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Is PVC Piping Firesafe?

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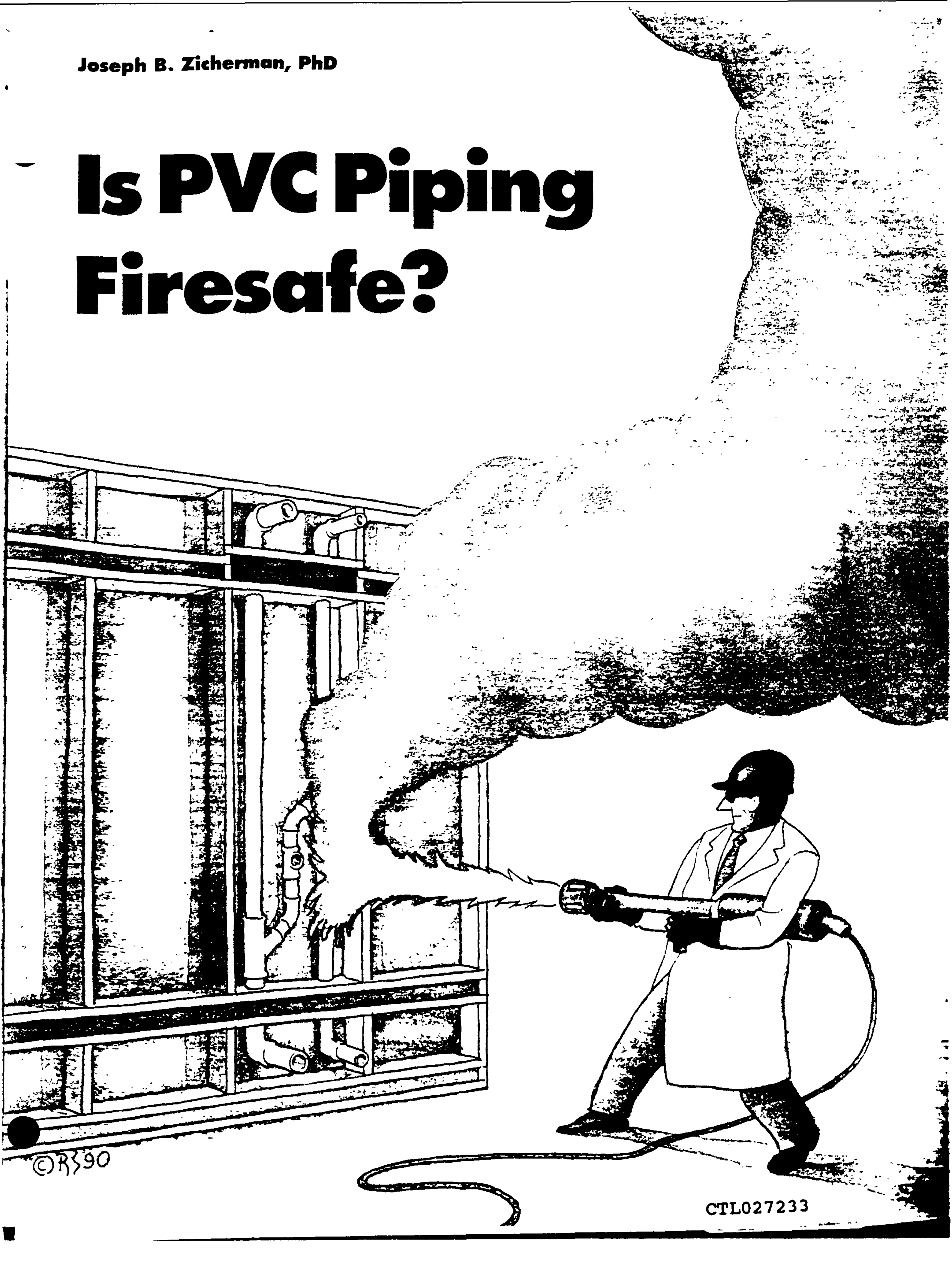

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Because polyvinylchloride (PVC) is an organic polymer, there are frequent firesafety questions about its use as piping in fire-resistive construction. What measures must be taken to ensure the integrity of fire-resistive assemblies penetrated by PVC piping or assemblies containing PVC piping in wall cavities or floor/ceiling spaces? What is the firesafety record of PVC piping used in plumbing applications?

Answers to these questions lie in a review of testing and research results, performance in the field, and applicable codes and standards.[1]

Historical Review

The performance of PVC pipe was originally evaluated in extensive ASTM E-119 fire-endurance test programs conducted in the early 1970s at the National Institute of Standards and Technology's (NIST) Center for Fire Research (CFR), Ohio State University, and the University of California at Berkeley.[2] These programs were designed to determine whether fire-resistive wall assemblies whose cavities contained plastic drain, waste, and vent (DWV) piping and whose membranes had been penetrated by fixture connections could maintain their fire ratings. The test results showed that, depending on how the pipe was installed, it would not reduce the fire ratings of such walls.

ASTM E-119 was used in these programs because it was the only test method available to assess uniformly the performance of such elements as plastic pipe that entered, exited, or went all the way through—that is, "through-penetrated"—a test assembly at the time the fire-endurance performance of assemblies containing plastic pipe became important to regulators. However, ASTM E-119 was not a perfect test method. It required a specimen no smaller than 100 square feet, but it did not provide specifics on instrumentation or specimen configuration. Nor were there any criteria defining the atmospheric pressures applied to specimens in the test furnace. Overlaying this situation, which itself contributed to variability in testing methods, were the large number of fire-resistive assemblies the codes accepted, none of which had ever been tested with piping installations of metal *or* plastic.

These factors, as well as the large number of plumbing system configurations and combinations possible, made it necessary to select and test the most basic plumbing wall designs available. The designs chosen were based on certain considerations. Among these was the fact that the most commonly used and most economical plumbing wall is the wood-stud cavity wall of minimum depth faced with gypsum wallboard. The drain, waste, and vent system is a more vulnerable plastic piping system than supply piping because it uses larger pipe sizes, the pipe is empty most of the time, the system is vented and includes stacks, and the connections must penetrate wall membranes at various locations. From a firesafety standpoint, the worst penetrations for DWV piping are back-to-back penetrations for trap connections. Single-side trap connections and pipe stacks or branches that are within a cavity wall, but have no trap connections, are less critical.

With these parameters in mind, each of the initial ASTM E-119 test series approached the problem from a different perspective. The CFR series, which was the most extensive, assessed the performance of PVC pipe on a side-by-side basis with cast iron, copper, and acrylonitrile-butadine-styrene (ABS) plastic pipe systems. This series evaluated walls as narrow as those based on 2-by-4-inch wood-framing and as deep as double-stud walls on wide plates, which are commonly found as party walls in townhouse-style construction. Test configurations also included various plumbing chase designs and a metal stud wall.

The CFR tests provided information on the base-line performance of the materials in various framing and piping configurations. The tests also demonstrated the importance of clearance between elements of PVC piping that penetrate gypsum wallboard and the importance of preventing stresses on wallboard, especially those that could be caused by fittings at through-penetrations, oversized pipe, and fitting contact. Installation methods, which included metal sleeving for plastic pipes, were also tested.

The Ohio State tests evaluated relatively standard ASTM E-119 test wall assemblies without attempting to account for vertical fire spread to simulated upper or lower floors. Grout was used as the firestopping material where plumbing traps connected to waste and vent stacks. One- and 2-hour-rated designs of 2-by-4-inch and 2-by-6-inch wood-frame walls with PVC drain, waste, and vent pipes were successfully tested for both fire endurance and hose stream resistance.

The University of California series tested 1-hour-rated, 2-by-6-inch wood-frame test walls with simulated floors above and below a fire floor. Two tested methods were successfully used to firestop locations where PVC traps penetrated gypsum wallboard: Either 16-gauge sheet metal heat shields were installed to protect the penetration area, or fiberglass batt insulation was placed in the piped stud cavity to a height of 48 inches.

These three test series revealed the importance of installation methods which included the use of grout, metal sleeves, heat shields, and thermal insulation. Installation detailing, which prevented pipe and fittings from pressing against gypsum wallboard membranes, was shown to help performance and to prevent the formation of openings that might lead to premature burn-through. Penetration diameters could not be oversized, and annular spaces had to be sealed with the appropriate materials. Nor could openings in plates be oversized unless they were filled with firestopping materials.[1]

New Test Method Adopted

In 1981, the adoption of ASTM E-814, *Fire Test Method for Through-Penetration Firestops*, provided a needed methodology for testing items penetrating fire-resistive assemblies. It was developed to define instrumentation, appropriate specimen sizes, and configurations to evaluate through-penetrations of an assembly whose fire rating had been previously established in the full-scale ASTM E-119 format. ASTM E-814 uses the ASTM E-119 time-temperature curve, but it allows for smaller specimens, since the test assembly need only be representative; from a practical standpoint, this means having sufficient clearances between the edge of the specimen, the test furnace, and the firestop itself. This does not preclude using ASTM E-814 with large specimens such as those required for ASTM E-119, evaluating multiple penetrations, or assessing other firesafety aspects of an assembly while assessing the integrity of the through-penetration.

The ASTM E-814 method has proven useful in developing new products because it provides a specific test method for regulators concerned with through-penetration integrity. It has proven especially appropriate for evaluating straight through-penetrations, such as those made for sprinkler piping, supply piping, and elements of other mechanical or electrical systems. ASTM E-814 has been adopted by all three US model code organizations and is referenced in the Conference of American Building Officials (CABO) guidelines dealing with ducts, shafts, and pipe and cable penetrations. A similar standard was developed by Underwriters Laboratories as UL-1479.

In contrast to generic plumbing elements installed in cavity walls, which typically are subjected to tests under ASTM E-119 or ASTM E-814 with ASTM E-119-sized specimens, most of the listed and labeled proprietary penetration firestopping systems and devices deal with straight through-penetrations of monolithic assemblies, such as slabs or walls. They are not generally applicable to plumbing wall penetrations of gypsum wallboard membranes, though exceptions do exist.

While few technical articles referring to the fire performance of PVC pipe were

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published in the 1980s, third-party laboratories and listing agencies conducted numerous ASTM E-119 and ASTM E-814 tests during that period. The outcome of these tests reflects a maturation of industrial technology and constitutes a substantial data base. Table 1 summarizes such fire-endurance test results on PVC pipe products with generic and proprietary firestopping systems, conducted by both public and private testing agencies under the ASTM E-119, ASTM E-814, and UL-1479 test protocols.

More recently published were the findings of an independent study conducted over the past several years to evaluate the firesafety of plastic piping products. The study, part of an environmental impact report for the State of California's Department of Housing and Community Development, examined the appropriateness of revising the state plumbing code to allow expanded use of plastic pipe. These findings indicate that PVC piping products are safe for use in fire-rated buildings, provided compartmentation is maintained.[15] The report recommends appropriate construction techniques and through-penetration firestopping methods to achieve this, and stresses effective enforcement of applicable codes and standards.

Fire Endurance of PVC Pipe

Once flashover has occurred in a building plumbed with PVC pipe, what can be expected to happen? And what have we learned from fire-endurance testing of these products over the past 20 years?

The ASTM E-119 test models a conservative, post-flashover structural fire. In such a situation, most heat transfer within the space affected by the fire is by radiation and re-radiation, as opposed to conduction through building elements, or by convection, as through the movement of hot gases.[6] From a practical standpoint, PVC pipe found in cavity walls is strongly affected by this balance of heat transfer modes because increased temperatures cause PVC pipe to soften, sag, and eventually fall to the bottom of a stud cavity or plumbing chase well before the gypsum wallboard protecting the cavity falls away. This results in minimal exposure of the pipe to direct thermal radiation.

For example, wallboard fall-off does not typically occur in a two-hour ASTM E-119 fire exposure of an assembly that consists of two layers of ⅝-inch gypsum wallboard on each side of metal or wood studs. As a result, the cavity heats up far more slowly than the fire compartment because it is shielded by the wallboard. PVC pipe within such a stud cavity will soften, melt, and drop to the bottom of the cavity in the first hour of the test. Rather than being distributed throughout the height of the wall, the pipe is thus found as a charred mass at the bottom of the stud cavity when interior temperatures there begin to approximate furnace temperatures. This observation has been borne out by examination of hose-stream specimens, whose exposure duration is half the rating of a test wall, where PVC stack materials are found at the bottom of plumbing chases.

How does PVC piping in a wall cavity or passing through a wall affect the fire performance of the rated assembly? The fire endurance of rated assemblies built with steel or wood framing, gypsum wallboard, and concrete-and-masonry walls, floor slabs, and floors/ceilings is well characterized from a regulatory standpoint. Examples of many wall, floor, and floor/ceiling designs that have 1-, 2-, or 3-hour fire ratings are found in the model codes, in UL's *Fire Resistance Directory*, and in the *Fire Resistance Design Manual* published by the Gypsum Association. One of the reasons the concept of generic, fire-rated assemblies is so widely accepted is that such designs have been tested repeatedly through the years under the ASTM E-119 method in similar, generally accepted configurations.

However, an almost unlimited variety of assemblies may exist when plumbing is installed in the field. For example, a wall is the most common type of fire-rated assembly used with plumbing systems. It may include a simple through-penetration, as for sprinkler piping; various configurations of pipe without penetrations,

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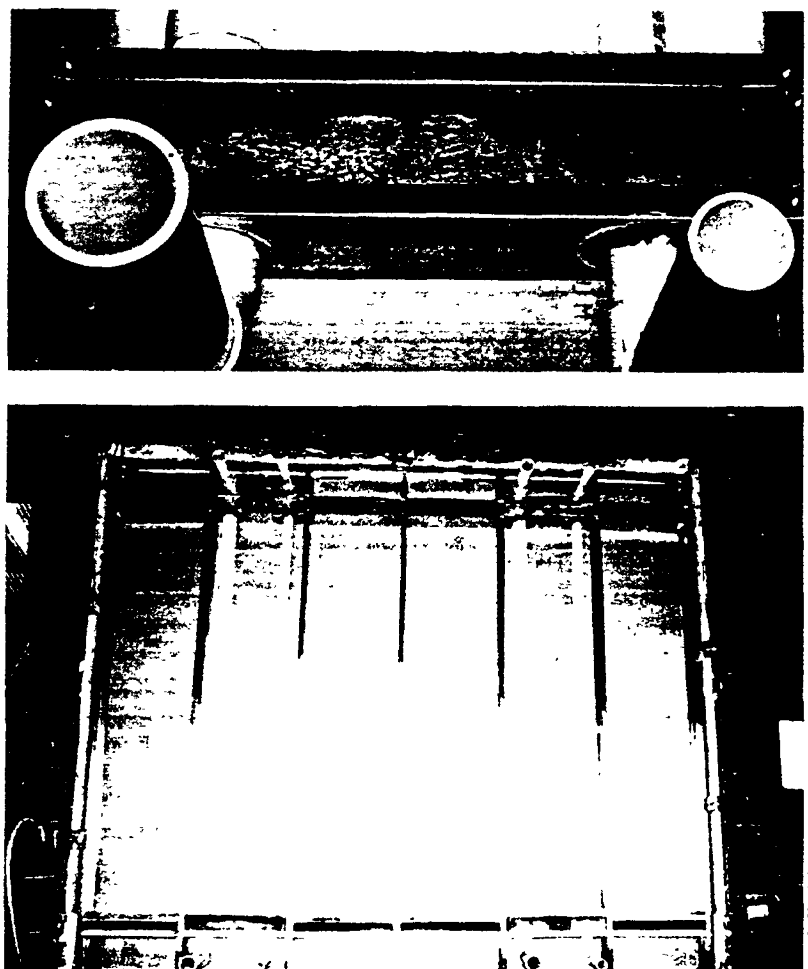
Fire-Endurance Testing of PVC Pipe Products: E-814 Test Preparation (Before)



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PVC piping was tested using ASTM E-814, Fire Test Method for Through-Penetration Firestops. It was installed in a fire-resistive wall assembly whose fire rating had been previously established in full-scale ASTM E-119 tests.

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as for runs of drain and vent pipe; or a single penetration, as for a single sink, often called a "membrane penetration." Back-to-back penetrations, such as those that occur in certain fire-rated, multiple-unit dwellings and include vertical runs of DWV pipe, are perhaps the most common, most critical configurations from a fire-safety standpoint.

In principle, a wall assembly penetrated by any material is more prone to failure than the same assembly without penetrations. This is because openings or disruptions in protective membranes such as gypsum wallboard cause stress that is absent from unpenetrated assemblies. For wall assemblies, the most stressful situations include DWV lines running vertically within the wall and through-penetrations, as opposed to membrane penetrations of only one side. For this reason, satisfactory fire test results from wall assemblies with vertical pipe runs and a through-penetration provide the "worst case" fire test scenario. Assemblies in which PVC piping materials run within cavities but do not through-penetrate the wall or penetrate just one side of the wall are less stressed and thus less prone to failure than the designs incorporating both through-penetrations and vertical runs of PVC drain and vent piping.

In the past, concern has been raised about the use of exposed PVC pipe in areas such as parking garages and the basements of fire-resistive buildings. Since such buildings incorporate compartmentation, the boundaries of the fire-resistive construction envelope are required to prevent fire spread, and they are designed accordingly. If through-penetrations are properly protected, fire spread from affected compartments is thus mitigated. In addition, PVC pipe will not ignite readily before flashover because it contains chlorine, which provides built-in resistance to ignition, and does not contain plasticizers, which would reduce that resistance. After flashover, the exposed PVC piping will contribute to the fire and smoke developed, along with any other combustibles in the affected compartment.

Firestopping Approaches and Systems for PVC Pipe

Firestopping for PVC piping systems falls into two categories. The first involves generic, passive approaches and non-proprietary materials such as grout, thermal insulation, and other filling or backpacking materials at penetration locations. These methods have been demonstrated in ASTM E-119 tests on cavity walls with DWV stack and trap connections. This approach has been successful for various 1- and 2-hour-rated plumbing wall assemblies, provided construction detailing is performed reasonably. The most typical of these methods use non-shrinking grouts or commonly available fiberglass batt insulation to prevent fire spread.

The second approach to firestopping PVC through-penetrations of fire-rated walls, slabs, or assemblies involves the use of proprietary firestopping products. Most of these products are specialized mastics, insulations, or thermally activated systems based either on mechanical closure of openings or chemical closure achieved through intumescent technology.[7] These systems rely on the fact that, during a fire exposure, PVC pipe becomes soft before igniting. Thus, an appropriate intumescent material will close and seal an opening containing such a pipe before fire can spread.

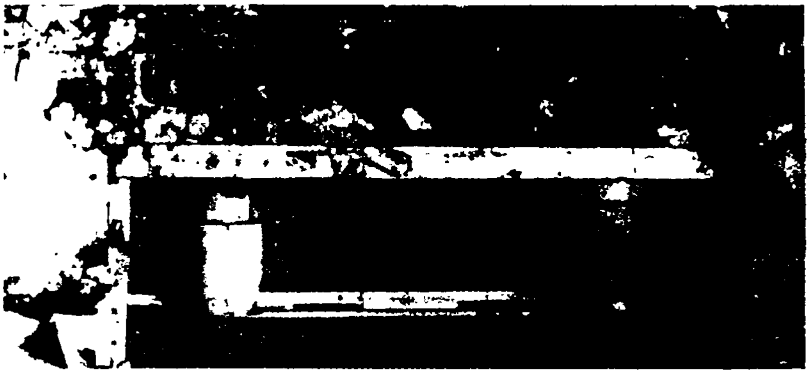
Successful 1-, 2-, and 3-hour fire tests have been conducted with intumescent systems for openings in masonry walls up to 12 inches in diameter, under positive-pressure fire-test conditions.[8] Tested and listed thermally activated mechanical firestopping devices include those that can plug a pipe at a through-penetration or cut through a plastic piping assembly and seal it with a guillotine-like device to prevent fire spread when elevated temperatures occur.

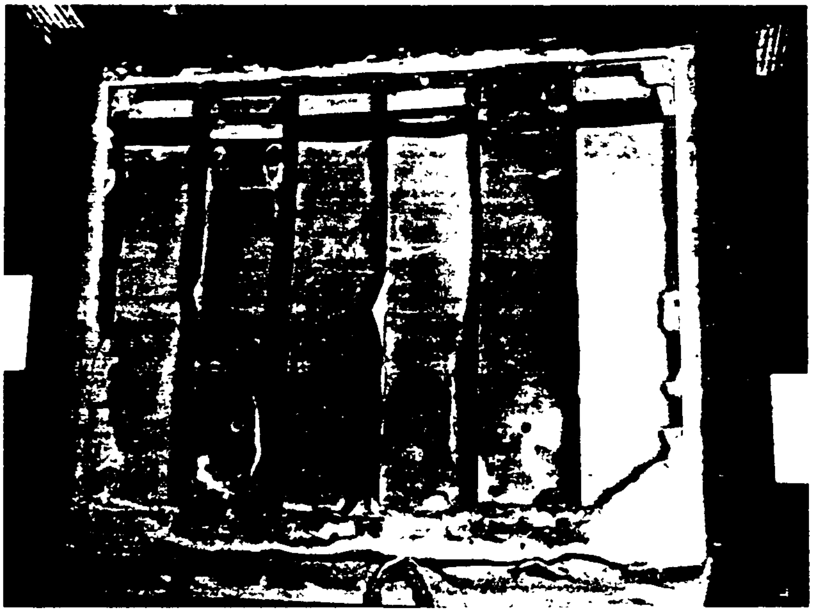
Recent Research

Since the early 1980s, research into PVC piping firesafety has focused on two areas. The first is proprietary systems for firestopping that require extended fire

FIGURE 2

Fire-Endurance Testing of PVC Pipe Products: E-814 Test Results (After)





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The results of the ASTM E-814 fire endurance test of PVC piping in a fire-resistive assembly are evident in these two photos, taken after the test was completed.

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endurance or involve larger openings and pipe sizes and larger numbers of penetrating elements. These efforts have led to the development of specific systems and associated installation methodologies to protect such openings, and to listing with approved third-party agencies. In most cases, the research committee of one or more of the model code organizations has also reviewed the performance of these products.

The second area of research involves development of generic firestopping systems for metal-framed walls similar to those demonstrated in the 1970s for 1- and 2-hour-rated wood-frame walls. In a recent test series conducted with generic firestopping based on grout or fiberglass batt insulation, PVC drain, waste, and vent stack systems with through-penetrating 1½-inch laterals and traps were installed in 1- and 2-hour non-combustible steel-stud wall assemblies faced with gypsum wallboard. The tests were conducted under positive pressure, as called for in the codes for ASTM E-814 testing. Both small- and large-scale assemblies—that is, 4-by-5-foot and 10-by-12-foot assemblies—were tested so that correlations between the former, which are most typically used in ASTM E-814 tests, and the latter, required for ASTM E-119 testing, could be observed. In the latter, instrumentation of through-penetrations was conducted according to ASTM E-814, and test specimens included vertical penetration of concrete inserts that simulated slabs at the top and bottom of exposed sections of test walls. Post-test photos of such penetrations show no vertical fire spread beyond the tested area (see Figure 1).[9,10]

These tests confirm that generic firestopping approaches for PVC pipe perform as satisfactorily with steel-frame assemblies as they did with the wood-stud wall assemblies tested earlier by the CFR, Ohio State University, and the University of California at Berkeley.

Pressure Effects of PVC Pipe

During a post-flashover fire, there are pressure gradients that increase from negative values in the range of −0.02 to −0.01 inches of water at floor level to zero at about one-third the height of the affected room. These pressures continue to increase so that, near the ceiling, positive pressure may be in the range of +0.02 to +0.04 inches of water.[11]

The effect of such pressure gradients on fire travel through assemblies that include penetrations has been debated extensively in code forums, where the pressures in test furnaces have been an issue. In response, each model code organization has stipulated that positive pressure be applied to assemblies tested under ASTM E-814. This is a conservative assessment, however, since a fire-resistive assembly is most commonly penetrated by a pipe at a sink, which will be under negative pressure during a post-flashover fire. Yet such pressure requirements are appropriate in testing, since piping may also pass through fire-resistive assemblies high in a room, as at floor penetrations or above a hung ceiling. Sprinkler piping, for example, is usually run overhead, as is domestic hot and cold water piping.[12]

Water Distribution Piping

Because the cooling effect of the water contained in both chlorinated polyvinyl-chloride (CPVC) sprinkler systems and domestic hot and cold water systems prevents ignition and because the additional chlorine atom on the CPVC molecule enhances its fire performance compared to the usual PVC piping materials, generic firestopping approaches are appropriate for these systems. For openings with a diameter greater than 2 inches, devices and proprietary systems tested with PVC or CPVC in these size ranges should be used as required by the codes.

Listings for CPVC-based fire sprinkler systems were obtained after fire tests that included both direct and indirect exposure of sprinkler piping and fittings to fire conditions. These included ambient exposures with temperatures up 1,700°F from burning wood cribs secondarily fueled with heptane. Various types of sprinklers were evaluated with the CPVC systems, and listings for both light and ordinary occupancies, as well as residential use under NFPA 13D, *Standard for Sprinkler Systems in One- and Two-Family Dwellings and Mobile Homes*, have been issued.[13,14]

Codes and Standards

In the 1980s, the plastic pipe industry increased its efforts to make systematic installation information available to code officials, specifiers, and engineers who used PVC piping products in fire-rated construction. These efforts included publication of the installation manual *Plastic Pipe in Fire-Resistive Construction.*[15] A second edition of this document has been prepared and is currently being reviewed by CABO's National Evaluation Service.

During this same period, changes in each of the model building codes allowed for performance specification of PVC plastic pipe products in all classes of structures, provided installation methodologies meet stated guidelines.[16] In addition, incorporating the ASTM E-814 test standard in the codes has led to a more uniform approach to testing and using PVC piping materials.

Field Data on Fire Performance

PVC plastic piping has been used widely in the United States for drains,

The Toxicity Issue

One aspect of PVC piping that may affect those who fight fires is the toxicity of its products of combustion. The NFPA's *Fire Protection Handbook* addresses this point in Chapter 4, "The Characteristics and Behavior of Fire."

When PVC burns, it produces hydrogen chloride, a potent sensory irritant and a strong pulmonary irritant. Concentrations as low as 75 ppm are extremely irritating to the eyes and to the upper respiratory tract, and impairment from a behaviorial standpoint may also result. Although studies have found that hydrogen chloride gas does not physically incapacitate non-human primates subjected to concentrations up to 17,000 ppm for 5 minutes, the toxicant has been reported to cause post-exposure death at doses which did not appear to incapacitate.

There is considerable controversy as to what concentration of hydrogen chloride is hazardous to man. Although numerous studies of the acute effects of hydrogen chloride have been conducted with rodents, it is questionable whether lethality data from rodents can be directly extrapolated to man because of anatomical differences in the respiratory tract of the rodent and the primate. Interestingly, exposure doses of hydrogen chloride that cause post-exposure death in rats are in the same range as those that have resulted in post-exposure deaths of baboons, although the data for baboons are very limited and the comparison is rather subjective. The lethal toxic potency of hydrogen chloride with rats is actually only somewhat greater than that of carbon monoxide. Consideration of the exposure dose of carbon monoxide thought to be hazardous to humans would lead one, based simply on relative lethal toxic potencies, to suspect that exposure to humans to the range of 700 ppm or more of hydrogen chloride for 30 minutes would be highly dangerous. It is prudent to realize that hydrogen chloride is dangerous to humans at concentrations well below those indicated by its lethal toxic potency.

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TABLE 1

Fire-Enduranc T sting of PVC Pipe Products

	Cavity Walls and Partitions	Cavity Floors/Ceilings	Solid Concrete Slab Masonry Walls and Floors/Ceilings
Construction	Bearing and non-load-bearing gypsum-clad assemblies with wood or steel studs, minimum frame 2- by 4-inch nominal; tests have included plumbing chases to 20 square inches	Wood- and metal-framed assemblies with 10-inch nominal joist systems with gypsum wallboard lower membrane and plywood or concrete upper surfaces	Thickness ranges from 4 to 8 inches details
PVC piping systems tested	1½-inch laterals with maximum 4-inch vertical DWV pipe, with generic fire-stopping approaches: maximum 6-inch through-penetrating elements tested with proprietary approaches tested	Maximum through-penetration size of 4 inches	Maximum opening size tested of 12 inches
ASTM E119 and ASTM E814 fire ratings achieved	One and two hours	Two hours	Two and three hours
Summary of tests conducted	Twelve using generic firestopping approaches; four using proprietary approaches	Two using proprietary fire-stopping	Seven using proprietary firestopping*

*These are included as examples Substantially greater numbers of assemblies have been tested with proprietary systems than are presented here

waste removal, vents, roof drains, chilled water, and low-temperature heating and cooling in non-fire-rated construction for over two decades. The firesafety record for these materials and the fire test results discussed above have been largely responsible for their increased use in more restrictive construction applications.

In addition, the sections on alternate materials and methods in each of the model codes have permitted installation of PVC drain, waste removal, and vent piping in fire-rated construction for some years. Among these are multiple-unit, fire-resistive structures, including high-rises. In those projects, no evidence of a fire-related product defect or failure has been reported or been the subject of a product liability action. The latter is a good barometer of PVC piping fire performance, given the litigious climate in which we work and live.

Rarely have products used in fire-resistive construction been subjected to as extensive evaluation as PVC-based piping products. They have been the subject of fire-endurance testing at both publicly and privately funded laboratories on numerous occasions and in a variety of configurations, and this test work has been further evaluated by third parties involved in the regulatory process at local, state, regional, and federal levels. The results of this testing and evaluation, as well as many years of field use, indicate that properly installed PVC-based piping products do not constitute a fire hazard in structures. **FJ**

Joseph Zicherman is President of IFT Technical Services, Inc., in Berkeley, California.

1 The specific products considered here include PVC drain, waste, and vent piping CPVC domestic hot or cold water piping, and CPVC (chlorinated polyvinylchloride) sprinkler piping CPVC is derived from PVC None of these products include plasticizing additives They are based on unplasticized PVC referred to in Europe as "UPVC "

2 See also NFPA 251, *Standard Methods of Fire Tests of Building Construction and Materials*

3. This is consistent with good practice since oversized openings at plates or other penetration locations for any penetrating elements, plastic or otherwise run counter to building code regulations that are designed to prevent spread of fire and smoke from compartment to compartment Each of the model codes contains language to this effect

4 SRI (Menlo Park). "Plastic Plumbing Pipe *Draft Environmental Impact Report*. State of California Department of Housing and Community Development. Draft I, 1983

5. SRI (Menlo Park). 'Plastic Plumbing Pipe *Draft Environmental Impact Report* State of California Department of Housing and Community Development Draft II, August 1989

6 A M Kanury and D J Holve *A Theoretical Analysis of the ASTM E-119 Standard Fire Test Building Construction Materials* NBS-GCR 76-50 U S Department of Commerce National Bureau of Standards 1988

7 Intumescent materials are those that are engineered to expand during a fire and create an insulating char barrier.

8 Underwriters Laboratories *Building Materials Directory*. Underwriters Laboratories. Inc . Northbrook, Illinois. January 1988

9 Warnock Hersey International, Inc , 'Report on the Fire Endurance and Hose Stream Tests of PVC Plastic Pipe Penetrations Through a 7¼-Inch-Thick, 1-Hour Rated Gypsumboard and Steel Stud Wall," *Fire Performance of PVC Pipe in Non-Combustible Construction* Files WHI-495-PSV-0580 and WHI-495-PSV-0635 Pittsburg, California January 1989

10 Warnock Hersey International Inc "Report on the Fire Endurance and Hose Stream Tests of PVC Plastic Pipe Penetrations Through an 8½-Inch-Thick 2-Hour Rated Gypsumboard and Steel Stud Wall ' *Fire Performance of PVC Pipe in Non-Combustible Construction*, Files WHI-495-PSV-0580 and WHI-495-PSV-0635 Pittsburg, California. January 1989

11 J B Fang, *Static Pressures Produced by Room Fires* NBSIR 80-1984 National Bureau of Standards Center for Fire Research 1984

12 Interestingly, in Canada, the building code calls for positive pressure testing to be conducted at a level 10 times that called for in the United States The justification for this is, in part based upon 'stack effect' arguments. One can question the requirement for such high pressure differentials at tests based on the presence of engineered smoke control pressurization systems in high-rise buildings constructed today Such buildings in the United States are also required to incorporate fire-resistive construction and sprinkler systems Conversely, the stack effect is not a factor in low-rise, fire-resistive buildings

13 R C Wilgmg, "Plastic Fire Sprinkler Piping 1967-1987," *The Building Official and Code Administrator*, July August 1988

14 Underwriters Laboratories Inc *Report on CPVC Pipe and Fittings for Sprinkler Systems*. File Ex3754 Project 85NK837. Underwriters Laboratories Inc Northbrook, Illinois, July 17 1985

15 Available from the Plastic Pipe and Fittings Association, Glen Ellyn, Illinois

16 For example, *BOCA Code* Sections 401 4 915 71 915 4, 915 41, ICBO Code 4302 4304 4305 1706 (additional changes will appear in the 1991 UBC), and *SBCCI Code* Sections 704 9 1, 705 1 4, 1001 3 1

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