Understanding the Failure Modes of Multilayer Composite PE Pipes

By PPN Editor

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Multilayer composite pipes (MLCP), characterized by their innovative construction of polyethylene with an embedded aluminium tube, have garnered attention in plumbing and construction industries for their unique properties. These pipes typically feature inner and outer layers of polyethylene (PEX or PERT) bonded to a central aluminium tube using a melt adhesive. This construction aims to combine the flexibility and corrosion resistance of plastic with the strength and pressure resistance of metal.

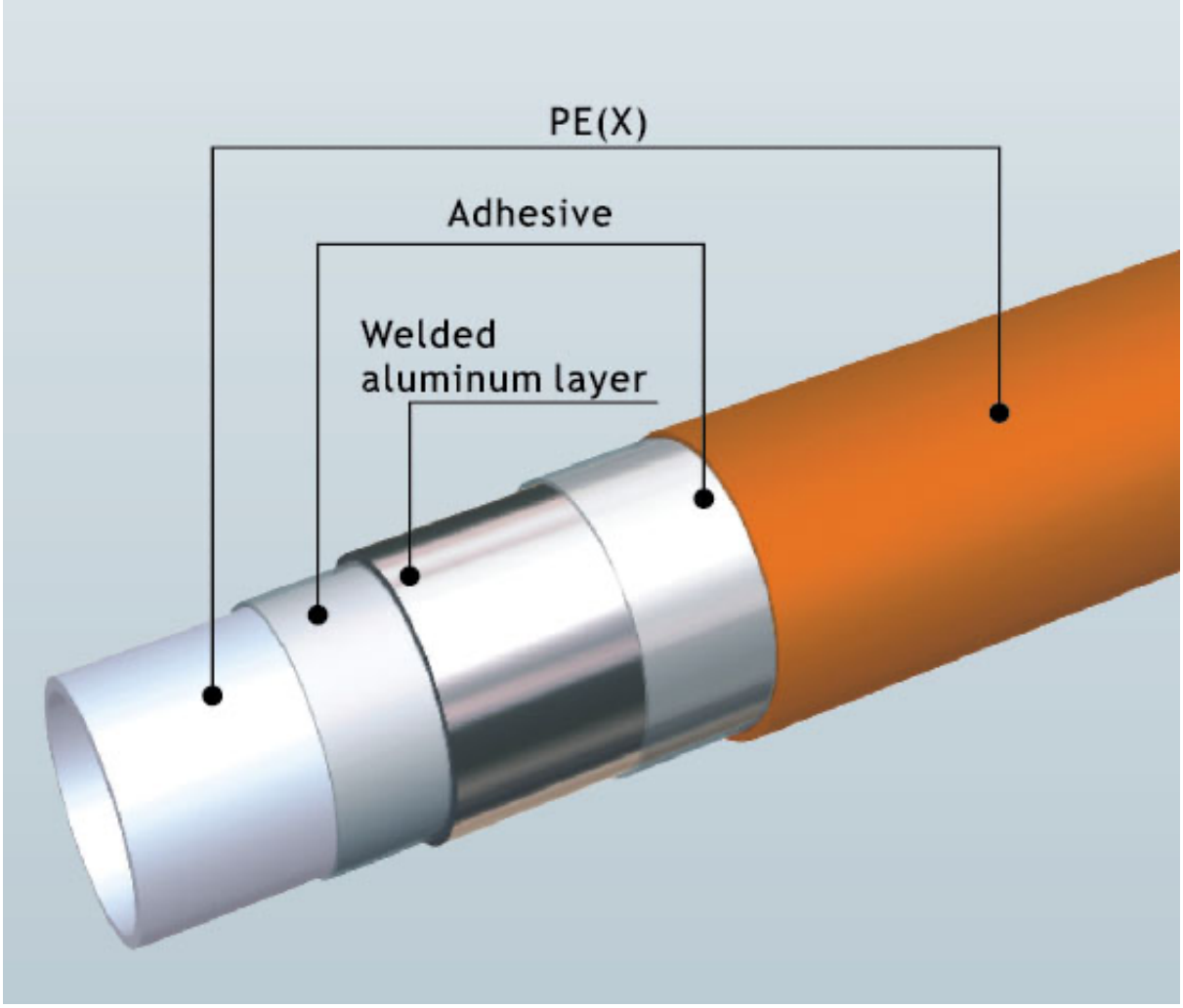
Construction and Types

The two primary types of multilayer composite pipes are PEX-AL-PEX and PERT-AL-PERT, each offering specific advantages based on application requirements. PEX-AL-PEX pipes utilize crosslinked polyethylene for both inner and outer layers, sandwiching the aluminium core, while PERT-AL-PERT pipes substitute PEX with polyethylene of raised temperature resistance (PERT) for enhanced thermal properties at a lower cost.

Manufacturing Process

Manufacturing involves using an aluminium strip of suitable thickness and width, which is then formed and welded into a continuous aluminium tube. The

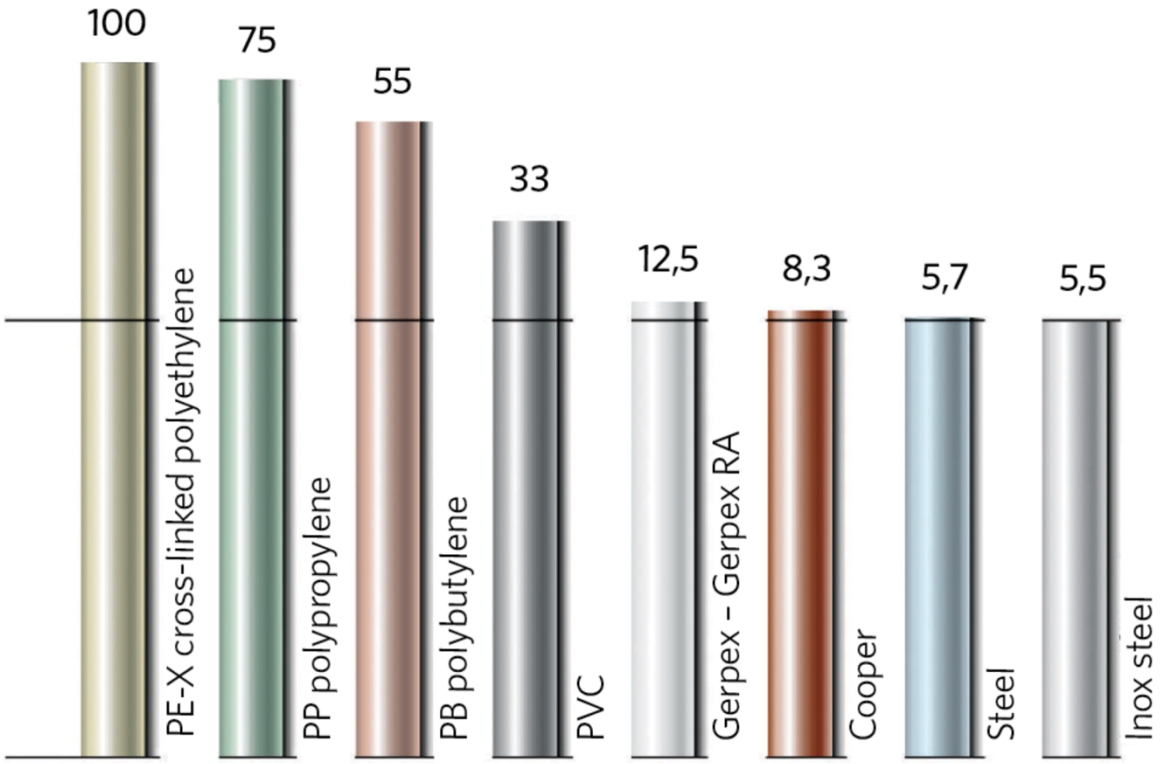
polyethylene layers are subsequently extruded over this tube and bonded through a melt adhesive process. Alternative techniques such as laser welding have been developed to create butt-welded seams, offering variations in construction methodology.



Properties

The internal aluminium layer that offers rigidity, form retention and a solid oxygen barrier to prevent internal corrosion of heating system components. The aluminium intermediate layer creates an oxygen barrier and the ability to form 90-degree bends while retaining its shape – something not associated with plastic pipes but expected with copper.

MLCP has also seen less dramatic price fluctuations in recent years compared with copper and steel. Compared with conventional plastic piping, MLCP has low expansion characteristics because of the internal aluminium layer. For design and specification purposes, thermal expansion of MLCP pipes is comparable to copper (see relative thermal expansion graphic below).



Relative thermal expansion of pipework materials

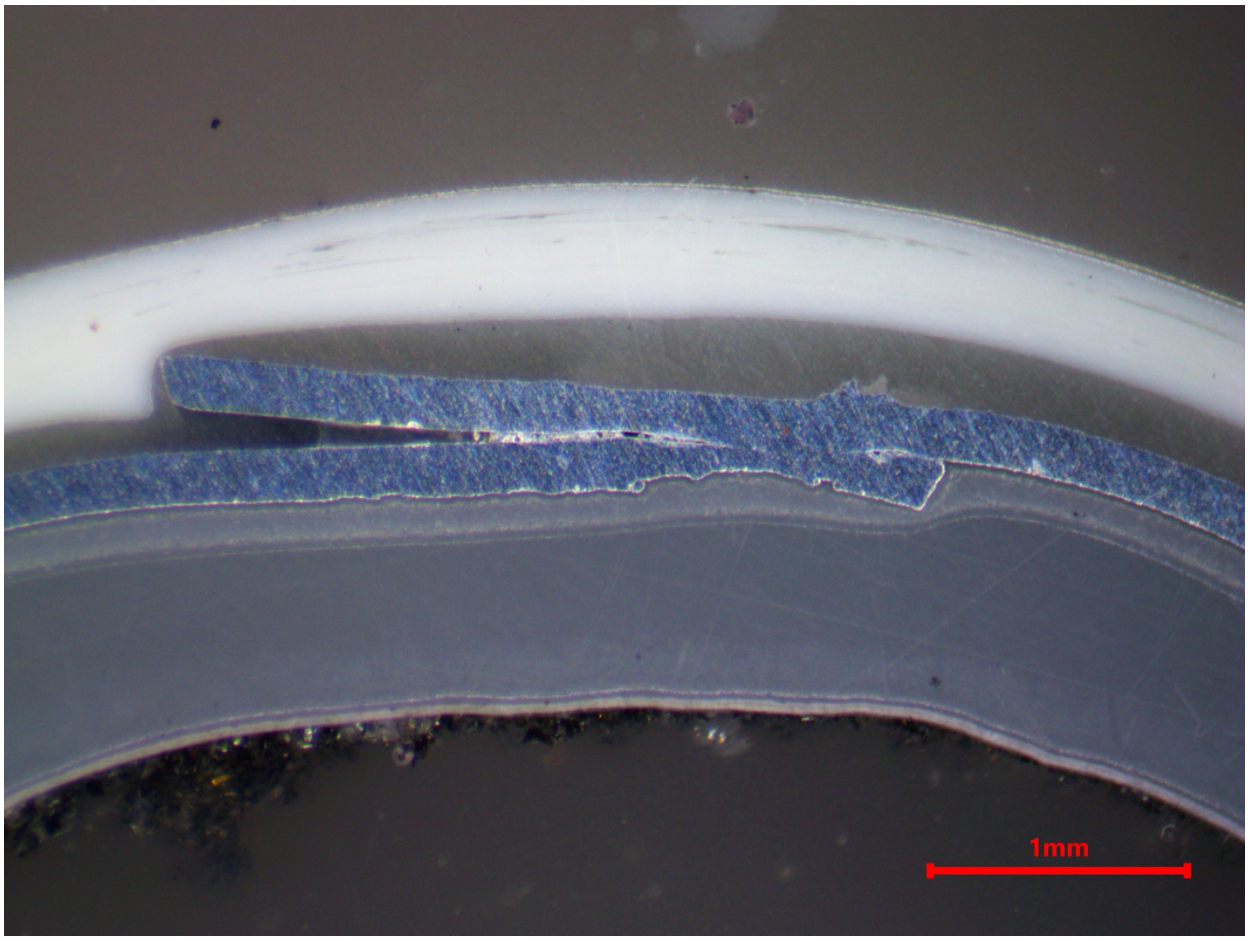
Issues and Concerns

Despite their promise, multilayer composite pipes face several potential issues that have raised concerns within the construction industry:

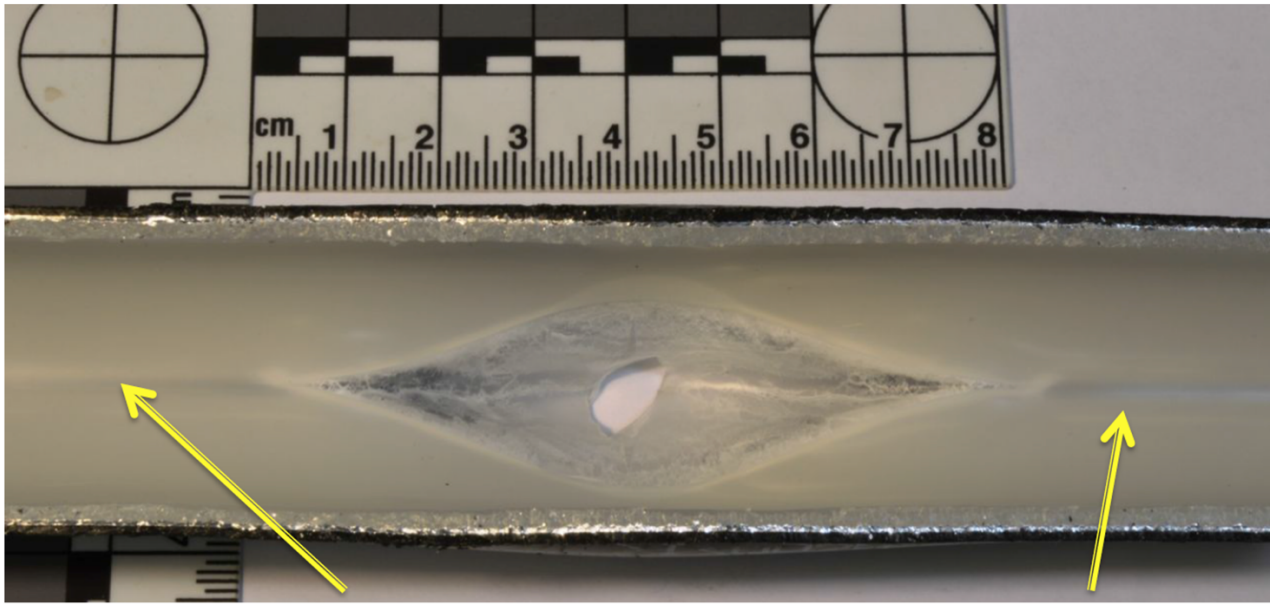
1. **Weld Quality**: The quality of welds between the aluminium layers can vary, impacting the structural integrity of the pipe. Poor weld geometry or defects in the bonding process can lead to localized stress concentrations, potentially resulting in premature failures under pressure.
2. **Delamination and Corrosion**: Delamination between the aluminium and polyethylene layers can occur, especially in regions where the bonding adhesive may not form a uniform seal. This can create spaces where moisture ingress promotes corrosion of the aluminium, leading to structural weakening and pipe failure over time.
3. **Crevice Corrosion**: In environments with high humidity or exposure to corrosive elements, crevice corrosion of the aluminium layer can initiate. This corrosion process can further compromise the integrity of the pipe, manifesting as bulges or fractures in the outer polyethylene jacket.
4. **Oxidation and Embrittlement**: Oxidation of the polyethylene layers over extended periods can lead to embrittlement of the pipe material. This degradation not only affects the flexibility and durability of the pipe but also exposes the aluminium core to additional corrosion risks.

Multilayer composite polyethylene (PE) pipes can exhibit manufacturing defects due to several reasons. One common issue is the uneven distribution of the adhesive layer, which can result in areas without glue, compromising the pipe's structural integrity. Additionally, the quality of the adhesive itself plays a crucial role; if the glue layer is not of high quality, it can lead to weak bonding between layers, making the pipe susceptible to delamination and failure under stress. Another significant defect is the presence of holes within the aluminium layer due to poor welding allowing water to penetrate the glue layer leading to delamination.

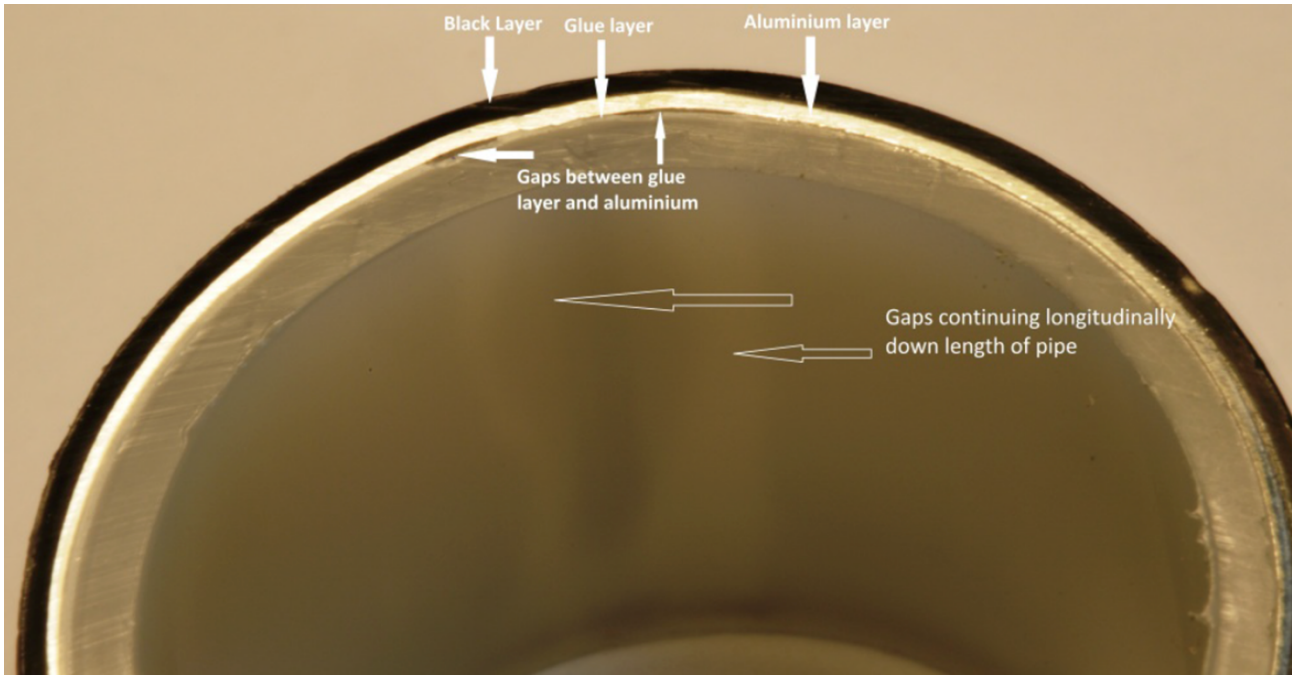
The photograph below shows a poorly forming overlap weld in the aluminium layer of a MLCP pipe that has led to bursting failures.



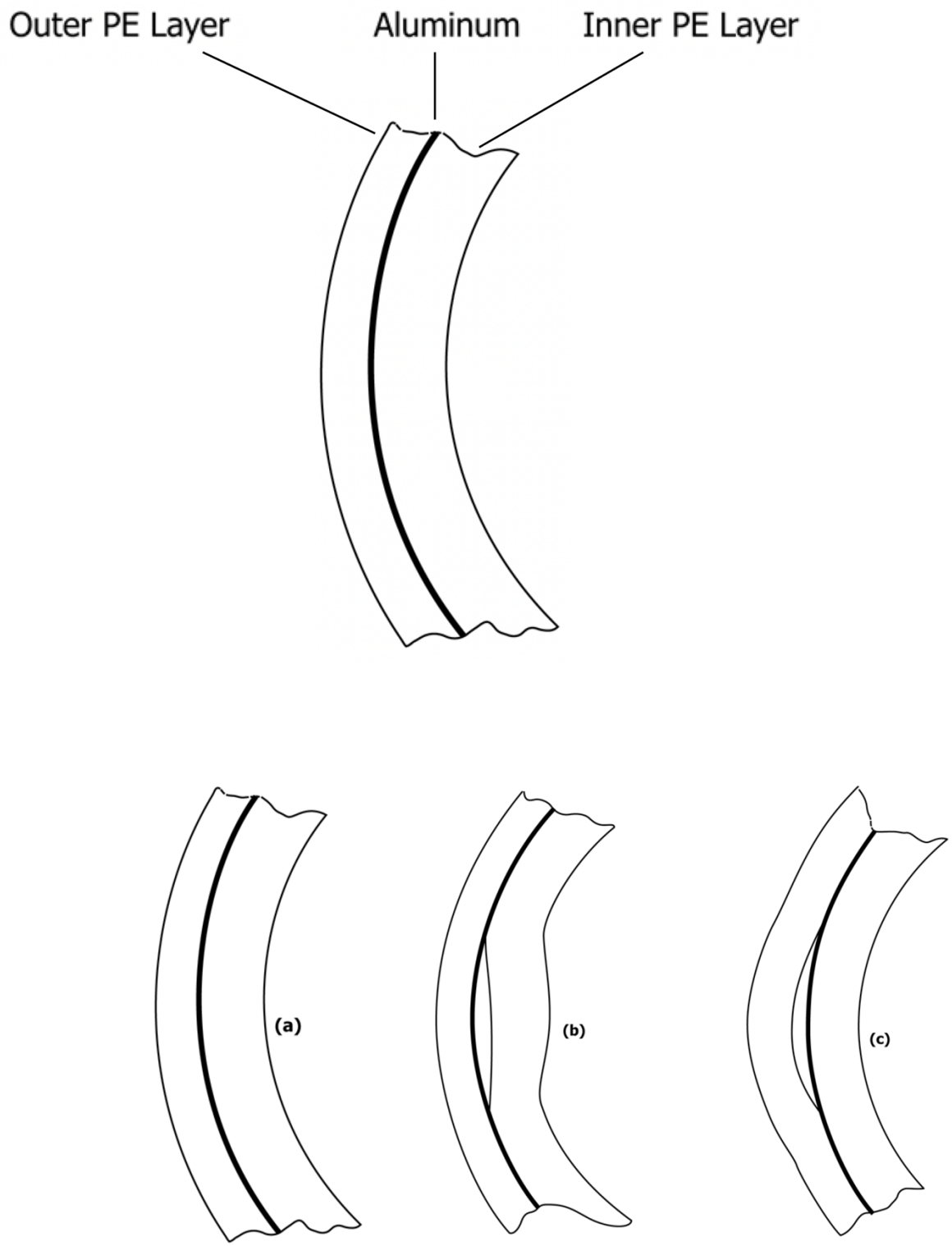
The photograph below shows the bursting failure of the MLCP pipe with the defective weld line which has acted as a stress concentration.



The photograph below shows zones of delamination in a defective MLCP pipe.

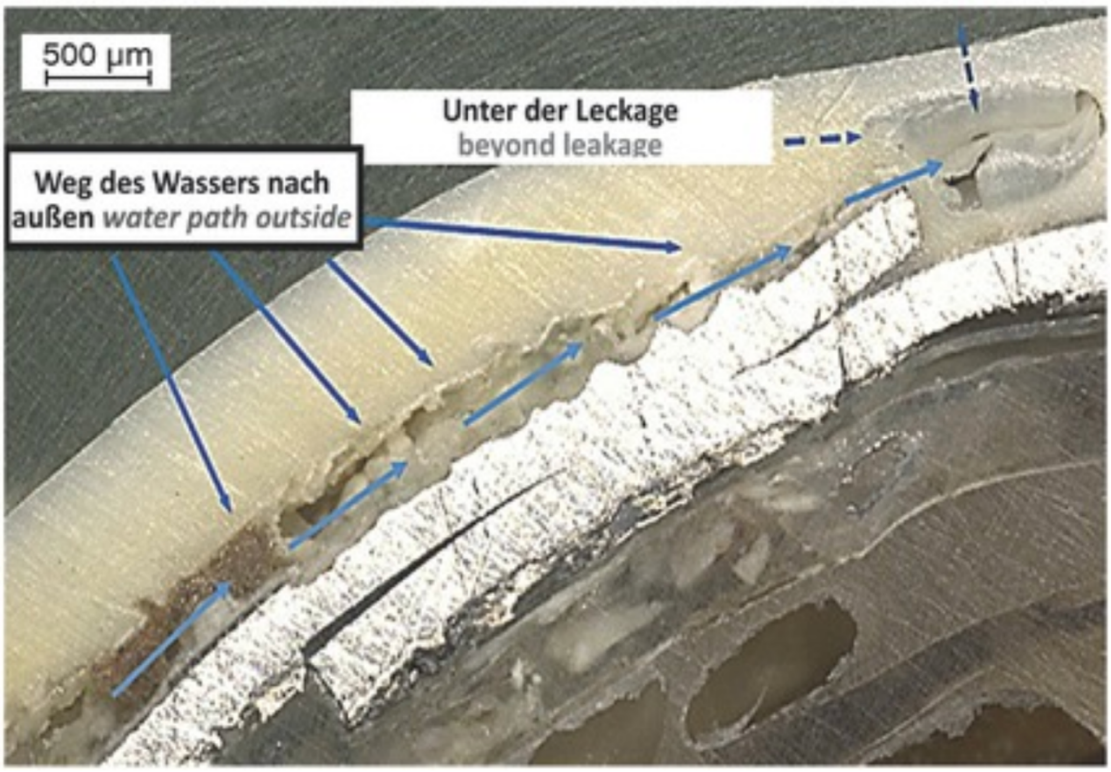


ASTM F1281 − 17 Standard Specification for Crosslinked Polyethylene/Aluminium/Crosslinked Polyethylene (PEX-AL-PEX) Pressure Pipe warns of the delamination risks of MLCP pipes and provides the schematics below.



NOTE 1—(a) Good pipe showing no delamination, (b) Delamination between the inner layer and the aluminum, and (c) Delamination between the outer layer and the aluminum.

The photographs below from Pajonk (2023) show the problems of corrosion of the aluminium layer due to water penetration through areas that have gaps in the glue and poorly formed welded in the aluminium layer.



At the aluminium interface, the glue failed and the PE liner detached from the aluminium barrier; thus, a gap was formed which was filled by water, by water compounds, as well as by aluminium and silicon salts. In this region corrosion caused voluminously aluminium salts; the outer PE-jacket bulged and fractured longitudinally forming a notch.

Industry Standards and Regulations

Initially introduced with standards like AS 4176-1994 in Australia, which outlined dimensional specifications and performance criteria, multilayer pipes have evolved under more stringent regulatory scrutiny. Recent standards and guidelines focus on addressing manufacturing defects and ensuring long-term reliability in various applications, from residential plumbing to industrial settings.

Conclusions

Multilayer composite pipes represent a technological advancement in piping systems, offering a balance of strength and flexibility suitable for diverse plumbing applications. However, concerns over manufacturing defects, corrosion resistance, and long-term reliability have prompted careful consideration among builders and regulators. Some of the largest construction companies in Australia have internal bans on the use of multilayer composite PE pipes owing to the potential for premature failure.

Multilayer pipes can potentially fail due to multiple mechanisms owing to their multilayer construction such as:
-Poor weld geometry of the butt or overlap weld of the aluminium liner leading to localized stress concentration/s
-Delamination and gaps between aluminium layer and PE layer/s
-Crevice corrosion of aluminium layer due to ingress of moisture
-Formation of voluminously aluminium salts causing the outer PE-jacket to bulge and fracture longitudinally forming a notch.
-Oxidation of the PE layers leading to embrittlement of the pipe and exposure of the aluminium layer to moisture and corrosion products.

Addressing these challenges through improved manufacturing processes and adherence to rigorous standards is crucial to enhancing the performance and acceptance of multilayer composite pipes in the construction industry.

As technologies evolve with respect to improved laser welding of the aluminium layer and standards are refined, the future of multilayer composite pipes holds promise in meeting the demanding requirements of modern infrastructure while ensuring robustness and longevity in service.

References

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Author Experience and Expertise

Senior Editor of PPN, Dr. John Scheirs is an Australian-based polymer scientist. He led PE100 resin development* in Australia in the early 1990s and has been involved with numerous plastic pipe litigation cases over a thirty three-year career in consulting and expert witnessing. He regularly writes technical books on polymer science, polymer chemistry, polymer analysis and polymer failure for John Wiley & Sons Publishers (UK). He has been successful in legal cases involving failure of defective Multilayer Composite Pipes.
* https://www.infona.pl/resource/bwmeta1.element.elsevier-05880311-f7ec-3a70-b361-9a08d8fc74c9