) and low thermal expansion ($24 \times 10^{-6}\,\mathrm{K^{-1}}$), while retaining strength up to 220 °C [10].

*2.2.2.2. Cartridge heaters*. To provide heating, commercial cartridge heaters [11] were installed in holes drilled in the aluminium plates described above. The two cartridge heaters used in the present work provided 250 W, were 63.5 mm long and 6.3 mm in diameter. A Type J thermocouple was also inserted in the hole drilled in each aluminium plate, to measure temperature via a Digital Multimeter (DMM).

*2.2.2.3. Final heating apparatus*. The upper heating apparatus, in the modified upper platen of the Instron, is shown in Fig. 1. The aluminium heating plate (1) is located beneath a refractory tile (2) which protects the Instron compression platen (3) from heat, but does not deform under compression. The heating plate is attached to the compression platen via an aluminium bracket (4) with two upper and one lower threaded bolts. On the lower bolt (5) a white polytetrafluoroethylene (PTFE) bush (6) can be seen, which has two functions: firstly it minimises the direct transfer of heat from the heating plate to the compression platen; and secondly it allows for some flexure during testing. This flexure ensures that the plate (and not the bracket) bears the compression load; and allows any thermal expansion of the aluminium heating plate to take place without damaging the remainder of the apparatus.

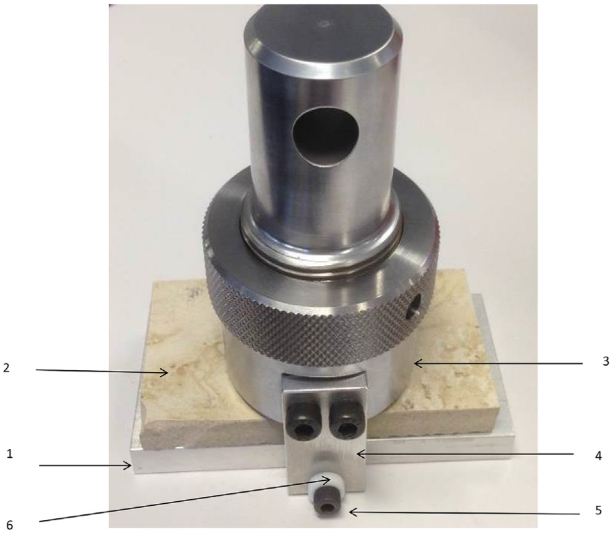

**Fig. 1.** Final (unwired) Heating Apparatus. (1) aluminium alloy heating plate, (2) refractory tile, (3) Instron compression platen, (4) aluminium bracket, (5) lower bolt, with (6) PTFE bush.

### 2.3. Testing

### 2.3.1. Room temperature testing

Room temperature testing was first undertaken without the heating apparatus, on both PEX and PEX-Al-PEX pipes, to establish mechanical properties at standard (ambient) operating temperatures. The compression rate was set at 12.5 mm/min as required by ASTM D-2412 [6]. The compression test was then initiated, with load applied externally from opposite sides of the pipe, via the compression platens; it continued until the internal diameter of the pipe had reduced from the initial value (20 mm) to zero.

### 2.3.2. Elevated temperature testing

A tile and an aluminium heating plate were (sequentially) placed on the lower platen; and the high temperature testing rig shown in Fig. 1 was installed on the upper platen of the Instron. Each Type J thermocouple was placed securely in the installation holes within each of the heating plates, then attached to their respective Digital Multimeters (DMM). Both DMMs showed the live voltage values representative of the room temperature before beginning the tests. The Instron was recalibrated to take into consideration the extra mass that had been added to the upper platen. A compression test procedure was then set up with a compression rate of 12.5 mm/min as per ASTM D-2412-11 [6].

The temperature of the two heating plates was monitored simultaneously by the two thermocouple readouts on the DMMs. Once these showed 220 °C, the temperature of the internal walls of the pipe (at the closest points to the heating plates, and at the furthest points) was measured with a laser pyrometer. The power supply to the heating plates was then switched off; the compression test was immediately initiated and completed as per ASTM 2412-11 [6].