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Polyvinyl Chloride (PVC) – Its Use in Construction

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Figure 1: PVC pipes (Source: Wikimedia Commons)

ABSTRACT

This note examines the risks and benefits of using polyvinyl chloride, or PVC, in construction. It looks at environmental impacts of its use and disposal, and the desirability and practicality of its substitution.

This note was originally published in May 1997, when it comprised two notes, PRO 13 and PRO 14. These notes were reviewed by John Gelder in May 2002. The two notes were subsequently revised and merged by Paul Downton in March 2012.

Introduction

Polyvinyl chloride is a durable, cheap plastic derived from chlorine and synthesised with chemicals to give it properties that it would not otherwise possess, such as flexibility, colour and fire resistance (plasticisers can comprise more than half the weight of PVC product.) Until the early 20th century, when ways were found to combine it with other chemicals to create usable products, chlorine was regarded as little more than waste material from making caustic soda. PVC production is a major sink for the excess chlorine production associated with many current industrial processes.

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The PVC production process relies on international supply chains and includes hazardous and toxic materials. To be thermally stable, PVC must be compounded with other chemicals. Different compounds enable it to deliver different functions. The two basic types are unplasticised or rigid PVC-U and plasticised, flexible PVC-P.

PVC use is widespread, and the biggest user of PVC is the construction industry. In recent years, concerns about its environmental credentials have grown to the extent that a specifier may find restrictions imposed on its use in design and construction, either by guidelines or outright prohibitions.

Alternatives are available for many applications, so for specifiers a PVC phase-out would be viable but phasing out PVC in building would have major consequences for the PVC industry – which is strongly defending the product.

Decisions about whether to use PVC-based products cannot be made with regard to environmental issues alone. Fitness-for-purpose (including durability and appearance), availability and cost are among the factors to also be considered.

Products

PVC resin is used in countless products, many of them in the building industry.

Pipes and Fittings

Due to its long-term strength, rigidity, durability, low weight and price, PVC-U piping is a widely accepted, general-purpose product with many applications. For drainage applications it is more resistant to corrosion than cast iron and resistant to acids and alkalis, but not to chemicals like acetone, benzene and methyl chloride. It is not reliably load-bearing beyond 60°C, so cannot carry hot water. Polypropylene and polyethylene are more expensive, less rigid, less UV resistant and harder to join, but have better chemical resistance. Some have higher impact strength. PVC-U is not as good for drainage inspection chambers as ABS or GRP. For tougher applications, PVC-U can be blended with butylacrylate, chlorinated polyethylene or other impact modifiers.

There are several standards for PVC pipe, depending on the application. They include:

- AS NZS 1254-2010 (PVC-U pipes and fittings for stormwater and surface water application),
- AS NZS 1260-2009 (PVC-U pipes and fittings for drain, waste and vent application),
- AS 1464.1-1984 (plastics pipes and fittings for gas reticulation) and
- AS NZS 4765-2007 (modified PVC (PVC-M) pipes for pressure applications) which explicitly disallows lead, cadmium and mercury

Electrical Cables

The standard power cable for residential and commercial work is PVC-P. It has the lowest cost but poor fire performance. The relevant standard is AS NZS 60227.5-2003 (Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V). Consideration of flammability may force specifiers to consider non-PVC cabling. AS/NZS 4507:2006 covers classification of characteristics when exposed to fire.

Mineral-insulated metal-sheathed (MIMS) cable has been replaced in lift wells by halogen-free thermoplastic cable which has a long history overseas including in underground railway stations and road tunnels. The insulation may be a polyolefin copolymer. Such cable must have low smoke emission and low flame propagation properties.

Floor Coverings

PVC is used to make calendered coverings, cushion vinyls, spread-coated coverings and carpet backing. There are three forms of vinyl flooring. The older, semi-rigid form is produced by calendering of PVC compositions filled with fibre. It is widely used in institutional and commercial work. Tiles consist of PVC polymer and copolymer, plasticisers and stabilisers, fire retardants, resins, cellulose fibres, chalk and pigments. Prior to 1981 the fibres were asbestos but the filler has since been cellulose fibre.

A second form, widely used in housing, is flexible multilayered unbacked vinyl which has more 'give' than the semi-rigid type.

The third form, also widely used in the domestic sector, is flexible multilayered backed vinyl (cushioned vinyl) – typically comprising a wear layer of PVC-P, a printed layer, and a foam underlayer with mineral felt.

Window and Door Assemblies

Imported PVC window and door frames have achieved some market penetration in Australia, largely because the insulating properties of the frames contribute to meeting requirements for window energy performance.

Shade Cloth

Australian production and use of shade cloth has increased enormously in recent years as concerns about protection from UV radiation and building thermal performance have increased.

Product Installation and Use

Handling PVC-based products on site is not hazardous, though solvents used for connecting pipes may be, as may adhesives for fixing flooring. Adequate ventilation is required.

Volatile organic compounds (VOCs) are partly responsible for 'sick building syndrome'.

Products In Use

In vinyl flooring under unfavourable conditions of high pH (e.g. caused by damp concrete), the most widely used plasticiser, diethylhexyl phthalate (DEHP), can hydrolyse to 2-ethyl-hexanol, which has a heavy, sickly odour, so a moisture content check of the substrate before laying the flooring is vital. Additives (e.g. calcium oxide) can also cause hydrolysis of plasticisers by affecting pH. Likewise phosphorus based plasticisers in fire-resistant vinyl flooring can hydrolyse to form the odorous cresol, also found in horse urine. PVC-coated cork tiles can release phenol, from the phenolic resin separating the PVC wear layer and the cork substrate.

The adhesives used to fix vinyl products can be a major source of VOCs (volatile organic compounds).

High temperatures, such as those found in cars left in the sun, cause loss of plasticisers from PVC-P. Because of the loss of functionality (e.g. embrittlement), and uncertainty about the health effects of DEHP and the like, designers should ensure that PVC-P products are kept out of direct sunlight, and away from underfloor and other heating installations.

Ozone generated by photocopier machines may react with PVC, and other polymers, to create high levels of aldehydes in indoor air.

Lead stabilisers can leach from piping in running water, but the extraction rate declines rapidly, posing a very small environmental risk.

Fire

PVC-based products are generally self-extinguishing, thanks to their high chlorine content. On the other hand, the high chlorine content means that when they burn they release gaseous HCl, which causes eye and respiratory tract irritation. HCl will also damage concrete and metallic components, damaging electrical equipment for example. Soot from burning PVC contains dioxins and furans, in quantities that depend on the fire conditions. Clean up and repair costs from even minor fires involving PVC can be significant.

Additives are released from burning PVC, along with carbon monoxide. PVC-U has low flammability. (UK Building Regulations were changed to require specifiers to switch from inexpensive styrene diffuser panels over fluorescent lights to more costly ones made from PVC or polycarbonate, over concerns about fire safety). PVC-P is less fire-resistant as the chlorine content is much reduced. The plasticiser is also a weak point – with more than 40% DEHP, the PVC will continue to burn once the source is removed. Flame retardants must be added, though these can increase smoke production – offset by smoke suppressants like molybdenum trioxide.

PVC in Waste

Building site PVC waste is very rarely recycled in Australia and is generally disposed of in landfill.

In Australia, PVC is mostly used in long-life (10-year plus) building sector products.

Options for disposal are

- recycling
- downcycling
- landfill
- incineration

Recycling and Downcycling

Recycling is the preferred option but requires the waste to be solely PVC, ideally clean. The waste is mechanically ground and mixed with virgin PVC at a rate of 10 to 15%. If cleaning is needed, the reprocessing consumes about 10% of the energy needed to make virgin PVC. If separation from other plastics is proposed, more energy is needed. A list of PVC recyclers is posted on the website of Vinyl Council Australia (www.vinyl.org.au).

An important consideration in PVC recycling is the compatibility of the stabilisers. Mixing different compounds makes downcycling rather than recycling inevitable. Recycling mixed plastics produces materials with low strength, suitable only for low-grade thick walled applications. These have little energy advantage over other materials of similar strength and function, such as wood and concrete.

Landfill

PVC-U in landfill has a very long life, unless granulated. Likewise additives in the PVC-based products tend not to leach, or to leach only negligibly. The exception seems to be DEHP, which some studies suggest off-gasses in considerable quantities from landfill.

Incineration

Municipal waste incineration is not used in Australia. Medical waste incinerators are widespread but modern technology controls combustion temperature and operational efficiency to reduce emissions associated with PVC to extremely low levels.

One would expect the chlorine content from PVC incineration to result in significant production of dioxins and furans, but several studies have indicated that this is not the case. While these are produced, this seems to be independent of PVC content.

However, hydrochloric acid (HCl) levels are raised. This can be addressed in three ways:

- neutralisation, resulting in sodium chloride, to be fed back into the chloralkali process
- less costly neutralisation, resulting in calcium chloride, to be dumped (there is no market for this product)
- distillation of the HCl, for resale

Substitution

PVC has taken the place of traditional materials in many aspects of construction, ranging from pipes to floor coverings and window frames. While it is clear that there are substitutes for PVC in all its building applications PVC often possesses a cost advantage that makes its substitution difficult for specifiers to justify.

Precautionary Principle

Given the availability of alternatives, and concerns about PVC's environmental impacts, the prudent designer may opt to exercise the Precautionary Principle.

The Precautionary Principle (built into Section 3.5.1 of the 1992 Intergovernmental Agreement on the Environment, between the Commonwealth, States and Territories, and local government) strictly applied can entail high economic cost, and so is often qualified with a requirement to use 'best available technology', and further qualified with the requirement that the action will 'not entail excessive cost'. Just where you draw the line will vary from project to project, and architect to architect.

Conclusion

The Australian situation regarding PVC is different to that of the USA or Europe. We are much more reliant on imports, and our major use is in piping. Also, alternative piping materials are not so widely used (one suspects that cost of transportation from metropolitan manufacturing centres is a factor favouring light-weight plastic pipes over, say, concrete or clay).

The PVC recycling industry in Australia is beginning to grow. It is more advanced overseas, partly because of greater quantities, and because landfill sites are disappearing rapidly. Incineration of PVC remains unpopular, and question marks remain over its safety.

The PVC industry has responded to problems in health and environment by revising practices, changing materials, and by altering products and processes. It is likely to continue to do so.

PVC isn't going to go away in the near future – it is too useful, economically attractive, and essential to the provision of a chlorine 'sink'. The industry has mounted strong campaigns to rebuff environmental and health argument against its use and it can now earn positive credits in Green Building Council Green Star ratings. There is evidence that PVC products and processes are getting better but maintaining that momentum requires continual pressure on manufacturers and ensuring that there are viable alternatives to its use.

Despite GBC's cautious acceptance of PVC, the position of organisations like Greenpeace and the Healthy Building Network has not softened towards its use and there is a continuing trend to limit or control PVC use in construction materials and eliminate particular additives.

In product selection, specifiers should consider alternatives to PVC irrespective of capital cost and cost of construction, and check availability of recycled PVC. Willingness to consider such alternatives will ensure that the PVC industry continues to address valid environmental and health concerns. Comparative life cycle assessments (LCAs) carried out in the UK suggest that linoleum flooring has a marginal overall advantage over PVC, PVC rainwater pipes are better than aluminium, and timber window profiles are better than PVC. However, it is not possible to confidently transfer these comparisons to Australia.

Australia still relies heavily on imported PVC product and this reduces a specifier's ability to ensure that the products they specify are made to the increasingly high standards that are being asked of the industry.

The building sector is the biggest user of PVC-based products, so it is important to the PVC industry. On the other hand, for most PVC-based building products there are non-PVC alternatives, so construction could get by without PVC. There are costs – environmental, social and/or economic – whether we use PVC-based products or the alternatives. The question, then, is which costs do we want to incur?

References and Further Reading

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Appendix

Manufacture of PVC

Polyvinyl chlorides are an unusually complex group of plastics – there are many sources for constituent materials, many manufacturing processes, a multitude of possible additives, and a wide range of products to consider.

Located in Victoria, the Australian Vinyls Corporation is the only PVC resin manufacturer in the country. All its resin is made from imported VCM. Around 65 to 70% of Australia's demand for PVC resin is met by domestic production.

Chlorine Manufacture

The major domestic uses for 'Australian-grown' chlorine are EDC manufacture, chlorination of drinking water, manufacture of titanium dioxide, and paper bleaching. The PVC industry is the largest single user of chlorine in Australia but most of this chlorine is generated overseas, then embodied in imported VCM and PVC-based products.

There are three main processes involving the electrolysis of rock salt in solution and all produce chlorine, hydrogen and caustic soda. The environmentally preferred process is the membrane process. This process (the membrane is made from perfluorinated polymers) combines advantages of both the other processes, giving a very pure caustic soda solution while using less electrical energy. There are no mercury emissions, nor is there asbestos to dispose of; however this method is not yet universally employed.

Ethylene Manufacture

Ethylene in Australia is derived from an energy-intensive process of cracking naphtha/LPG.

EDC Manufacture

EDC (1,2-dichloroethane) is made by direct chlorination (using chlorine) or oxychlorination (using HCl) of ethylene. Direct chlorination uses liquid ethylene and releases high levels of heat. Oxychlorination is done at high temperature under pressure, in the presence of air or oxygen.

EDC is classified by the International Agency for Research in Cancer as a possible human carcinogen. Historically, Australian production sites (e.g. Botany) have been contaminated with EDC, vinyl chloride monomer, mercury and other PVC-related pollutants found in soil, groundwaters and the estuary. The Altona site is also contaminated with EDC and other chlorinated hydrocarbons, particularly in groundwater.

VCM Manufacture

Globally, over 90% of VCM (CH_2CHCl) is produced by cracking EDC. From this, and from EDC manufacture (by oxychlorination), acetylene, benzene, chlorinated hydrocarbons and tars are produced as byproducts (34 kg/t of VCM).

VCM is a gas at room temperature, requiring handling as a liquid under pressure. It is explosive in air with a half-life in air of around 24 hours. It has a narcotic effect at 8 to 12% by volume; below these levels it can still precipitate illness, including a bone condition called acroosteolysis (AOL), and a circulatory complaint called Raynaud's phenomenon. It can kill at higher concentrations. Removal of workers from exposure to VCM leads to an almost complete recovery.

VCM is also a human carcinogen that can cause angiosarcoma of the liver; around 180 VCM/PVC process workers worldwide have died from this cancer. Since 1974 strict regulatory controls have been in place worldwide to limit worker and consumer exposure to VCM, and Australian industry emission limits of 70 g/t of PVC to air, and 0.5 g/m3 in water effluent are well under the safe exposure levels recommended by

The following 'three-step' description of its manufacture is drawn from the Vinyl Council Australia website (www.vinyl.org.au)

Step 1 - Producing ethylene dichloride ($C_2H_4Cl_2$)

Chlorine is extracted from sea salt via electrolysis, and ethylene is derived from hydrocarbon raw materials. These are reacted to produce ethylene dichloride (1,2-dichloroethane).

Step 2 - Producing vinyl chloride monomer (VCM)

The ethylene dichloride is then decomposed by heating in a high temperature furnace or reactor. The hydrogen chloride is reacted with more ethylene in the presence of oxygen (a reaction known as oxychlorination). This produces further ethylene dichloride. The resultant ethylene dichloride is decomposed, and the hydrogen chloride is returned for oxychlorination.

Step 3 - Manufacturing polyvinyl chloride (PVC)

PVC is made using a process called addition polymerisation. This reaction opens the double bonds in the vinyl chloride monomer (VCM) allowing neighbouring molecules to join together creating long chain molecules.
Only this third polymerisation step is carried out in Australia.

Australian regulatory authorities.

VCM Polymerisation

In a process of suspension polymerisation VCM is vigorously stirred in water to produce a fine suspension. Small amounts (less than 1 part in 1000) of granulating agents such as methyl cellulose or polyvinyl alcohol, and initiators such as peroxyesters, are added, and the whole process is controlled to produce a polymer with the required molecular weight range. The addition of heat stabilisers avoids uncontrolled decomposition of PVC, which would result in hydrochloric acid being formed. The only VCM found in PVC-based products is manufacturing residue. Australian legislation permits no more than 1g/t residual VCM in PVC products. The latest Australian PVC resin manufacturing emissions standard determines that vinyl chloride emissions resulting from manufacturing shall not exceed 30 grams per tonne of PVC produced. The European standard is 100 grams per tonne.

Compounding PVC

The PVC content of products is not pure polymer. Additives are incorporated to facilitate processing, impart desired properties, and stabilise what is an inherently thermally unstable material. PVC is an unusual plastic in that it is compatible with a wide range of additives, so a wide range of product properties can be achieved – but additives must be compatible with each other. Compounding may be done by the PVC resin suppliers, by independent compounders, or by the product manufacturers themselves.

PVC-U contains fewer additives than PVC-P. The principal PVC-U additive is a chlorine-free copolymer to enhance impact strength. The principal PVC-P additive is plasticiser, to give flexibility.

Lubricants and Stabilisers

PVC-U is highly viscous so, for extrusion at 160°C, lubricants melting at 100-120°C are added. These include lead stearate, calcium stearate, and paraffin wax and stearic acid mix. Lubricants account for 8% (by weight) of additives used globally (excluding fillers and pigments).

Stabilisers impart heat stability during processing and use, and resistance to light and weather. Lead-based stabilisers have been dominant – particularly for electrical cable insulation and piping. According to the industry, under the terms of the PVC Industry Voluntary Commitment, sales of lead stabilisers will be reduced in stages and ended by 2015. The use of lead stabilisers for potable water piping has been voluntarily discontinued by pipe manufacturing members of The European Plastic Pipes and Fittings Association. In 2009 the Plastics Industry Pipe Association of Australia agreed to a voluntary initiative to phase out use of lead stabilisers in pipe.

Pigments and Plasticisers

The most significant pigment used with PVC is titanium dioxide. A range of inorganic and organic pigments is used to produce other colours. Choice of pigment can affect weathering resistance.

Plasticisers are solvents with high boiling points. The manufacture of PVC-P consumes 75 to 95% of plasticiser production – other polymers do not benefit as much from the addition of plasticisers. The percentage of plasticiser used is between 20 to 50% by weight. Most plasticiser is used in the building sector, chiefly in cabling but also in vinyl flooring, paints and polyester resin. Different plasticisers have different properties, so they are not necessarily interchangeable, and are often blended.

Phthalate Plasticisers

Phthalate plasticisers are inexpensive but increase flammability and many are being phased out of products in the United States, Canada, and European Union over health concerns. Some phthalates has been restricted in the European Union for use in children's toys since 1999 and in 2010, in response to research linking it to reproductive difficulties, the Australia government announced a ban on items containing more than 1% of the most widely used plasticiser, Diethylhexyl phthalate (DEHP).

Phthalates are suspected of being endocrine disrupting chemicals (EDCs), along with DDT, dioxins, organochlorine termiticides and PCBs (all banned in Australia). They are suspected of having oestrogenic and/or androgynous effects. Research continues but appears to remain inconclusive.

Flame Retardants and Other Additives

Flame retardants account for 30% of additives globally (excluding fillers and pigments), and are used in PVC-P. There are several classes. The dominant types are aluminium trihydroxide and magnesium dihydroxide. Others include ferrocene as a smoke inhibitor, and halogenfree triaryl phosphates.

Antioxidants account for 5% and impact modifiers (in PVC-U) for 12% of additives globally (excluding fillers and pigments). Typical impact modifiers include ABS and acrylic polymers.

About the Author

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