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ABSTRACT BOOK

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EFFECT OF CREEP IN ESTIMATING DEFLECTION OF BURIED HDPE PIPE

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Limiting deflection is the main design parameter for buried non-pressurized plastic pipe. Deflection limits are based on maintaining joint tightness, structural integrity, and flow capacity. The two parameters that play the greatest role in estimating buried pipe deflection are the elastic modulus of the pipe (E) and the reaction modulus (E') of the embedment soil. Variations of deflection equations can be found in textbooks, papers, and standards. Some include using time dependent (creep) E-values while others use short-term E-values or ASTM D2412 pipe stiffness (PS) values. Most plastic pipe materials exhibit creep under constant loading but is it necessary to consider it for deflection estimates? Results from this analysis as well as testimonies from other authors suggest that deflection estimates using a PS value or short-term elastic modulus value are sufficient.

This paper investigates whether creep (e.g., continuous strain deformation over time when under constant loading) should be considered or not when estimating deflection of buried HDPE pipe. Data from historic deflection study papers of buried solid wall and corrugated HDPE pipe are reviewed and compared to deflection estimates using the US Bureau of Reclamation Equation with and without creep considered.

A-109

ADVANCING SUSTAINABILITY IN THE PLASTIC PIPE INDUSTRY: STRATEGIES FOR CIRCULAR SOLUTIONS AND CO2 REDUCTION

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Sustainability and mitigating global warming are top priorities for both the planet and our plastic pipe industry. The urgency for action has been growing rapidly, driven by increased awareness, stricter regulations, and the negative perception of plastics due to single use and waste management issues. While the industry is on a journey of discovery and adaptation, there remains significant uncertainty and complexity in implementation, with regional differences adding to the challenge.

In Europe, the Green Deal's vision for 2050 and the "Fit for 55" initiative, which mandates a 55% reduction in CO2 emissions by 2030, versus a 1990 baseline, have started to shape a clearer roadmap, with initiatives like Taxonomy and the Renovation Wave.

This paper explores sustainability strategies and insights from two major companies at different stages of the value chain—both in virgin and recycled polymer production, as well as pipe system manufacturing. The focus is on accelerating the transition to circular solutions and reducing the CO2 footprint during construction, use, and even at the end of life in construction and demolition.

Recognizing the collaborative nature of this challenge, the authors will share their experiences from involvement in associations like TEPPFA and PE100+, as well as discussions in various forums on the topic of sustainability. The next steps involve deepening industry-wide cooperation and refining strategies to close the loop on materials and significantly reduce environmental impact.

A-110

INNOVATIVE APPROACH TO MEASURE LAYER TRANSITIONS OF CORRUGATED PIPES

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Currently, there is no suitable equipment available to measure important parameters during corrugated pipe production. Manufacturers are limited in their ability to save scrap and increase quality. There are two crucial phases during the production of corrugated pipes. In the beginning of manufacturing, it must be ensured that the different layers of the pipes are concentric. This evaluation can take several minutes, even hours, where only scrap is produced. After the startup phase, the products must be evaluated in order to comply with predefined specifications at a certain line speed. In both cases, the measurement of corrugated pipes is an ambitious task, because of the outer pipe contour.

For corrugated pipe manufacturing, an innovative approach to quality control by using penetrative recording systems in order to measure the transitions of the individual layers of the pipe has been developed. Based on the detected layer transitions using an AI-model relevant radii, layer thicknesses and center positions of corrugated pipes can be determined. Therefore, this approach provides a desired solution for the plastics market to support pipe manufacturers to produce high-quality products with most efficiency.

In this paper, the innovative technological approach how to measure corrugated pipes by outlining the functional principle and giving real measuring examples is introduced.

A-112

GREEN COMPOSITION - MAKE MULTI-LAYER PIPE RECYCLABLE AND SUSTAINABLE

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Aluminum-plastic composite pipe is widely applied on portable water, air, heating and air conditioners. However, it is a long-lasting headache issue that there were not good solutions to recycle the factory waste MLP pipe and building trash MLP pipes, since the first day of multi-layer pipe created.

Based on our customers request, after hundreds of times of trying, we had completed the “green composition” project development: recycle the MLP pipe, reuse all plastics, and make it profitable.

Three high challenge work have been overcome by 4 steps: 1, separate the plastic from aluminum completely, 2, reuse the plastic after it was separated from aluminum, as well as PEX, 3, keep aluminum in a safe and good condition. 4, reuse the PEX in a sustainable and environment friendly way. Up to today (March 15, 2025), we have recycled about 80 tons PERT-AL-PERT pipes, 20 PEXb-AL-PEXb pipes, 20 tons PPR-AL-PPR pipes in our trial plant in Hangzhou, China.

1. New way of separation

There are three different separation solutions on factory production MLP pipe waste and social building MLP pipe trash. 1, Grinding powder static electricity separation, 2, crush and heating in chemical formulated water or steam, 3, multi-stages physical cut-heat separation.

1. Grinding powder static electricity separation is a well know solution, but leads to problems on a) aluminum powder mixed in the plastic, which can be applied on lower grade plastic production. B) Aluminum powder in dry condition is prone to flash explosion and burning. C) environment pollution on powder flying.
2. Crush and chemical heating solution, use big volume of water. it is a good way to deal with the crushed MLP pipe and social building MLP pipes.

3. Multi-stage physical cut-heat separation process does not use water or chemical, does not produce powder, and plastic is completely separated from the aluminum. Aluminum is collected and pressed into bricks from separated aluminum strips, it is safe and transport friendly. The separation machine size is 15meters length by 2 meters width, one people easily operation.

2. Better application of recycled plastics.

Because of slit glue containing, the separated PERT, HDPE and PPR can be applied on irrigation pipes, sewage pipes, corrugated pipes, and injections by appearance of virgin materials.

3. Aluminum is pressed into rectangular blocks or bricks, easy carry by folk truck and transport by truck or containers.

4. PEX recycled scraps can be extruded into pellets, which is a nice formulation material on irrigation tape production, and can be extruded into PEX wax as lubricant in lower quality level applications.

Conclusion:

The solutions in this presentation for aluminum-plastic composition pipe separation, also can be applied on cooper-plastic pipe and wires industry.

A-113

BEYOND HOOP: AXISYMMETRIC STRESS IN PVC PRESSURE PIPE JOINTS

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Hoop stress, defined as the force over area exerted circumferentially on a cylinder wall, and estimated by thin wall theory, is the fundamental approach to relate pressure pipe diameter, wall thickness, fluid pressure and stress. Standards relevant to PVC pressure pipe combine this theory with definitions such as design coefficient, minimum required strength, design stress and dimension ratio to establish wall thickness for every pipe size and various preferred nominal pressures.

While this approach is adequate for straight pipe, it doesn’t show the complete picture at a pipe joint. The profile of a socket has changes in direction to make room for the gasket. This deviation from the shape of a cylinder introduces longitudinal and bending stresses on the axisymmetric plane, as well as a different distribution and level of hoop stress.

If the joint is internally restrained, there are structural elements inside the socket that prevent the spigot from pulling out, and those stresses become greater. Thus, while long-term stress crack resistance of straight pipe is often not a concern, it becomes relevant in a restrained joint. This requires special analysis and design considerations to ensure structural integrity of the joint and that it remains more cost-effective than external restraints or thrust blocks.

This paper reviews these axisymmetric stresses in commonly used restrained and un-restrained pipe joints, as well as equivalent representations of the joint without them. While the analysis of joints with gaskets and restraining elements requires nonlinear Finite Element Analysis, a linear approximation is still useful for pipe stress purposes and can be performed with FEA available with most CAD software. Optimization of socket shapes to minimize their stress and resulting accessories required to make them work properly are also covered. This work is applicable to other pipe materials.

Stress at the joint is not fully axisymmetric. The socket, the spigot and the gasket must interact structurally to hold the gasket inside the joint under pressure. When gaskets are blown out of a joint, this doesn’t happen evenly. Usually, only part of the gasket is blown out and this is enough for the joint to fail. Furthermore, there may be angular and lateral deflection loads, as well as restraining elements, usually discontinuous around the circumference, which also contribute to non-axisymmetric stress distributions.

Three-dimensional stress distributions such as those described above are discussed briefly, and remain beyond the main scope of this paper. This topic would need to be covered in a separate paper. However, the axisymmetric approach is shown to be very illustrative to convey the importance of going beyond hoop stress, and useful for design purposes.

A-116

STRUCTURAL DESIGN OF PLASTIC MANHOLES: FOCUS ON THE KEY VERIFICATIONS

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Since about 50 years, circular plastic manholes gain constantly market shares in drainage and sewerage networks in competition with traditional concrete products. Structural behavior of flexible plastic manholes is very different from rigid concrete manholes. However, so far no international standard exists on design of these products. There are some national regulations like ASTM F 1759 in North America or a preliminary draft DWA Worksheet M 127-4 in Germany. Of course, there are various approaches and different focuses. Against this background, TEPPFA will provide a state-of-the-art web tool for structural design of plastic manholes. This tool is approved by the writer and based on findings gained in extensive in-situ testing of plastic manholes in a sandbox of a German test house in 2022.

A key challenge for developing the web tool is to define the relevant load cases and verifications. In comparison to pipes, manholes are more complex structures which often combine various materials regarding cover, shaft and bottom plate. Structural assessment of pipes is broken down to verifications on a circular structure in a 2D-plane. This is simple and effective. For manholes, vertical soil pressure is distributed in the subsurface 3D space normal and longitudinal to the shaft. The horizontal soil pressure acting on the manhole is changing with depth. While pressure from traffic is decreasing with depth, pressure from soil is increasing together with water pressure if present. Potentially, there is many load cases and parts of the manhole, which can be assessed.

The presentation will explain what the governing design criteria are to be covered by the TEPPFA design tool. The application is focused on plastic shaft and bottom plate, since most covers are not product specific and installed independently from the manholes. The tool follows the Eurocode principles with partial safety factors, which is called load and resistance factor design (LRFD) in the ASTM standards. In ultimate limit state, stress and buckling analysis is conducted for the shaft at the respective depth and stress analysis for the bottom plate. In case of ground water, also an uplift verification is provided. In serviceability limit state, deflections are calculated for the upper edge of the shaft and the bottom plate in case of ground water.

A-121

PREPARING THE INDUSTRY FOR THE UPCOMING HARMONISED RULES FOR PRODUCTS IN CONTACT WITH DRINKING WATER

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European standardization of plastic pipe systems has been on the agenda since the eighties and almost all applications are now described in common European standards. However, an important exception are the hygienic requirements for products in contact with drinking water: Most of the EU Member States have until now not coordinate their regulation. The result is a multitude of different national requirements for the marketing of materials and articles in contact with drinking water, first and foremost plastic pipe systems.

The revision of the European Drinking Water Directive was agreed in December 2020 and article 11 describes the requirements to our products. The commission was then empowered with six legal and implementing acts and has now specified the details of the European Positive lists, requirements to the products, assessment of conformity and marking. These six acts were agreed in Q1 2024.

The legislation will come into force 1st January 2027 where all new approvals must be in accordance with the harmonised rules. Until end of 2032, a transition period will allow producers with existing approvals and certificates to place products on the European market.

As of today, more than 15 different certification and test organizations within the European Union regulate the products and materials suitable for use with drinking water and the industry therefore welcome the harmonisation across Europe.

However, we still must see the final decisions of a number of the details in the legislation. For that reason, the member states and ECHA has worked out two guidance documents to help interpreting the law-text and to help the notified bodies to align across member states. This work is very important for our industry as we see several concerns already, e.g. in lack of laboratory capacity, the method of translating the GC-MS results into concentration of “unexpected Substances”. Also, the requirements of testing in chlorinated water will be new territory for us as only one France has experience with this. Finally, we are monitoring the member states regulation regarding the transition period as we fear a too strict interpretation.

The paper will explain the status of the regulation, the transition period and also the content of the guidance documents. The paper will also discuss the challenges we see for our industry and the measures we as TEPPFA are taking to mitigate.

A-123

RESEARCH AND PRACTICE OF ANTI-SAG TECHNOLOGY FOR HIGH YIELD EXTRUSION OF PE LARGE DIAMETER THICK WALL PLASTIC PIPE

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After deeply studying on the melt sagging occurred on large diameter PE pipes with thick walls, a series of solutions were established from the raw material and equipment point of view. Including raw material selection, low temperature extrusion, anti-sagging die design, and highly efficient cooling on inner and outer surface of the pipe base.

To increase the yield and stability of extrusion, the smoothing temperature interval during low temperature extrusion, the design of the screw, barrel and feeding seat, and the roughness on the inner wall of the barrel were closely surveyed, furtherly optimized, and newly developed.

The melt is well blended and treated under low temperature before entering the die, by which easier cooling down on the pipe base could be expected, and less melt sagging will occur.

To reduce the turbulence and accumulation of the melt inside the die, the core of the die cooled by air, and cavity gap adjusted by two steps. To control the flow speed of the melt, ramp designed in the channel, and temperature controlled independently in separated zones. The compensated flat section in the channel were introduced, to develop the anti- sagging die.

Large air flow and air fairing used for the pipe base inner cooling. Calibration sleeve with better heat radiation, spray system with cooling water reflection function, cooling devices based on the water evaporation circulation, and extension of vacuum cooling time, all efficiently reduce the melt sagging.

A-124

PERMEABILITY COEFFICIENTS OF SUSTAINABLE GASSES THROUGH PLASTIC PIPES

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The largest source of gas emissions in the gas transport and distribution sector are leakages in the gas network. Nevertheless, the contribution of permeation to gas emissions cannot be neglected, not only from an environmental point of view, but estimating these values also gives an insight in the economic loss of the transported gas and the possible safety risks due to the accumulation of the permeated gas.

Gas losses due to the naturally occurring, inescapable process of permeation is expressed as the 'permeation rate' (gas volume per period of time). Estimating permeation losses requires details on the gas network including dimensions, the partial pressure difference and the permeability coefficient. The permeability coefficient is a material characteristic that is strongly dependent on the type of gas and temperature. To accurately estimate the permeation rate of methane, hydrogen or carbon dioxide through a gas distribution network a suitable permeability coefficient is required.

The permeability coefficients of gases for different types and grades of PVC, PE and PA pipes under different temperature and pressure conditions are determined experimentally by many different laboratories. The amount of data available from literature is therefore extensive and constantly growing. However, the experiments described in literature have been carried out under a variety of different circumstances (e.g. sample shape, temperature and pressure) and results are reported in a wide range of units. Selecting a suitable permeability coefficient from these data can therefore be a complicated and extensive assignment. And an unsuited permeability coefficient can lead to an over- or underestimation of the permeation rate of a network.

To facilitate the selection process, this paper presents the permeability coefficients from over twenty different literature sources and presents a comprehensive overview of the experimental conditions. The coefficients are recalculated to equal units and to operating conditions, making direct comparison between the permeability coefficients possible. Moreover, it is explained how these permeability coefficients can be used to calculate the permeation rate of a given gas network for any dimension and operating pressure. This creates an accessible method for estimating the permeation rate of methane, hydrogen and carbon dioxide for PVC, PE and PA piping systems.

Note: This paper is not intended to compare PVC, PE and PA. Instead, it is to provide the gas transport and distribution industry with the means to applicate plastic pipes for the distribution of a variety of gasses.

A-127

EVALUATION OF SLOW CRACK GROWTH RESISTANCE IN PE100RC: WILL A SINGLE TEST EVER BE POSSIBLE?

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Slow Crack Growth (SCG) is the main long-term failure mechanism in polyethylene (PE) pressurized pipes. The innovative, ultra-resistant PE100RC grades represent the greatest development in PE pipes to date, guaranteeing a service life of more than 100 years. In this sense, European test standards such as the EN1555 and EN12201 series have been updated to include the PE100RC grade.

To evaluate the SCG resistance of a compound in the form of granules, three different SCG tests have been proposed: Strain Hardening (SH) test, Crack Round Bar (CRB) test and Accelerated Full Notch Creep Test (AFNCT). On the other hand, The Accelerated Notch Pipe Test (ANPT) was developed in the case of a compound in the form of pipe by introducing a surfactant into the standard version of the NPT test to accelerate the SCG failure process.

All these tests can be considered fast and especially when attempting to evaluate materials with such high resistance, varying the test times from a few hours for Strain Hardening Test to approximately a month or more for the AFNCT test. On the other hand, it is not only the time but also the economic cost of having to perform all these tests including also environmental issues related to the use of surfactants and even a possible interaction between the surfactant and the PE after long test periods at elevated temperatures [1].
Depending on the characteristics of the material: density, molecular weight and molecular entanglements, type and comonomer content [2,3], the response in some tests may be different from others, as it has been shown in previous works [4], which is the reason for establishing more than one test to evaluate the correct resistance to SCG of a PE100RC grade and thus ensure its correct designation. The question that arises here is: Is it possible to envision a future with a single SCG test or at least a reduced number of required tests?

To try to answer this question, the characteristics of the material that most influence each test will be discussed, as well as the search for possible correlations between the different tests. Furthermore, some issues that appear during the tests that are being carried out in our laboratories will be presented.
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A-128

INNOVATIVE HDPE PIPES WITH SUPERIOR ABRASION AND CRACK RESISTANCE FOR MINING APPLICATIONS

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The mining industry frequently faces the challenge of replacing PE100 pipes due to the severe abrasion caused by the transport of materials such as mines, rocks, sand slurry, and water. This constant need for replacement leads to increased installation costs, production downtime, and workflow interruptions. To mitigate these issues, SCG Chemicals Co., Ltd. has developed a Very High Abrasion Resistance HDPE pipe, specifically engineered for highly abrasive applications.

Through the enhancement of molecular weight to 600,000 g/mol and optimization of the polymer structure using SCGC's patented technology, this innovative material exhibits superior performance. It retains the minimum required strength classification (MRS > 10 MPa) in accordance with ISO9080 standards. The material's abrasion resistance has been tested following ISO15527 and shows double the resistance compared to PE100, as verified by wear resistance application tests. Field trials conducted in actual mining environments with a slurry solid content of 25% by weight and a solid velocity of 4 m/s have demonstrated significant improvements in pipe longevity and performance, offering substantial cost savings and operational benefits to the mining sector.

In addition to its superior abrasion resistance, the new material demonstrates excellent impact resistance under normal and extreme conditions. Moreover, it shows enhanced resistance to rapid crack propagation, further increasing its durability in harsh environments when compared to PE100 pipes. The optimized polymer design structure with high molecular weight allows it to be processed using conventional pipe extrusion process for diameters ranging from OD 32 mm to OD >1100 mm without requiring modifications to existing tooling. It can also be coextruded to produce pipes with multi-layers designed for specific applications.

This development represents a significant breakthrough in HDPE pipe materials for mining applications, offering improved durability, extended service life, reduced maintenance needs, and enhanced cost-efficiency for industrial operations.

A-129

THE RECYCLING COMMITMENT OF THE EUROPEAN PLASTIC PIPE INDUSTRY

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Mid 2021 TEPPFA launched its new vision and strategy. It underlined TEPPFA's commitment to the EU's ambition for a circular economy and climate neutrality by 2050 as part of the EU Green Deal.

The major must-win battle of TEPPFA's new strategy is its contribution to the Circular Economy. TEPPFA is committed to pave the way to increase use of recycled content / material in plastic pipe systems in Europe all whilst maintaining the performance (technical, hygienic and longevity).

To achieve the ambition TEPPFA is opening the EN standards for an increased use of recycled materials. TEPPFA further supports scientific research for qualifying recycled materials for long lifetime and developed a CEN/TS for design for recycling of thermoplastic pipes.

Awaiting a European legislation on recycled content for building products including pipes, some countries have already decided on legislation, such as in Flanders, a region in Belgium, which from 2027 onwards imposes 20% recycled content in non-pressure sewage pipes for public procurement. In other countries, such as in The Netherlands, Italy and Germany it is currently being discussed if a minimum threshold should be imposed especially for plastic building products.

Plastic pipes have an expected lifetime ranging from 50 to up to 100plus years, which means that sources from other end-of-life plastic products need to be found to meet the industry's recycling objectives. Therefore, the industry calls on European and national authorities to develop supportive measures to guarantee a constant availability of recyclate that meets the quality and economic requirements of plastic pipe manufacturers, especially if demand increases in other plastic sectors. Moreover, TEPPFA members are currently investigating and setting up additional voluntary collection schemes for pipes in Switzerland and monitoring the experience gained from the French EPR schemes for Building and Construction. In addition, BureauLeiding (NL), KRV (DE) and recently BPF Pipes (UK), have conducted studies of the material flow to better map the available quantities of installation scrap and end of life pipes as well as a better understanding of the existing collection and recycling infrastructure.

This paper provides information and background of the initiatives taken to support a growth in the use of recycled material for plastic pipes including the development of collection and recycling systems for installation scrap and end of life pipes in an EU perspective.

A-131

ADVANCED RECYCLING OPTIONS FOR LEGACY ADDITIVES-CONTAINING PVC PIPE WASTE

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PVC pipe compounds can be mechanically recycled several times without any significant loss of its key mechanical properties. While mechanical recycling should be the preferred option for economic and environmental impact reasons, some provisions of the new Lead in PVC Reach restriction (closed loop recycling, lead concentration in article <0.1%) will set constraints on the mechanical recycling of lead-containing PVC pipe waste in the next decade.

This presentation will review advanced recycling processes developed by the European PVC industry that should help the European PVC pipe manufacturers to meet their recycling commitments, despite new regulatory constraints appearing on legacy additives such as lead.

Four advanced recycling technologies that have the most promising advantages for processing PVC pipe waste with legacy additives such as lead, will be discussed: chlorine recovery in waste to energy plants, selective dissolution, pyrolysis and gasification:

- Thermal decomposition of PVC waste in modern waste-to-energy plants allows to recover chlorine for reuse. Processes have been developed to convert the chlorine part of PVC waste into new chemicals. These processes are aligned with the definitions of recycling provided in the Waste Framework Directive and ISO472.

- Selective dissolution offers the possibility to recover an additive-free PVC resin without breaking the chemical structure. The additives are selectively extracted in solvents or supercritical CO2.
- Pyrolysis converts the PVC waste, potentially together with other mixed plastics, into a naphtha-like feedstock that can be re-processed in steam crackers into ethylene.
- Gasification has the highest flexibility in terms of PVC waste composition and converts PVC waste into syngas from which ethylene and/or other valuable products can be manufactured.

Pyrolysis and gasification can both be operated to also recover and recycle chlorine into valuable chlorinated feedstocks (e.g. HCl).

All technologies have the potential to be highly efficient means to reduce the environmental impact of legacy-additive containing PVC waste and ensure PVC circularity.

A-132

RESEARCH ON THE PERFORMANCE OF AXIAL COEFFICIENT OF LINEAR EXPANSION AND APPLICATIONS FOR PLASTIC PIPES

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The axial coefficient of linear expansion reflects the dimensional variation of the pipe in the axial direction as the temperature changes, which is of great significance for the design and application of the plastic pipeline system.[1,2] In this paper, the axial coefficient of linear expansion of plastic pipes made from different materials, such as polypropylene (PP-R), fiber reinforced polypropylene (F-PPR), cross-linked polyethylene (PEX) and polyethylene of raised temperature resistance (PE-RT) will be tested and compared with the coefficients of linear expansion of the corresponding raw materials measured by the vitreous silica expansion meter method according to ASTM D696-2024. Combining microscopic tests such as infrared and thermal analysis, the characteristics of plastic pipes made of different materials will be analysed in response to temperature changes. The F-PPR pipes are produced by compounding polypropylene plastic pipes with reinforcing fibers. Compared to PPR pipes, the axial coefficient of linear expansion of F-PPR is nearly three times lower. Therefore, F-PPR pipes are more resistant to temperature changes in the external environment and transport medium, which compensates for the application limitations of the plastic pipe in the building riser, exposed pipe, hot water pipe and so on.[3] The F-PPR pipes also present a promising development prospect in market applications, which is of guidance for the development of high-value pipes.

A-133

PAVING THE WAY FOR THE USE OF POLYMERS AS BARRIER MATERIALS IN DRINKING WATER PIPES

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High demands are placed on materials that come into contact with drinking water for example according to the Drinking water directive (DWD (EU) 2020/2184 [1] with Implementing decisions (EU) 2024/365,367-371 [2]). The DWD regulates, among other things, the migration of additives from materials in contact with drinking water for the whole European Union. Pipes carrying drinking water must not only meet the requirement that there is no increased migration of substances from the material they are made of, but also ensure that any contaminants from the surrounding soil or groundwater do not contaminate the drinking water over the entire service life. We present a two-stage process that ultimately enables an assessment of different pipe materials in terms of their suitability as a barrier pipe against permeation from the outside in a reasonable time frame. Parts of this process are carried out in accordance with the BRL K-17102 [3] guideline, but certain material properties of the plastic barrier layers require an adaptation of the procedure.

The first step is to select model migrants that represent the actual contamination in the soil as closely as possible. These model migrants are used to carry out permeation experiments from a saturated solution of the migrant (donor) through the barrier layer into initially pure water (acceptor). The breakthrough time and the increase in migrant concentration in the acceptor make it possible to determine the so-called diffusion coefficient, which describes how quickly the migrant moves in the barrier layer matrix. Another parameter to be determined is the so-called partition coefficient, which makes it possible to describe the behavior at the interfaces by determining the solubility of the migrant in the individual layers.

In the second step, the experimentally determined parameters are used to assess the permeation behavior of the pipe over its entire service life. This is done via the repeated numerical solution of Fick's 2nd law in cylindrical coordinates.

Overall, we can thus demonstrate a completed and reproducible procedure for assessing the suitability of plastic pipes as a barrier against contaminated soil/groundwater.

A-134

ANALYSIS OF SGF ORIENTATION OF POLYETHYLENE REINFORCED WITH SHORT GLASS FIBERS PIPE BY SPIRAL CROSS WINDING METHOD

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Polyethylene reinforced with short glass fibres (PE-sGF) pipe, manufactured by combining short fiber glass (sGF) with PE100 as a reinforcing material, has a higher pipe rigidity in the pipe circumferential direction than that of PE100 because of the reinforcing effect of the reinforcing material and a performance similar to PE100 in terms of flexibility in the pipe axial direction. This performance is clarified by the numerical value of the tensile yield stress or tensile modulus of elasticity, which can be obtained by tensile tests that use specimens extracted from the PE-sGF pipe in the circumferential or axial direction. However, the factors behind the mechanical behavior remain unclear.

Therefore, the orientation of the sGF was confirmed using X-ray CT analysis. The results show that the striped pattern orientation angle mapping results toward thickness were obtained in the extrusion direction and thickness directions. This striped pattern indicates that the orientation of the sGF is cross-oriented with a slight inclination to the extrusion direction; the orientations switch at an interval of constant thickness. These thicknesses are equivalent to the thickness of each layer of the PE-sGF pipe, similar to the cross-winding molding method. Therefore, the sGF were proven to be oriented according to the extruded manufacturing angle, while the pipe was mostly reinforced in the circumferential direction. Nevertheless, in first study to provide PPXXI[1] and previous study[2], the orientation results of sGF discharged from the twin screw extrusion as same as PE-sGF pipe extruder was no oriented in the extrusion direction at the center of flow as like generals[3]. So, while physical properties and orientation analysis are not in match then. In this second study continued to analyze the flow path at the die head of PE-sGF extruder in more details and perform flow analysis. It was the focus on the glass fibers flow by cross winding method with actual die flow and appearance of a sGF actual orientation was formed by the pipe with a discussion regarding the developmental length of the fiber to transfer the shear. As a result in the die flow analysis, glass fibers were oriented in the extrusion direction as same as real production.

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REDUCING GREENHOUSE GAS EMISSIONS THROUGH INNOVATION IN THE PLASTIC PIPE INDUSTRY: PATHWAYS TO LOW-CARBON POLYETHYLENE

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Climate change poses one of the most significant challenges to our planet. The consequences are far-reaching, from changing weather patterns that jeopardize food production to rising sea levels that heighten the risk of devastating floods. Addressing these global impacts requires a concerted effort to reduce greenhouse gas (GHG) emissions, particularly carbon dioxide (CO2), stemming from human activities.

In recent years, the plastic pipe industry has made substantial strides in minimizing GHG emissions throughout the production process. This includes adopting more efficient and cleaner methods upstream and exploring alternative raw materials that are not fossil-based. Additionally, downstream efforts focus on applications that support the energy transition, such as protecting high-voltage cables installed underground and transporting clean molecules like hydrogen and CO2.

This paper will present specific examples of pathways to achieve low-carbon polyethylene, including the use of renewable feedstocks and cutting-edge cracking technology. These alternative feedstocks, which do not compete with food production, include sources such as crude tall oil (CTO) from the paper industry and used cooking oil (UCO). The resulting renewable bio-based HDPE serves as a drop-in alternative to fossil-based products, offering the same performance while benefiting from biogenic greenhouse gas credits due to CO2 removal via photosynthesis. The carbon footprint of polymers can be reduced by up to 150%, depending on the type of renewable feedstock used. Additionally, polyethylene's carbon footprint can be further lowered by improving cracking technologies. For example, a new gas cracker under construction in Antwerp is designed to be CO2 neutral after ten years of operation, resulting in a reduction of at least 41% in polyethylene's carbon footprint from its start-up.

Some case studies highlighting the increasing interest in high-density polyethylene (HDPE) pipes for new applications, such as hydrogen transport and storage, or long-distance delivery of green electricity will be shown as well.

For certain uses, HDPE pipes are preferred over traditional materials like steel and concrete due to their outstanding long-term performance (with an underground lifespan of at least 100 years), recyclability, and lower environmental impact and cost.

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ΦOD 1600 MM PVC-U PIPE: PIONEERING NEW POSSIBILITIES IN MODERN INFRASTRUCTURE

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Since early 1960s, PVC-U pipes have been widely used for underground piping systems, due to their corrosion resistance, durability, ease of installation, cost-efficiency, and ability to withstand high pressure. As urbanization and industrialization continue to grow, the challenges to environmental sustainability are intensifying. This has created an urgent demand for efficient and sustainable water management solutions, especially for large diameter piping systems.

This paper gives an introduction of the world's largest PVC-U pipe extrusion line with a production capability of OD 2000mm, including online socketing system. Currently pipe diameters up to OD 1600mm, PN8 (thickness: 49mm, not yet included in any international standards yet), have been successfully produced. The maximum output of the line can reach 1800kg/h. The pipes are designed to replace conventional piping systems, such as steel pipes, in infrastructure projects.

The extrusion line features a parallel twin-screw extruder, specifically designed to ensure effective plastification for high-capacity production of tin-based PVC-U pipes, addressing one of the key challenges.

Another critical challenge involves managing rheology within the die head, focusing on three key factors:
1. Flow uniformity, 2. Optimal compression ratio, and 3. Preventing heat buildup.

A key design element to ensure flow uniformity is the expansion angle of the torpedo. Two approaches were simulated:

- Approach A: Large expansion angle with a small die gap, resulting in less material storage, shorter residence time, reduced over plasticization risk, but higher flow unevenness

- Approach B: Smaller expansion angle with a moderate die gap, offering more material storage, longer residence time, increased over plasticization risk, but more uniform flow

Considering production data and PVC material residence time from the PVC 1200mm line with the same client, Approach B with an optimized torpedo shape was selected.

The next challenge is determining the optimal compression ratio. Based on simulation and experience, and considering actual production results from PVC-U 1200mm and other large-diameter pipes in the same formulation system, we determined the optimal compression ratio for the PVC-U 1600mm die head. Based on that, target cross-sectional area value of the die cavity flow channel were calculated, as well as the die body diameter and die gap.

Last but not least, to prevent heat buildup, a critical issue for PVC-U material, we incorporated a cooling system inside the die cavity to ensure high-efficiency heat dissipation.

Additionally, quality and capacity targets are balanced with raw material costs, providing a significant advantage for large diameter PVC-U pipes.

Furthermore, the paper will introduce a government infrastruction project in northern China. The project aims to utilize two reservoirs as major water supply sources for water-deficient region. By constructing water transmission pipelines, tunnels, auxiliary structures, and pump stations, it will provide household water and industrial water across a large area. The new infrastructure includes a total of 55.28 kilometers of pipelines, with 11 kilometers made of PVC-U 1200mm pipes.

A-141

EVALUATION OF TIGHTNESS TESTING FOR PE PIPES

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Pressure testing of pressurized distribution networks for water and wastewater is a very important method for quality assurance, reducing the risk of costly damages and disruptions and securing long-term functionality. For plastic pipe material there are many national developed methodologies and procedure, despite attempts to resolve it on for instance on European level. However, the used procedures all have in common is that they measure the pipeline's change in volume as a function of the viscoelasticity of the material, monitoring either the pressure or added/subtracted amount of water. The discrepancy between them is time consumption and the test pressure.

The focus in this project, financed by participating companies and the Swedish Water and Wastewater association, was to investigate the advantages and disadvantages of the methods when it comes to finding welding defects in welded joints and the easiness of preforming the testing. A literature review was performed discussing existing European methods for tightness testing. Four methods (EN805, DVS2210 and two Nordic methods) were selected for comparative studies on similar pipe system setups with controlled and produced faults such as uncomplete welding or joints.

A key result from the project is that more advanced and complicated methods do not give any beneficiaries when it comes to identifying defectively executed welded joints. However, results show that testing procedures need a certain time and pressure to provoke the known errors to appear. Beside the conducted experiments what type of defects that are detectable in butt-, and electrofusion joints, statistics were gathered from pressure tests conducted in Sweden in recent years. Results from nearly a hundred pressure tests conducted according to the national standards [1] were anonymized and compiled, with a focus on how the current methodology identifies faults and to investigate if there is any limitation in dimension or length of pipeline.

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REDUCING THE LEVEL OF ARVIN SUBSTANCES IN PIPE APPLICATIONS

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In 2002, Professor Eric Arvin from the Department of Environmental Engineering at the Technical University of Denmark in Lyngby published his findings on the migration of organic additives from PE pipes into drinking water [1)]. He detected ten different organic substances, identifying them as either starting materials or decomposition products of the antioxidants used.

To limit the migration of these Arvin substances into drinking water, the new Drinking Water Directive (EU) 2020/21842[2)] established Maximum Tolerable Concentration levels (MTC) for all Arvin substances.

A detailed analysis of the antioxidants used revealed significant variations in the content of Arvin substances from different suppliers. Compounds were prepared using the best and worst combinations of additives based on their Arvin content, and pipes were then processed from these compounds. These pipes underwent migration tests, and the concentration of Arvin substances was also measured directly in the produced pipes.

Additionally, further compounds were created using antioxidants with different chemical structures that could not degrade into Arvin substances. Pipes made from these compounds were also subjected to migration tests in drinking water.

This paper will explore how cleanliness and alterations in the chemical structure of antioxidants affect the migration values of Arvin substances into drinking water. The findings will contribute to optimizing antioxidant packages used in drinking water pipes, ensuring they meet the requirements of the upcoming Drinking Water Directive.

A-146

LOW CO2 FOOTPRINT HIGH VOLTAGE CABLE DUCTS BASED ON PE100-RC-HT COMPOUND FOR GREEN ELECTRICITY TRANSPORT IN GERMANY

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To transport green electricity from offshore wind farms and those in northern and eastern Germany to the high-consumption areas in the south, Transmission System Operators (TSOs) are constructing several extra-high voltage transmission lines over long distances using underground cables. For safe installation and easy replacement, these high voltage cables are laid in conduits.

The underground cables are pulled into conduits to facilitate easier replacement of faulty cables or those at the end of their service life. Due to the heat generated by high current flow, these protective conduits are exposed to long-term temperatures of approximately 70°C, with short-term peaks up to 95°C. Therefore, the PE compounds used to produce the conduits must be proven to have a service life of at least 50 years at 70°C. This paper will describe the requirements and qualification tests for “PE100-RC-HT” compounds, according to the specifications prepared by TenneT [1], one of the TSOs.

To meet their sustainability targets, TenneT aims to develop their electricity network in an environmentally responsible manner, considering the materials used and their environmental impact [2]. This ambition includes reducing the Product Carbon Footprint (PCF) of the cable conduits, which measures greenhouse gas emissions in CO2 equivalents. TenneT undertook a pilot project in October 2024 which involved the installation of a 1 km section of the SuedOstLink in Germany. The data generated by the pilot project has been used to help evaluate how the construction of power lines can be made more sustainable, by minimizing their PCF.

The production of PE100-RC-HT compounds typically involve using a fossil feedstock with a high Product Carbon Footprint (PCF). However, by using a bio-based feedstock derived from waste and residue biomass materials on a mass balance basis, the PCF of the compound is significantly reduced. In Germany, Gerodur utilized green electricity to produce DN 250 cable conduits from the PE100-RC-HT, and the entire process along the supply chain was certified by the ISCC PLUS scheme (International Sustainability & Carbon Certification) [3]. Life Cycle Assessment data [4,5] indicated a significant reduction in the carbon footprint of the cable conduits. This paper will present the outcomes of these calculations and the insights gained from the pilot project.

A-147

DESIGN METHOD FOR CALCULATING LOAD REDUCTION WHEN USING PLASTIC INSTEAD OF CONCRETE PIPES

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Several design methods exist for designing plastic pipes, summarized in "Transportation Research Circular," E-C230 (2018). A maximum 7 m height of cover for HDPE and PP pipes with diameters up to 1,5 m is recommended by Babcanek and Currence (2021). This is based on the "Handbook for Corrugated Polyolefin Pipe," Plastics Pipe Institute (2020).

The Nordic Plastic Pipe Group has published a simplified design method for plastic pipes with up to 10 m height of cover in "Plastic pipes design and construction," NPG Norge (2021), but there is a need for a method that can be used for plastic pipes below high fill.

As shown in "Load reduction on rigid culverts beneath high fills - long term behaviour," Vaslestad et.al (1993), EPS Geofoam (expanded polystyrene) can be used as the compressible material in load reduction installations on rigid pipes. Instrumented field tests conducted in the study, "Load Reduction On Buried Rigid Culverts, Instrumented Case Histories and Numerical Modelling," Vaslestad and Sayd (2018), have documented the load reduction (arching) on rigid pipes.

Laboratory scale tests and numerical analyses as demonstrated in "Laboratory Scale Tests of Expanded Polystyrene and High-Density Polyethylene Pipe Induced Trench Conduits," Jafary and Arellano (2018) have shown that this method can also be used on plastic pipes.

The reduction in vertical stress (arching) on the plastic pipes is shown to be reduced by up to 70 %, and this reduction is verified by long term instrumented full scale tests on rigid pipes, Vaslestad and Sayd (2018).

By using plastic pipes instead of concrete pipes below high fills up to 40—50 m using this method, the carbon footprint can be greatly reduced, and a design method for calculating the amount of load reduction will be shown in the paper.

A-148

OPTIONS FOR DEFOSSILATION OF PEX RESINS AND RECYCLING SOLUTIONS FOR INTERIOR PIPING

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PEX pipes are widely used inside buildings and contribute to well-being and energy efficiency when used for applications such as wall or floor heating in combination with heat pumps. Such systems powered by green electricity can contribute significantly to the decarbonization of thermal energy consumption in buildings. Besides the positive environmental impact during operation, increased focus is now being placed on the entire life cycle carbon footprint of the pipe systems themselves. It is unlikely that pressure pipes, such as those produced using PEX raw materials, could be manufactured from mechanically recycled materials. An alternative approach to significantly reduce the carbon footprint of PEX raw materials is to make use of bio-feedstocks in the production of polyethylene on a mass balance basis. Biofeedstocks are available in significant commercial volumes, whilst feedstocks derived from chemical recycling are currently available in limited amounts, but with more plants coming on stream in the medium term [1]. The first interior PE pipe systems were installed over 50 years ago and increasing amounts of materials will be reaching the end of their life in the years to come. A pyrolysis process has been developed which is in line with the requirements and can be integrated in our typical petrochemical processes for producing polyolefins. A catalyst system has successfully been tested for the efficient depolymerization of plastic waste, including PEX and multilayer pipes. The resulting product is a liquid that can be used as a feedstock for crackers that produce ethylene. Closed loop recycling and the defossilization of the production process can be demonstrated if this ethylene is used to produce PEX raw materials. This paper will provide insights into the screening trials undertaken on PEX mono and multilayer pipe scrap using pilot systems, together with the first ton scale PE-X volume process in a medium scale chemical recycling plant.

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A SOLUTION FOR PVC PIPE WASTE LEGACY ADDITIVES

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At INEOS Inovyn, our mission is to make all PVC waste fully recyclable, with the ambitious target of having our first industrial unit operational by 2030. To advance this goal, we have launched two pilot plants in Jemeppe-sur-Sambre, Belgium, home to our main R&D center.

These pilot plants build on the industrial experience gained from Vinyloop™ technology, which was in use in Ferrara (I) from 2002 to 2018, and are specifically designed to enhance PVC dissolution technology. Extraction of the legacy stabilisers present in pipes is part of the development and testing on the pilot plants showing REACH compliance. This technology Vinyloop™-D, based on Vinyloop™ experience (2002–2018), is pivotal for recycling complex PVC waste, including composites and the ones containing legacy additives. The goal is to have an industrial unit with this technology ready by 2030, advancing sustainable PVC recycling.

In parallel, INEOS Inovyn is advancing a 2-step pyrolysis and gasification technology aimed at chlorine recovery, along with valorizing the carbon content and extracted additives. This process converts recovered chlorine into hydrochloric acid (HCl) and the carbon into ethylene, both of which are recycled through the Oxychlorination process to produce recycled PVC (rPVC) efficiently. This innovative approach not only maximizes resource recovery but also strengthens the company’s commitment to sustainable PVC production and recycling.

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ADVANCEMENTS IN MATERIAL SAVINGS IN PO PIPE EXTRUSION

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In modern pipe extrusion, material savings play a key role in cutting costs and reducing the ecological footprint. A key aspect of this is the fully automatic centering of the extrusion dies which ensures precise alignment of the tools, which minimizes wall thickness variation. This makes it possible to produce pipes with thinner walls without compromising on strength or quality. Automatic centering is made possible by advanced sensor technologies and control algorithms that make adjustments in real time. This not only saves material, but also increases product quality, which again reduces waste.

Another important approach to saving material is the rapid color change, which makes it possible to operate production lines more efficiently. Traditionally, changing color granules led to significant material losses, as the old material had to be purged out of the machines before the new color could be used. Thanks to the use of modern technologies, such as optimized extrusion dies and high-precision control systems, colour changes can now be carried out much faster and with minimal losses. This saves material and reduces scrap.

And final the use of 3D-printed components in an extrusion line. Especially in the pipe head we see possibilities for 3D-printed components. These components for example can be specifically designed to optimize the flow of the material within the die. In particular, the formation of stripes in colored plastic pipes is reduced, which leads to a more homogeneous color distribution and reduces waste. The ability to produce 3D-printed parts quickly and cost-effectively also offers flexibility in adapting and optimizing the dies, resulting in shorter set-up times and lower material consumption.

Overall, the combination of the fully automatic die centering, the fast color change technology and the use of 3D-printed components to optimize the material flow offers considerable potential for material savings in pipe extrusion. These measures contribute to more efficient, resource-saving production and improve competitiveness at the same time.

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STANDARDS DEVELOPMENT CONTINUES SUPPORT OF POLYPROPYLENE PIPE MARKET IN NORTH AMERICA

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The market for polypropylene (PP) pressure pipe continues to grow in North America. While still a relatively small market in North America, systems designers and engineers are finding that the higher temperature capability or mechanical properties of PP piping systems are opening a new and broad range of applications for thermoplastic pipe in plumbing and mechanical applications including hydronic heating/cooling and chilled water piping.

As the market for PP pipe and fittings has grown, so too has the importance of standardization in support of these piping systems. Introduced in 2004, ASTM F2389 has quickly become the ASTM standard specification of reference for PP piping products in NA. ASTM F2389 is referenced in US and Canadian model plumbing and mechanical codes, showing that compliant PP piping systems are approved for the covered applications. More recently, an industry initiative has been focused on the development of an ASTM standard practice for heat fusion joining of PP pipe and fittings, and this effort was successful, resulting in the publication of the new document in late 2024.

This paper will provide an overview of the recently published ASTM F3722, “Standard Practice for Heat Fusion Joining of Polypropylene (PP) Pipe and Fittings”. This discussion will focus on the four basic heat fusion procedures addressed within this new standard; socket fusion, butt fusion, sidewall fusion and electrofusion. Our discussion will also review the development of the standard using both the task group procedure of the Plastics Pipe Institute (PPI) and the consensus standard process of ASTM International (ASTM). Further, this paper shall provide an understanding of the similarities and differences between the new ASTM F3722 and DVS Technical Code 2207-11. From this paper, the reader will gather a comprehensive understanding of another foundational building block for PP piping systems in North America.

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THERMAL ANALYSIS OF STRUCTURAL PROPERTIES FOR GRAVITY FLOW CORRUGATED POLYPROPYLENE PIPE AT ELEVATED TEMPERATURES

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The use of corrugated polypropylene PP pipe for gravity flow culverts is a growing trend throughout the United States as the need to design and construct more resilient stormwater infrastructure increases. Many of these drainage culverts are buried in shallow cover conditions in highway applications with heavy traffic. A comprehensive study was completed at Ohio University and the University of Minnesota Duluth investigating the response of the pipe systems under shallow cover under heavy loads at elevated temperatures simulating wildfire events. Factors examined for influence on pipe structural response and performance include pipe material, vehicular loading, and temperature. Included in the results are the analysis of full-scale test data for PP pipe under vehicular loading at elevated temperatures under asphalt pavements, discussion of best installation practices, and design guidelines for thermoplastic pipes exposed to wildfire events which include the effects of temperature on soil arching and other American Association of State Highway Transportation (AASHTO) Load and Resistance Factor Design (LRFD) criteria.

A-157

INVESTIGATION OF A PP-RCT PIPE AFTER 5 YEARS USE WITH 95 °C HOT WATER

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For many decades, pipes and fittings manufactured from polypropylene random-copolymer (PP-R) have been successfully used for the distribution of hot and cold water in heating and plumbing applications inside buildings or in industrial processes. The development of PP-R with raised crystallinity and temperature resistance (PP-RCT) about 20 years ago resulted in significant further improvements of the material performance.

This study examines the long-term performance of a multilayer PP-RCT pipe used for water transportation at 95°C for five years. The 160 mm SDR7.4 pipe, taken from an Italian co-generation plant, features a glass fiber middle layer, insulating polyurethane foam, and a PE jacket. Utilizing a combination of Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), Wide-Angle X-ray Scattering (WAXS) and Differential Scanning Calorimetry (DSC), the material's structural integrity, thermal stability, and beta crystallization content were evaluated. The stabilization package of the material was also investigated using High Performance Liquid Chromatography (HPLC).

The results were benchmarked against standardized application classes and reference curves as outlined in ISO 15874 and ISO 15494. While the actual application of the pipe took place under harsher conditions than described in the defined application classes, the generated results indicate that the investigated multilayer PP-RCT pipe still exhibits superior durability and reliability, meeting and even exceeding the required performance criteria set by these international standards.

Notably, the tests did not indicate any chemical degradation of the polymer even on the inside of the pipe, and the long-term stabilization remains sufficient for several more years of use. For actual lifetime assessments, further testing at various points in time would be necessary.

The study concludes with a discussion on the implications of these results for future applications in high-temperature environments. The findings suggest the possibility of extending the scope of the application classes for PP-RCT in the future, further enhancing its versatility and utility in various industrial and domestic settings.

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MODELING OF BRITTLE FRACTURE BEHAVIORS OF POLYETHYLENE PIPES UNDER OXIDATIVE ENVIRONMENTS

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Polyethylene pipes have been widely used in gas or water distribution systems, due to their flexibility, ease of installation, and resistance to seismic loading. In addition, the structural durability of the polyethylene pipes has been continuously improved through advancements in catalyst and polymer processing. Due to these improvements in material properties, polyethylene pipes are now frequently used in high-pressure piping systems that demand high structural integrity; thus, suitable lifetime assessment methods are required.

Polyethylene pipes exhibit different failure modes depending on the applied stress[1-2]. At the high level of hoop stress, the localized large plastic deformation leads to ductile failure. At the intermediate stress range, the pipes fail in brittle fracture consisting of crack initiation, slow crack growth, and fast fracture. Furthermore, when the polymer pipes are exposed to highly oxidative environments, premature brittle fracture due to oxidative degradation occurs[3]. Among the distinct failure modes, field failures under normal operating conditions are known to be closely related to the second and third modes. Under the oxidative environments, the effects of the mechanical stress and chemical oxidation act simultaneously to reduce the polymer properties[4]. Therefore, durability assessment methods should take these combined effects into consideration.

In this study, a model was developed to simulate crack initiation and slow crack growth behavior of the pressurized polyethylene pipe under oxidative environments. The multiple crack initiation behavior observed in oxidative conditions was simulated using the fracture energy method, and the slow crack growth of the main crack under chemical degradation was also represented. This approach is expected to improve the accuracy of lifetime predictions for polyethylene pipes in chemically aggressive environments.

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SPECIALIZED MULTILAYER DIE-HEAD DESIGN – NEW CONCEPTS FOR NEW QUESTIONS

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New applications, difficult market environments, legislative regulations and social changes implicate increasing technical and commercial create new tasks for the manufacturing industry. This abstract will show, how machine manufacturers can support their customers with answers including machine concepts as well as software solutions.

With changing requirements, high performance grades become more important. This can be caused by environmental circumstances as well as by the transported liquid or gas. One big topic is the future layout of a hydrogen transport grid. While existing pipe designs are considered to be able to transport hydrogen, the loss by permeation is an issue. Barrier layers, e.g. made of PA, can help to reduce those losses, but add extra cost to the pipe. they tend to be processed different and to be costly. This implies the need of adapting the equipment an leads to the demand to use as less as possible material. Ideally, only thin barrier layers are made, while mechanical stability has to be maintained by less costly materials in thicker layers. New multilayer designs with a different thickness distribution of the single layers are created. Specialized polymers are used in dedicated dimensions.

Additionally. those high-performance polymers are processed differently. E.g., process temperatures are higher than those of the partnering grades. Temperatures of e.g. 300°C plus can damage the other polymers, if the contact is too long.

To overcome this issue and meet the requirements, a new 3-layer pipe-head was developed with a heated and insulated melt channel, taking the functional inner-layer right to the front, so contact to the other polymers is minimized. An adhesive layer ensures the bonding to the outer layer made e.g. of PE. Polymers like PPS, PA, PVDF can be processed this way. This allows the creation of new pipe concepts for various applications presented here and is also the basis for other specialized tooling concepts for unique applications, meeting both commercial and process related requirements.

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DATA STRATEGY IS KEY TO THE CIRCULAR ECONOMY – HOW GRAVIMETRICS, INLINE-MEASUREMENT SYSTEMS AND DATA CONTRIBUTE TO SUSTAINABILITY

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Sustainability in plastic pipe production is crucial for minimizing environmental impact. It enhances resource efficiency, reduces carbon emissions, promotes recycling, and supports long-lasting infrastructure, contributing to a more sustainable future. In this context, data strategy plays a central role in using resources more efficiently, minimizing waste and making value chains sustainable.

Quantifying the positive impact makes it necessary to gather data along the whole value chain, provide sustainability data such as carbon footprint and make them easily accessible for partners, customers and authorities. A company can use the following stages to determine its own level of maturity and define a strategy and measures:

1. Data Generation and Measurement Systems: Collecting data along the entire value chain is the first step. Gravimetrics and inline measurement systems contribute crucial quality information and help quantifying the CO2 product footprint.

2. Control Loops for Process Automation: The process information can be used within the same line to automate production, reduce material consumption and enhance product quality.

3. Data Collection and Aggregation: The next step is to collect and aggregate data in suitable databases. Here it is important to build robust and flexible data infrastructures, as this is the basis for the next steps.

4. Data Analysis and Business Intelligence: New optimization potential (e.g. resource and energy consumption) is possible through analyses that are both cross-location and look at longer periods of time.

5. Virtual Assistants: Virtual assistants can optimally support the implementation of a circular economy.

6. Outlook AI: AI applications have the potential to boost efficiency and accuracy. From optimizing recycling processes to predicting product lifespans, AI is helping to take data-based sustainability strategies to the next level.

The presentation focusses on how a data strategy can be developed for an extrusion company.

- How is the company's current position determined?
- Which quick wins can be realized and how does the implementation work?
- Which questions are important in the individual stages?

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PVC-U PIPES: OPTIMAL EXTRUSION CONDITIONS FOR A 100+ YEAR DESIGN LIFETIME (PART II)

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To generate public data demonstrating that pressure PVC-U pipes can be serviced for 100+ year, an investigation project has been launched in 2020 by CEIS and PVC4Pipes to clarify the relationships between the processing and QC testing conditions, and the design lifetime of PVC-U 250 pipes.

Calcium-based stabilized pressure pipes were extruded with different processing temperatures and characterized by their DSC onset temperature, DSC degree of gelation and resistance to dichloromethane. Their long-term hydrostatic strength was predicted using the methods described in ISO 9080. The main desired outcome of this project was to set up a correlation between the extrusion temperature and the 97.5% Lower Prediction Level of the stress that a PVC-U pipe can withstand after 100 years (LPL100y).

The results of this study show that an extrusion temperature of 180ºC is high enough to achieve a MRS250 classification. A moderate increase (+5ºC or +10ºC) of the extrusion temperature leads to a smooth decrease in the slope of the regression curve at 20ºC and, therefore, to an increase of the predicted LPL100y values. Higher processing temperatures (≥195ºC) result in only marginal increases in LPL100y, with clear risk of material degradation during processing.

The increase of LPL100y allows the initial MRS250 classification to be extended up to 100+ years. The resulting benefit for the prescribers and designers of pressurized water supply networks is to design their networks for 100+ years by using of design stress and design coefficient values typically used for a design lifetime of 50 years.

Note: Part I of this work has been presented in Orlando Plastic Pipes Conference.

A-172

DETERMINING ACCURATE FRICTION FACTORS FOR HIGHLY CRYSTALLINE, ULTRA-SMOOTH, WATER REPELLENT PP-RCT PIPING SYSTEMS AND EQUIVALENT LENGTHS AND K FACTORS FOR MOLDED LONG RADIUS 90^{O} ELBOWS AND STANDARD SHARP-TURN MOLDED 90^{O} ELBOWS BY FULL SCALE FLOW TESTING

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PP-RCT is a patented high performance, high temperature thermoplastic that has been developed with up to 80-95% beta crystallization according to the patent[1]. The material is extruded with an exceptionally smooth interior bore, which has been confirmed by laboratory testing using a Bruker Dektak XT System. Further, PP-RCT is highly non-polar and acts to repel water molecules. Given its hydrophobic nature, and the exceptionally smooth surface, when water flows through the pipe it does not develop an interior film layer. Interior film layers contribute to the overall frictional resistance of a pipe. For these reasons, it is a goal of this full-scale study to determine actual frictional resistance factors appropriate for PP-RCT piping and to compare them to traditionally used values.

A unique set of larger molded bends have been developed that are injection molded with a completely smooth interior bull with a full circular cross section throughout the interior bore of the bend. These bends, which have been injection molded with long radius and extra-long Long Radii patterns, have been produced initially molded in nominal diameters 6" (160mm) through 14" (355mm) with a relative radius ranging from r/D = 2.5 to 1.

A testing program has been undertaken at major State University to take advantage of their well-known hydraulic laboratory capabilities and expertise and to seek an independent confirmation of the results. The testing includes 200-ft long sections each of 2-inch pipe, 6-inch pipe and 12-inch pipe with SDR 17 thickness. These three tests will collect physical measurements of head loss through each pipe at various full pipe flow rates over a wide range of flow velocities so that the friction coefficient can be calculated. For these tests, plots of Reynolds number versus Darcy f, Hazen Williams C and Manning’s n will be developed. Elbows will also be tested to compare standard elbows which lack a curved profile on the inner crotch to that of long and extra-long radius elbows in four different sizes. Plots of Reynolds number versus minor loss “k” as well as pipe equivalent length will be developed. The results will provide accurate data to compare head loss in the two elbow types, as well as to provide a comparison to data used heretofore.

A-174

CHLORINE RESISTANCE TESTING OF HOT & COLD-WATER PIPES A 30 YEAR REVIEW AND NEW CHALLENGES

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Testing for resistance to oxidation of polyolefin pipe and pipe resins has become an integral part of the North American (NA) industry. In potable water applications, this has culminated in ASTM F2023, "Standard Test Method for Evaluating the Oxidative Resistance of Crosslinked Polyethylene (PEX) Tubing and Systems to Hot Chlorinated Water."

The ASTM F2023 test method has been adapted for use in polypropylene pipe systems resulting in ASTM F3497, "Standard Test Method for Evaluating the Oxidative Resistance of Polypropylene (PP) Piping Systems to Hot Chlorinated Water". The two test methods are essentially the same and utilized in similar fashion to create either a full data set to assess chlorine resistance or a Dependent Listing Transfer (DLT) data set to determine comparable performance of a specific pipe product to an existing full data set.

The ASTM F2023 test method and its associated implementation protocol under NSF Standard 14 have served the needs of the NA potable water pipe market successfully for 30+ years. The test method and implementation protocol provide a basis by which to determine the suitability of PEX pipe and tubing for service in hot chlorinated water applications. From humble beginnings as demonstrated by Tokyo Gas in 1992 and later by Hewing Pro Aqua in 1996, ASTM F2023 has become a mainstay within the NA market for polyolefin pipe in hot chlorinated water applications.

ASTM F2023 was first published in 2000 and since that time it has been reviewed, revised or updated several times. The ASTM F2023 test method is used in combination with the PEX product standard ASTM F876, "Standard Specification for Crosslinked Polyethylene (PEX) Tubing. The extrapolation coefficients determined in ASTM F2023 are utilized in accordance with ASTM F876 to determine qualification of a specific PEX pipe product to Class 1, 3 or 5 service levels that are established under defined combinations of stress and temperature using Miner's Rule.

The period between 2000 and 2024 provides an extensive period over which oxidation testing and the associated test results for polyolefin materials typically associated with potable water applications. This paper will review the refinements to the ASTM F2023 test method that occurred over the years. A discussion of test results for these materials obtained in the time period 2000-2024 will be presented as well as investigation of the role that activation energy at different temperatures may play in the variance or reproducibility of test results.

This discussion is not a comparative assessment of chlorine resistance of different polyolefin materials. Rather, the focus of this paper is a detailed discussion of the ASTM F2023 test method and anomalies observed over an extensive time period when applied to those polyolefin materials commonly used in potable water applications. A review of test results obtained of over the 2000-2024 timeframe combined with a discussion of activation energy at various temperature mays serve as a basis for a more thorough discussion on the ASTM F2023 test method and its implementation going forward.

A-177

VALIDATION OF END-USE APPLICATION CONDITIONS FOR HDPE CONDUIT WITH RECYCLATE

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This paper builds upon previous research presented at the 21st Plastic Pipes Conference, which investigated the incorporation of recycled High-Density Polyethylene (HDPE) into conduit applications for power and telecommunications. The concern is the increased risk of failure with the inclusion of recyclate during storage, installation and service. The focus of this study is to verify and validate the underlying assumptions regarding the critical operating conditions identified in the earlier work. Specifically, this paper examines the thermal and stress history during storage, including the effects of solar heating and stress relaxation, as well as the thermal and mechanical stresses in end use applications of conduit in telecommunications and power conveyance.

The research involves a comprehensive analysis of the thermal and mechanical stresses experienced by HDPE conduit and the implications for conduit with recyclate. The study includes detailed evaluations of the effects of solar heating on stored conduit, the impact of stress relaxation over time, and the mechanical deflection experienced during installation and service. Additionally, the heating effects of power cables housed within the conduit are analyzed to understand their contribution to the overall stress profile during the life of the installation. Current requirements of high temperature performance of conduit are examined.

The findings from this study are used to recommend reasonable service condition assumptions for power and telecommunications applications. These recommendations aim to establish minimum Un-Notched Constant Ligament Stress (UCLS) values for conduit manufactured with recycled materials for inclusion in product standards, ensuring long-term performance and reliability. The results provide valuable insights for the industry, supporting the broader adoption of recycled materials in HDPE conduit applications while maintaining stringent performance standards.

A-179

MIAMI UNIVERSITY TURNS TO POLYPROPYLENE (PP) PIPE FOR CAMPUS-WIDE HYDRONIC HEATING UPGRADE

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This is the third in a series of papers on the development of hydronic heating systems for educational institutions within North America. Combined, the three papers provide a detailed perspective on the development of this application with polypropylene pipe with raised crack and temperature resistance (PP-RCT) for institutional hydronic heating systems.

The first paper titled; “Polypropylene Pipe for Demanding Hydronic Heating Applications” was presented in September, 2021 at PPXX in Amsterdam in the Netherlands. This initial paper was a case study of a relatively small expansion of an existing hydronic heating systems at the University of Illinois. This initial paper gave an understanding of the numerous innovations that were utilized on this project that was originally specified for carbon steel pipe. The second paper titled, “Polypropylene (PP) Pipe – A Carbon Footprint Assessment” was presented in September, 2023 at PPXXI in Orlando, FL. This second paper analyzed the hydronic heating case study at the University of Illinois project from a carbon footprint point perspective.

Today, interest in the use of PP pipe for institutional hydronic heating systems continues to grow in North America. In this third paper, we provide a detailed look at a recent campus-wide conversion from carbon steel steam heating to high temperature hydronic heating using dual-wall, pre-insulated PP-RCT pipe and fittings. Over the course of 2022 and 2023, Miami University utilized a combination of direct burial and horizontal directional drilling to completely replace a deteriorating carbon steel steam system. This discussion will address specifics regarding selection, design and installation of the PP-RCT hydronic heating system. Various factors, such as, energy efficiency of high temperature hydronic heating as compared to steam heating systems, chemical and corrosion resistance of PP-RCT as compared to carbon steel, and numerous installation considerations that led to the construction of this campus-wide, high temperature hydronic heating system. From this, the reader will gather a greater understanding of the benefits associated with high temperature hydronic heating systems constructed using PP-RCT pipe and fittings for various institutional applications such as colleges and universities, hospitals, corporate campuses and much more.

A-181

UPDATED POLYETHYLENE PRODUCT STANDARDS DOING THEIR PART FOR A SUSTAINABLE FUTURE

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This paper discusses the latest changes and improvements to the international and European product standards for polyethylene (PE) piping systems for gas and water supply. The updates affect four series of product standards that are relatively similar for PE piping systems:

- EN 1555 (European standards series for PE for gas supply)
- EN 12201 (European standards series for PE for water supply)
- ISO 4427 (International standards series for PE for water supply)
- ISO 4437 (International standards series for PE for gas supply)

The standards are updated in more or less three steps. First, PE100-RC was added, then the assessment of conformity has been revised or is in preparation, and finally hydrogen gas and disinfectants will be included in the standards.

One of the first steps was to include PE 100-RC in almost all standards. The main technical advantage of this material is that it is even more resistant to slow crack growth (SCG), making it a good choice for trenchless techniques.
Standardisation of PE 100-RC was a long wish from the industry, as the first types of PE 100-RC already entered the market in 2001. Experts agreed on a comprehensive set of test methods, including the strain hardening test (SHT), the cyclic cracked round bar test (CRB), the accelerated full notch creep test (AFNCT) and the accelerated notched pipe test (ANPT).

Following the inclusion of PE 100-RC, a balanced agreement on the Assessment of Conformity (AoC) has been reached in Europe. The AoC ensures the required high quality of the compounds and products, but also limits the test load on the industry. Internationally, an AoC document is being prepared for ISO 4437 that will provide global guidance on type testing (TT), batch release testing (BRT), process verification testing (PVT) and audit testing (AT).

At present, the product standards for gas and water supply are being revised again to respond to two other important requests from the market: hydrogen gas for the standards for gas supply and disinfectants for the standards for water supply.
The gas standardisation working group has prepared an annex to provide more information on the suitability of PE pipe systems for 100% hydrogen and its mixtures with natural gas. It shows that approved PE gas pipes are fully resistant to hydrogen gas.
The product standards for water supply will receive an informative annex on secondary disinfection to guide users on the effect of disinfectants on polyethylene pressure pipes.

A-184

THERMOPLASTIC LINING SYSTEM AND LIFE CYCLE COSTING: A BUSINESS AND ENVIRONMENTAL PERSPECTIVE

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Corrosion remains a significant challenge for oil and gas operators worldwide, demanding effective solutions that balance cost, functionality, and sustainability. As organizations seek to minimize both CAPEX and operational expenses, they must also ensure that these reductions do not compromise the technical quality or longevity of their assets. A comprehensive carbon steel plus nonmetallic piping system can enhance asset reliability by providing robust corrosion protection from the reservoir to the processing facility.

Life Cycle Cost Analysis (LCCA) is gaining traction among National Oil Companies (NOCs) as a vital tool for ensuring the sustainability of assets. This methodology adopts economic and engineering principles to evaluate costs from inception to decommissioning, including environmental impacts. Integrating carbon footprint assessments with LCCA provides valuable insights, enabling operators to select solutions that not only minimize costs but also reduce environmental impacts.

In this presentation, the author will explore the use of Thermoplastic Lining Systems for internal corrosion protection of CS pipelines, highlighting the necessity of a holistic approach to non- metallic piping systems. This strategy aligns with profitability goals while addressing environmental concerns.

Key points to be covered include:

1. Cost Efficiency: An analysis of how Thermoplastic Lining Systems can lead to lower life cycle costs compared to traditional materials.
2. Environmental Impact: A detailed examination of the carbon footprint associated with thermoplastic systems throughout their life cycle, showcasing their potential to mitigate environmental harm.
3. Real-World Application: A case study of the largest thermoplastic lining system in the Middle East, demonstrating successful implementation and the benefits realized in terms of both cost savings and environmental protection.

The adoption of Thermoplastic Lining Systems represents a strategic move for oil and gas operators aiming to enhance asset longevity and environmental responsibility. By leveraging LCCA, companies can make informed decisions that support their financial health while contributing positively to the planet. This presentation aims to illustrate the synergistic benefits of combining innovative materials with sound economic analysis, ultimately advocating for a sustainable future in the energy sector.

A-185

HIGH FILLED CONTENT OPVC PIPES FOR LOW TO MEDIUM PRESSURE RANGE APPLICATIONS

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OPVC pipes are commonly used in high-pressure applications (>12 bar or 160 psi) due to the high MRS (Minimum Required Strength) and ductility achieved through the orientation process. These enhanced properties enable the use of relatively thin walls for high-pressure applications. However, a significant portion of the network lacks OPVC pipes due to the "thin wall" present in these pipes. While these pipes technically provide adequate ring stiffness, installation companies generally prefer thicker walls, often two to three times the wall thickness of OPVC, as they are accustomed to handling thicker plastic pipes. In these low to medium pressure applications, such as irrigation systems, installation companies tend to prefer pipes with greater body, particularly as installation conditions are sometimes less controlled than in infrastructure projects.

To address this challenge, the objective of this study is to develop an OPVC pipe as thick as any UPVC pipe for the same application but with a cost-competitive formulation that allows it to compete in the same market. Instead of orienting a standard UPVC pressure pipe formulation, is proposed orienting a UPVC sewer formulation (with a lower-cost, high-filler composition) and comparing its performance with that of a standard UPVC pressure pipe of the same pressure ratio.

The study reveals that a “lower-grade” formulation, typically used for non-pressure pipes, when subjected to the orientation expansion process (patented by Molecor), produces a pipe that outperforms conventional non-oriented UPVC pressure pipes. Internal pressure and fatigue cycling tests on both UPVC and OPVC-high filler pipes demonstrated significantly superior mechanical performance for the latter, making it a highly competitive and reliable solution for low to medium-pressure applications.

A-187

ASSESSING LONG-TERM EFFECTS AND PERMEATION OF HYDROGEN TRANSPORTED IN POLYETHYLENE PIPES

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A major contribution to the green transition is provided by the growing application of hydrogen gas as an energy carrier. Hydrogen can be produced from surplus energy of renewable energy sources and it is central to the Power-To-X concepts aiming to transport hydrogen in the existing polymer pipe networks. The transition from natural gas to hydrogen in gas networks requires the understanding of short-term and long-term effects as well as permeation and gas loss in polymer pipes.

Previous studies showed that short-term effects of hydrogen on Polyethylene (PE) pipes are negligible [1], while long-term effects especially the lifetime have not been thoroughly investigated [2]. This work focusses on lifetime assessment of one selected PE100-RC pipe after two years of hydrogen exposure at 8.9 bar. Applying cyclic Crack Round Bar (CRB) tests, only a slight slope change in the CRB failure curves was detected. Similar changes were found in case of another PE100-RC pipes exposed for 1000 h at 10 bars in water. The observed changes in CRB tests and slow crack growth (SCG) resistance probably originate from morphological changes caused purely by the applied pressure. Exposure to hydrogen showed no effect on SCG resistance and lifetime of PE pipes.

As hydrogen is the smallest gas molecule, permeation and gas loss through PE pipes was reported to be four times higher [3] compared to natural gas. In semi-crystalline polymers, the crystalline phase has several orders of magnitudes lower gas permeability than the amorphous phase [4]. To assess the relationship between PE morphology and permeation, seven injection molded PE pipes with different processing parameters were investigated. Spectral crystallinity, derived from IR spectroscopy, showed crystallinity differences up to 25 %, while permeation coefficients varied by only 13 %. This suggests that morphology and crystallinity effects hydrogen permeation only in a small extent. Understanding this relationship may lead to PE products with lower permeability and clarify permeation rates during long-term use where morphological changes may take place.

A-188

CARBON BLACKS IN PRESSURE PIPES – A SUCCESSFUL HISTORY WITH A SUSTAINABLE FUTURE

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For over half a century, carbon black (CB) has been an important ingredient of HDPE formulations for pressure pipe applications, ensuring UV protection of the polymer during outdoor exposure. CB particle size and addition rates are regulated under the ASTM and ISO systems – but not in the same way. This study provides a technical exploration of the different particle sizes used in pressure pipe applications – not to determine a winner, but to highlight the merits of either approach.

The paper will start with a brief history of the development of carbon black and its manufacturing processes, followed by a deep investigation into the influence of carbon black morphology on pressure pipe performance. CB effectiveness in protecting polymer against UV-induced degradation is closely linked to particle size. Smaller particles (<25 nm) offer increased UV absorption due to a higher available surface area, crucial for maintaining polymer integrity and preventing premature failure.

Additionally, plastics and their use in many applications have gained public attention with an increased focus on sustainability. This analysis dives into case studies and approaches for enhancing the sustainability of pressure pipe products through carbon black. Traditional furnace carbon blacks already contribute to sustainability by value-adding petrochemical waste streams into key components for durable systems—such as plastic pipes and fittings with lifespans exceeding 50 years.

This study examines strategies to reduce the carbon footprint by incorporating reclaimed carbon black (rCB) from end-of-life tires into pressure pipe formulations, comparing its performance with conventional P-type carbon black and blended formulations in polyethylene (PE) samples exposed to UV weathering. Weathering testing on 140 µm PE samples revealed that P-type carbon black significantly outperformed rCB in retaining tensile elongation at break after 500 hours of UV exposure, with retention levels of 123%. This suggests robust UV stability for P-type carbon black. Conversely, rCB retained only 33.2% of its tensile elongation, indicating a reduction of over 50% and potential challenges in UV resistance. These findings highlight the trade-offs between sustainability and performance, suggesting that while rCB is a promising sustainable alternative, additional modifications may be necessary to meet the UV durability of traditional carbon blacks in high-demand applications.

The analysis concludes with recommendations for effectively incorporating reclaimed carbon and other sustainable solutions in plastic pipe applications to enhance sustainability.

A-189

LEVERAGING VOLUNTARY DATA TO IMPROVE THE SAFETY OF GAS DISTRIBUTION SYSTEMS THROUGH THE PPDC

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The Plastic Piping Data Collection Initiative aims to proactively monitor the performance of plastic piping systems used in gas distribution networks across the U.S. This initiative, managed by the Plastic Pipe Database Committee (PPDC), brings together stakeholders from regulatory agencies, industry groups, and gas operators to address safety concerns, particularly focusing on identifying trends in failures and improving system integrity.

The PPDC leverages data from voluntary operator submissions to proactively monitor the performance of plastic piping systems used in gas distribution. This data collection initiative enables the identification of failure trends, attributed causes, and vulnerabilities in both vintage and modern plastic materials. Through aggregated reports, the PPDC provides insights into installation errors, material defects, and stress-related issues affecting pipes, fittings, and joints, helping operators identify risks.

PPDC's data supports regulatory compliance, particularly with Distribution Integrity Management Programs (DIMP), and aligns with federal reporting requirements under PHMSA. The data further informs decision-making, enabling operators to prioritize material replacement and maintenance strategies. Collaboration with manufacturers ensures continuous improvement in product design and installation practices, while engagement with operators encourages best practices across the industry.

Ultimately, the PPDC's initiative strengthens public safety by offering a data-driven framework for helping operators identifying risks, guiding proactive maintenance, and helping to refine industry standards. The ongoing collection and analysis of data remain essential in ensuring the long-term integrity and safety of gas distribution systems.

A-190

POTABLE WATER DISINFECTION RESISTANCE CLASSIFICATION METHODOLOGY FOR HDPE PIPE RESISTANCE AS IMPLEMENTED IN NORTH AMERICA

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This paper presents research, standards and methods that were adopted in North America to ensure the long-term resistance of high-density polyethylene (HDPE) pipes to disinfectants that are commonly used in potable water systems. It begins with a concise overview of secondary disinfection methods in North American water treatment, particularly focusing on the use of chlorine and chloramine. The paper will detail the standard procedures for testing HDPE pipe materials against oxidative degradation, using methodologies outlined in ASTM standards such as F2263 and D3350. Additionally, it will explain how these materials are categorized into performance classes (CC0 to CC3) based on their oxidative resistance.

Key modeling tools will be described to demonstrate how inputs such as temperature, disinfectant concentration, pH, and stress are factored into the prediction of HDPE pipe performance. The paper will further explore the sensitivity of these inputs and their influence on the projected lifespan of pipes under different operational conditions. Results from case studies will be used to validate the model, showing its application in real-world conditions, including a discussion of its inherent conservatism and limitations. This comprehensive assessment aims to inform engineers and industry stakeholders about the robustness and long-term viability of HDPE pipes in potable water applications across diverse climates and water quality conditions in North America. Recommendations on further work will be provided.

To support the finding and procedures, the paper will reference established AWWA Standards such as ANSI/AWWA C901, ANSI/AWWA C906 and PPI technical notes, such as PPI TN-44, TN-49, and TN-43 and HDPEapp.com to support the findings and methodologies.

A-192

PAVING THE WAY FOR THE USE OF REINFORCED THERMOPLASTIC PIPES FOR THE TRANSPORT OF CARBON DIOXIDE

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One of the few ways in which the energy-intensive industries can avoid large amounts of CO_2 emissions in the short term is through the use of Carbon Capture, Utilization, and Storage (CCUS). This will require a CO_2 transport system between the carbon capture site and the storage site, providing an opportunity for new piping systems. However, changing the transport medium to CO_2 is accompanied by a change in the properties of the medium. This affects the product performance, which needs to be reconsidered and defined accordingly. This paper describes the tests and the model used to define the behavior of a reinforced thermoplastic pipe (RTP) in terms of chemical resistance and permeation to carbon dioxide.

Carbon dioxide has a high solubility compared to other media, such as nitrogen and methane, for most materials. The main product properties that this high solubility can affect are:

The chemical compatibility of the materials, in particular the resistance to rapid gas decompression (RGD). During a rapid decompression event, absorbed gases in the polymer can expand rapidly, resulting in blistering and cracking of the material.

The permeation rate of the RTP. The permeability coefficient depends on both the diffusivity and the solubility of the permeant in the material. A high solubility can therefore result in a high permeability. The resistance to RGD of a HDPE liner is demonstrated by submerging test pieces in supercritical CO_2 at 156 bar and 65°C and quickly reducing the pressure to atmospheric conditions for 20 cycles. The test shows no formation of blisters, or slitting, or other defects.

The permeation rate of the RTP is determined by two different methods. The first method uses the permeation properties of each material in each layer, which are combined in a model to estimate the overall permeation rate. Some of the parameters were first determined in a separate permeation experiment. The second method consists of a full-scale permeation test of the product at 40 bar and 65°C using gaseous CO_2. The latter measurement is used to validate the previous model, providing an overall understanding of the product's performance.

The results presented in this paper show that RTPs are a mature product and are able to compete with steel pipes for the transport of carbon dioxide at high pressure and temperature, making them an excellent alternative as piping system for CCUS.

A-193

EFFECT OF INITIAL MORPHOLOGY ON THE DRAWING BEHAVIOR AND FINAL PROPERTIES OF BIAXIALLY ORIENTED POLYPROPYLENE PIPES

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Bi-axially oriented Polyethylene and Polypropylene pressure pipes have shown outstanding improvement over the whole property range as were reported in our last presentation at PPXXI. However, when exposed to elevated temperatures, nearing draw temperatures, biaxially drawn pipe products undergo dimensional changes that are well beyond acceptable limits for typical high temperature applications. These changes are mostly connected to relaxations or rearrangements in the processing-induced microstructure when exposed to higher temperatures.

An evaluation of Polypropylene resins using the "stepwise isothermal annealing" (SIA) protocol provided important insights regarding the melting behavior upon extended annealing near the melting point of those resins. The SIA studies suggested that it is possible to increase drawing temperatures by up to 15oC, compared to values previously used. The increase in drawing temperature led to several improvements in the properties of the final product:

- major reduction of the drawing forces required during the biaxial drawing process
- reduction of shrinkage level of the final product to a level which is now within acceptable limits
- an increase of hoop yield stress that is in largely related to an increase of crystallinity upon annealing

Furthermore, we will highlight how these findings can be captured and steered using the latest developments in processing and online data capture for the process and quality control. Temperature control from melt to crystallization and reheating to the desired draw temperature uniformly for biaxial stretching and stretch ratio control are most critical parameters for ensuring optimal performance of these biaxially oriented pipes. To optimize the process conditions thermal profile simulations were carried out and validated in practice. We will shed light on these key process controls.

A-194

PRESSURE TESTING OF A LONG SECTIONS OF LARGE DIAMETER PE PIPELINE

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The political and economic situation in Central and Eastern Europe forces the diversification of energy fuel supply directions and the increase of their storage capacity. Underground storage facilities for natural gas, crude oil or liquid fuels are one of the possible solutions. In Poland, post-exploitation brine production caverns are used as storage facilities for crude oil and liquid fuels. Proper operation of such tanks requires appropriate infrastructure enabling both filling and emptying. During the emptying of the underground tank, brine is fed to the lower part of its interior, which pushes the oil or fuel into the appropriate transmission pipelines. As part of the investment, a pipeline was built of PE100 ø630×57.2 mm pipes and a total length of 43,439 meters for transmitting brine under pressure of up to 16 bar. The choice of polyethylene as the material for the construction of the pipeline was made on the basis of its high chemical resistance and ease of assembly.

The paper presents experiences related to pressure testing of the build pipeline. Due to technical, terrain and time conditions, it was decided to test relatively long sections. The longest was 11,100 meters long. The method of air venting of the pipeline proved to be very effective. Testing such long sections was associated with various problems.

Direction changes were made along the pipeline route using segmented bends. In order to prevent the creep of polyethylene in places of stress concentration, concrete bands with dispersed reinforcement were used on site. These bands also function as thrust blocks.

A-195

PREDICTING THE "1000-HOUR" TEST ACCORDING EN 1852-1 OF VIRGIN AND POST-CONSUMER RECYCLED POLYPROPYLENE GRADES AND CORRESPONDING MIXTURES

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Engineering structures like pipes depend critically on a material's resistance to slow crack growth (SCG) [1]. Although long-term performance of polyolefins has significantly improved over last decades, recycled materials present new challenges due to the unpredictable effects of polymeric or non-polymeric impurities. A recent study has shown that even minor variations in the size of non-polymeric impurities can drastically affect a structure's lifespan [2]. A 400 μm defect size instead of a 100 μm would turn a "PE100-like" grade into a "PE63-like" grade. Thus, traditional material tests are increasingly inadequate in capturing the full impact of impurities on SCG performance.

To address this, current standards rely on product-level tests for non-pressure pipe applications made from recyclates. For example, the "1000-hour" internal pressure test according to EN 1852-1 for PP sewer pipes. However, since waste streams are highly variable [3], resulting post-consumer recyclate batches also tend to be highly inconsistent. This is even the case for materials coming from the same recycler and processed in an identical way [4]. "Trial and Error" testing on product-level of each batch and each blend made thereof, on the other hand, is a highly uneconomic and not sustainable.

To overcome these limitations, a data-driven, numerical approach is used to simulate the "1000-hour" test on the basis of short-term tests and by determining the maximum defect sizes of a material. This approach represents a transformative shift of plastic pipe industry towards greener testing strategies due to considerable savings in production and energy costs to otherwise maintain large numbers of product tests.

A-199

DESIGN CHARACTERISTICS OF HIGH-DENSITY POLYETHYLENE FOR LARGE DIAMETER PRESSURE PIPE

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High density polyethylene resin designed for pressure pipe applications have seen multiple breakthrough innovations in the last few decades. The multimodal resins designed by major polyolefin companies provide excellent balance of resistance against slow crack growth, ductile failure due to long term hydrostatic pressure, and rapid crack propagation resistance. Balancing these properties require an intricate balance of molecular weight distribution and comonomer distribution in the resin. The designed high-density bimodal products offer extended design life, high pressure rating, and sag resistance. Achieving optimal performance properties requires controlled microstructural characteristics, which are significantly influenced by the catalyst type and process technology used in resin manufacturing.

This study systematically establishes correlations between the microstructural characteristics of seven commercially available bimodal PE resins, produced using either dual slurry or gas phase reactors, and their performance properties. Comprehensive microstructural characterization was conducted using GPC-IR (high-temperature gel permeation chromatography coupled with an infrared composition detector), 13C NMR (nuclear magnetic resonance), TREF (temperature rising elution fractionation), and DSC (differential scanning calorimetry). We also measured mechanical, thermal, and rheological properties, focusing on crystallization kinetics, density, slow crack growth resistance (PENT and strain hardening modulus SHM), and low-frequency shear rheology.

Comparisons were made between key properties of interest, including slow crack growth resistance and low-frequency rheology, both relevant for sag resistance, and microstructural characteristics. Theoretical and empirical correlations based on phenomenological models were employed for the analysis. The study identifies critical levels of short and long chain branching, as well as molecular weight distribution characteristics, essential for producing bimodal PE-4710 certifiable high-density polyethylene resins with low sag resistance. These design principles provide a foundation for efficient reactor recipe design and post-reactor modification processes, advancing the development of pressure pipe polyethylene resins and paving the way for next-generation pressure pipe grades.

A-202

NEW TECHNOLOGY FOR IMPROVEMENT OF STRENGTH OF EXTRUDED INLINE SOCKETS ON DOUBLE WALL CORRUGATED PIPES

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Extruded, in-line sockets in corrugated pipe systems show certain weaknesses in their resistance to external pressure compared to injection-molded sockets. They tend to deform. This usually occurs when these pipes are stored, especially if the storage and proper handling requirements are not followed.

A new technology for producing these sockets allows the implementation of a significantly more robust design without negatively affecting the production output of the corrugated pipe production line. This is achieved, both by an advanced design of the socket and by the introduction of a new cooling system for corrugated pipe production lines.

A-205

ASSESSING ENVIRONMENTAL IMPACTS OF CIRCULAR PE-X PIPES

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PE-X pipe solutions have enabled comfortable heating and safe plumbing with a successful 50-year track record. However, due to the specific material characteristics of PE-X, mechanical recycling of PE-X waste currently enables only downcycling to other product systems. Advanced recycling methods are needed for closing the raw material loop and re-using PE-X scrap as a raw material for new pipes. It has already been demonstrated that chemical recycling can close the loop with non-mechanically recycled PE-X waste to produce a high quality, drinking water safe PE-X pipe system.

In this paper, findings from a comparative life cycle assessment (LCA) focusing on PE-X manufacturing and recycling are presented. The study was with the aim to provide detailed information about potential environmental impacts of closed loop recycling of PE-X scrap. To understand the performance of chemical recycling, results are compared with two alternative raw material sources: primary fossil-based and biobased plastics.

Several future alternative raw material sources are needed for PE-X pipes. The aim of this study is to understand the differences in environmental performance of different raw material sources and closed-loop recycling. This information is necessary for guiding future R&D activities, and to minimize total environmental burdens.

The LCA is conducted following the main principles of the ISO14040-44 standards, using the Product Environmental Footprint (PEF 3.0) impact assessment method, and adapting the requirements to those of EN15804 standard for construction products. All 16 environmental impact categories from the PEF are considered, to create a comprehensive view of environmental impacts and to identify potential hotspots. Primary data for the main processes is collected from the project partners.

The studied system comprises organizations from all steps of the closed-loop recycling value chain: PE-X pipe production and resulting manufacturing waste, breaking down the waste polymers into their building blocks, refining the liquefied waste plastic processes it, polymerizing the feedstock into cross-linkable PE, and finally utilizing the recycled raw material and manufacturing the final crosslinked PE-X pipe product.

A-206

HIGHER QUALITY RECYCLATES FOR PIPE APPLICATIONS BY IMPROVED MECHANICAL RECYCLING

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The plastics industry, including the pipe industry, is faced with the challenge of using recyclates in new products while maintaining the same quality [1]. Common problems with recycled plastics include contamination and degradation, which can reduce performance and long-term stability [2]. However, even if these issues are tackled, the mixing of different grades of the same polymer also poses problems. When different grades are mixed, the tailored properties of the individual grades are lost and the recyclates can usually only be used in less demanding applications or added in small quantities to virgin materials. However, to be used in more demanding applications, such as pipe applications, recyclates must fulfil specific requirements [3].

The aim of this work is to improve the quality of polypropylene (PP) recyclates so that they can be used in a wider range of applications and in higher amounts. Common problems with PP recyclates are the low viscosity (i.e., high MFR) and the loss of the tailored properties of PP homopolymers, block- and random copolymers, i.e., high stiffness and high impact strength, respectively [4]. The state-of-the-art method for sorting plastics are near infrared (NIR) sorting lines. These currently do not distinguish between different PP types and grades. In this work, data from NIR sensors from industrial sorting lines are used to build new sorting models to investigate the possibility of separating PP waste by grade. The goal is to be able to produce recyclates with lower MFR values and to separate between the different PP types (homopolymer, block- and random copolymer). The classification with the newly developed models showed promising results. Separation of PP waste into the different types and grades would be an important step towards higher quality PP recyclates that can be used in greater quantities in plastic pipes.

A-208

THE IMPACT OF DIFFERENT WAYS OF MEASURING THE NOTCH DIMENSIONS IN CRB TEST

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In order to provide an accelerated test method to characterize the relevant long-term failure resistance of thermoplastic pipe materials against slow crack growth (SCG), the Cracked Round Bar (CRB) test was developed and standardized in ISO 18489. The standard is currently under revision where the importance on how to measure the actual notch depth is stressed, so that the real stress applied on the sample can be evaluated.

This paper will discuss the practical challenges when measuring the notch depth after the CRB test with a PE-RC material. Precise notch measurement is crucial as it directly affects the real applied stress and the subsequent stress intensity factor (K) which results in different fracture behavior. Small discrepancies in notch depth, width, and shape can lead to misrepresenting the material's resistance to crack initiation and growth. The findings underscore the necessity for standardized notch measurement protocols to ensure consistency and reliability in testing of the resistance to slow crack growth.

The paper is composed of three separate parts:

1. Different ways to analyze a notch using a microscope;
2. Comparison of the initial crack length when measured in different ways;
3. Impact on the end result. The work is applicable to other materials.

A-210

NEW EU REPRESENTATIVE ENVIRONMENTAL DATASETS (LCIS) FOR RECYCLED PVC (FLAKE & MICRONIZED POWDER)

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Exchanges between TEPPFA, PlasticsEurope, VinylPlus and EUPC experts hinted at the lack of reliable, up-to-date Carbon Footprint values for rPVC used in PVC pipes in Europe to support EPD developments according to EN 15804 A2+:2019.

Preliminary analysis indicated a very limited number of, old, scattered and not very well documented sources at EU or national level. Therefore, it would be highly useful to get updated & harmonized European datasets for r-PVC grades.

Consequently, TEPPFA decided to start developing EU representative Lifecycle Inventories (LCI) i.e. generic datasets, for r-PVC grades used in EU pipe & fittings manufacturing and ecoprofiles including Carbon Footprint values. The project is co-funded by VinylPlus and TEPPFA and involves 4 PVC recyclers, ensuring a good geographical & technological representativeness of the generated datasets.

An 1-to-1 internal enquiry among TEPPFA members, in compliance with EU competition rules, concluded that r-PVC micronized powder between 500µm & 650 µm was the most used feedstock, either purchased directly from recyclers or flakes milled internally or externally into micronized powder. Therefore, it was decided to develop 2 r-PVC LCIs, 1 for micronized powder and 1 for flakes, compliant to the ILCD Entry Level Requirements and directly usable for EPDs. A Technical report explaining how the datasets have been generated will be part of the deliverables. A third-party review of the datasets and the LCA model will be performed and the LCA study will be compliant with ISO 14040/44.

The project outcome will allow some flexibility as the user will be able to associate a specific electricity mix to get Carbon Footprint values reflecting where flakes are produced or milled.

The paper will present the methodology followed, present the main LCIA indicators for both r-PVC grades and make the connection with EPDs & the new CPR environmental indicators reporting obligations, which will progressively apply to construction products

A-211

INFLUENCE OF SERVICE LATERALS ON THE SEISMIC RESPONSE OF HDPE PIPES

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There are two main seismic hazards for buried pipelines, wave propagation and permanent ground deformation. Both involve deformation of the soil surrounding the pipeline, which in turn imposes a deformation on the pipe itself. The more important of these ground-imposed deformations is axial rather than flexural, inducing axial tension or axial compression in the pipeline. As a result, one of the key parameters controlling the seismic behavior of buried pipelines is the axial soil friction force per unit length τ_u.

The soil friction τ_u is an increasing function of the pipe diameter, pipe burial depth, unit weight of soil, and the friction coefficient at the soil-pipe interface. It has been widely used by lifeline earthquake engineers since the 1970's. However current relations for τ_u assume there are no service laterals or other pipes connected to the pipeline of interest. As one might expect, the presence of an interconnecting pipe at nominally 90˚ to the pipeline of interest tends to increase the effective soil friction acting upon the pipeline of interest.

The paper will develop a modification factor to account for the presence of service laterals upon τ_u. It will be assumed that there is a fixed connection (no relative rotation) between the service lateral and the pipeline on interest. It will be shown, as one might expect, that the modification factor increases τ_u, and itself is an increasing function of the service lateral diameter, wall thickness, burial depth and soil unit weight. The modification factor is a decreasing function of the spacing between the laterals.

A-212

TOWARD A COMPREHENSIVE UNDERSTANDING OF THE GRAFTING & CROSSLINKING OF POLYETHYLENE USING THE SIOPLAS SYSTEM FOR THE PRODUCTION OF PEX PIPE

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There is a growing demand for plastic pipe, particularly pipe able to be used under continuous pressure at elevated temperatures. Crosslinked polyethylene (PEX) has become the preferred material in elevated temperature applications, particularly to produce pipe & tubing used in residential potable water applications in many regions worldwide. Several processes have been developed to produce PEX. One popular method developed in 1967 and commercialized about 1990 is the Sioplas system where vinyl trimethoxy silane (VTMOS) is grafted to polyethylene (PE) and subsequently crosslinked. Cross-linking is carried on when a catalyst & stabilizer masterbatch is extruded together with the grafted PE to produce pipe and then crosslinked with heat & humidity. Increased demand for PEX has created an environment that can support research into improved grafting, cost reduction, improved productivity and improved product quality. here are a significant number of scientific works published examining the PE-VTMOS grafting process and grafted PE crosslinking. However, the experiments described in these publications were often carried on in laboratory conditions and only a limited number of works used reactive extrusion, and the extruders used were rather small. Grafting kinetics depend on reaction conditions which will vary between laboratory and large commercial equipment. For this reason, our research was focused on data obtained using a commercial size extruder designed for PE grafting and a factory commercial set up for PEX pipes production.

This paper presents an increased understanding of the technology used to produce, on a commercial scale, PEX compounds for pipes in the Sioplas process and extrusion the pipes. Understanding of silane grafting enabled identification of existing process shortcomings and introduction of improvements. Our interests were by-product formation reactions, elements of chemistry kinetics and the final composition of the grafted PE. FTIR spectrometer, DSC and DMA methods are used.

Specific insights gained will be presented as follows:

- Similarities in composition of the PEX-b resins designated for manufacturing pipes and made by different manufacturers globally;
- Presence of free VTMO monomers and oligomers in grafted PE;
- Extension of grafting reactions during pipe extrusion process;
- Analysis indicates the likely presence of grafted VTMO dimers and trimers in the grafted PE.

A-214

RESISTANCE OF POLYPROPYLENE RAISED CRACK AND TEMPERATURE RESISTANCE (PP-RCT) TO CHLORAMINE SOLUTIONS

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As the market for polypropylene (PP) pipe continues to grow in North America, so too has the diversity of applications for which it is used. While the resistance of pipes and fittings produced from PP-RCT to chlorinated water has been well-documented using the test protocol of ASTM F2023, extensive interest has been expressed in the resistance of these piping products to solutions of chloramine. Chloramine is generated in hot water in many municipalities due to the addition of both sodium hypochlorite and ammonia to the public water supply. Chloramine resistance is of particular importance to hospital environments where solutions of chloramine are often self-generated and widely used as disinfectants.

While the resistance of PP-RCT pipes and fittings to chlorinated water has been extensively researched, very little data has been generated specifically on chloramine solutions. Currently, industry practice is to make a comparison to research that was conducted on the resistance cross-linked polyethylene pipes (PEX) to chlorinated water and chloramine. In that study, it was concluded that “Based on these results, it is the position of PPI BCD that chloramines are less aggressive than free chlorine to PEX pipes and tubing. Testing of oxidative resistance using free chlorine, in accordance with ASTM F2023, will provide a conservative estimate of the time-to-failure for PEX pipes and tubing when used with the disinfectant chloramines.”

The resistance of PP-RCT pipe to chlorinated water has been determined by industry practice in accordance with ASTM F2023. As a result, industry practice is to simply state that the resistance of PP-RCT to chloramine is “better” than its resistance to chlorinated water based on the research conducted on PEX and published as PPI Statement A. Yet, hard data does not exist. This paper will describe a collaborative research effort in which the chloramine resistance of pipe produced from PP-RCT is being researched. Using newly acquired test equipment, a design of experiment has been structured to clarify the resistance of PP-RCT pipe and tubing to chloramine solutions at elevated temperatures. This paper will discuss in detail the test protocol undertaken and present the test results obtained to date. It is anticipated that the test results obtained can be used to broaden the use of PP-RCT pipe and fittings in healthcare and related industries that rely on chloramine disinfection methods.

A-215

THE IMPACT OF COMONOMER ON HIGH TEMPERATURE PERFORMANCE OF POLYETHYLENE OF RAISED TEMPERATURE (PE-RT) RESINS

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Polyethylene of Raised Temperature (PE-RT) pipes have been used in domestic hot and cold-water piping systems for decades. PE-RT resins meet the requirements of ISO 22391, providing elevated temperature performance without the need for crosslinking. PE-RT offers several advantages over traditional materials such as copper, iron, and steel, including durability, flexibility, lightweight, and recyclability [1].

Polyethylene (PE 100) pressure pipe materials are high-density polyethylene resins with a base resin density ranging from 0.940 g/cm3 to 0.949 g/cm3. The density of PE materials is commonly controlled by the introduction of an alpha olefin comonomers such as butene, hexene, or octene. In PE-RT, hexene and octene are the most common comonomers.

The probability of tie chain formation within the resin is influenced by the amount, type, and statistical distribution of comonomer. These tie chains improve mechanical performance, such as tensile strength and elongation, as well as slow crack growth, which can be observed in the Strain Hardening Test, Cracked Round Bar test, or accelerated Full Notch Creep test [2]. Moreover, comonomer type affects the regression line, particularly at elevated temperatures.

This work compares resins prepared with similar densities using hexene and octene comonomers. The effects of the comonomers on the thermal stability of a pipe, performed at elevated temperature and pressure and the slow crack growth (SCG) are investigated.

A-216

25 YEARS OF COLLABORATIVE EFFORTS TO SUPPORT THE PE100 PIPE INDUSTRY

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The PE100+ Association was founded on 24th February 1999 by Borealis, Elenac, and Solvay. It currently has a diverse international membership consisting of 15 companies located in Europe and across Asia. The association is supported by an Advisory Committee of independent experts and collaborates with other trade associations. It also has a Technical Committee consisting of material and pipe experts from the member companies. With the support of the Advisory Committee and the Technical Committee, the association aims to ensure consistent quality in the production and use of pre-compounded PE 100+ pipe materials. These activities include promoting the use of PE pipe systems, providing information support to end-users and building global trust in high-quality pre-compounded PE materials.

This paper will provide a comprehensive overview of the PE100+ Technical Committee activities, which support different aspects of the industry including test method development, standardization, technical communications and responses to technical queries from across the value chain. It covers the committee's significant activities over the last 25 years, with focus on the past decade. These have included the support provided to the development and revision of key ISO standards such as:

- ISO 13479 Notched Pipe Test (NPT);
- ISO 18488 Strain Hardening Test (SHT);
- ISO 18489 Crack Round Bar Test (CRB); and
- ISO 16770 Full Notched Creep Test (FNCT).

The paper will also highlight the results of several round robin tests managed by the committee with the assistance of KIWA, the results of the hydrogen gas permeation project and discuss ongoing and future projects aimed at enhancing the performance and reliability of PE100+ materials. In summary, the paper will provide insights into the collaborative efforts and technical achievements of the PE100+ Association in advancing the standards and practices for polyethylene pipe systems.

A-218

PLASTIC PIPES IN SUSTAINABLE INFRASTRUCTURE: DISPELLING COMMON MISCONCEPTIONS

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Plastic pipes have faced scrutiny from NGOs over alleged safety and environmental issues, influencing decision-makers, specifiers, and public perception. These claims may lead to preferences for alternatives like ductile iron, which have higher environmental footprints.

In response, PVC4Pipes and VinylPlus – the European PVC industry's commitment to sustainable development – have countered misinformation by providing robust evidence from academic research and trusted sources, confirming that modern PVC pipe systems meet stringent safety and environmental standards.

Drawing on findings from the European Chemicals Agency (ECHA) in 2023, which affirmed that risks associated with PVC production are adequately controlled, VinylPlus launched an infographic in late 2023 and a comprehensive Q&A in 2024, both multilingual. These resources addressed NGO concerns, including PVC pipe safety, and were made publicly available on websites and disseminated through newsletters to the European PVC value chain. From there, they cascaded further through industry networks, reaching specifiers, customers, and end users.

To amplify impact and reinforce confidence across the value chain and market, these materials were central to targeted social media campaigns that successfully rebutted misinformation, engaged diverse audiences, and promoted evidence-based narratives.

The campaigns clarified PVC's compliance with regulatory standards and highlighted its advantages: durability, cost-efficiency, eco-efficiency, and suitability for applications including drinking water, sewage, irrigation, hydrogen, biogas, cable protection, and rainwater management.

This approach demonstrates how coordinated communication strategies, rooted in transparency and data, can effectively counteract misconceptions and support balanced decision-making in sustainable infrastructure development. It serves as a model for other materials facing similar challenges.

A-219

HOW CHINA'S PLASTIC PIPE INDUSTRY IS PREPARING TO BE SUSTAINABLE

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In recent years, many countries have formulated a series of environmental protection policies and green sustainable development goals. The United Nations is also working on ending plastic pollution (including marine environmental pollution), and INC-5-1 will be held in 2025. These new situations have had a great impact on the application and development of plastic products.

How the plastic pipe industry can better adapt to the requirements of relevant environmental protection policies and promote the healthy development of the industry from upstream raw and auxiliary material supply, pipe production to market application, and post-waste disposal is a topic we need to focus on. Since 2022, CPPIA has issued the "Outline for Green Development of China's Plastics Industry" to contribute to the realization of carbon peak and carbon neutrality goals. Jointly promote new technologies and methods for the treatment of recyclable, recyclable and degradable waste plastic pollution with upstream and downstream of the industrial chain, advocate green design, add material and recyclability regulations to the product standard logo, promote the full life cycle assessment management of plastic pollution and the coordinated governance of all links in the whole chain, and promote the green ecological cycle and sustainable development of the entire plastic industry chain.

A-220

APPLICATION CASE OF HDPE SIPHON RAINWATER SYSTEM ON THE ROOF OF LARGE INDUSTRIAL BUILDING

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The HDPE siphon rainwater system features a smaller suspended pipe diameter, greater installation flexibility, and horizontal laying capability, thereby enabling conserving vertical space in industrial buildings. Due to the fast water flow velocity of HDPE siphon rainwater system, the number of suspended pipes, drainage risers, and outlet pipes can be reduced, which can save industrial building space and reduce investment costs. In the meanwhile, it can satisfy the safety requirements of large building roof structures.

This project is a large industrial building located in a rainy city in Guangdong province, with a complex roof structure and a roof area of 59362.59 m2. With a 10-year recurrence interval, the 5-minute rainfall intensity reaches 608 L/(s·ha). To meet design and usage requirements, the project was ultimately designed with 14 catchment areas, 47 HDPE siphon rainwater systems, 208 siphon rainwater hoppers, and 10 rainwater overflow systems. The suspended pipes range from De110 (4.2 mm wall thickness) to De250 (9.6 mm wall thickness). And all pipes in both siphon rainwater systems and rainwater overflow systems are constructed of HDPE. Water flow velocities range from 1.17 m/s to 5.86 m/s.

The practical application demonstrated exceptional performance over the course of the previous year, showcasing its remarkable capabilities in real-world scenarios.

A-221

EVALUATION OF THE HYDRO-AXIAL STRESS RUPTURE TEST FOR PE100 BUTT FUSION JOINTS

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The hydro-axial stress rupture (HASR) test method evaluates the uniaxial creep strength of butt fusion joints by applying hydrostatic pressure at a specified temperature. A new work item proposal for the standardization of this test method, ISO/NP 19251-2:2024, has been accepted for further development and standardization under ISO TC 138/SC5/WG17.

In contrast to traditional mechanical tests that subject only a small portion of the weld area to axial or bending loads, the HASR method utilizes the entire weld area. This approach captures potential welding defects across the whole weld. The testing assembly restricts hoop stress, allowing the butt fusion joint to elongate mainly in the axial direction, thereby ensuring that failure occurs precisely at the weld area.

In the current study, the effectiveness of this test method was assessed for PE100 pipes with diameters ranging from OD 63 mm to OD 250 mm. The evaluation incorporated intentionally added welding flaws, including recycled materials in monolayer and multilayer pipe structures. Additionally, the impact of the welding bead on creep rupture behavior was examined both with and without its presence. The findings offer valuable insights into the reliability and efficacy of the HASR method in assessing welding performance in plastic pipe assemblies. Furthermore, it elaborates on how this test method can be utilized for weld qualification and its potential benefits for researchers developing new welding procedures for novel materials.

A-230

SUCCESSFUL IMPLEMENTATION OF PLASTIC PIPES IN MINE SUBSIDENCE AREAS

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The paper investigates the implementation of polyethylene (PE) pipes for pressure sewer systems in mine subsidence areas, addressing the challenges posed by ground movements from longwall mining. The compressive or tensile strains from mine movements can be as high as 5 mm/m which can be induced to the pipe. By analyzing the structural and hydraulic performance of PE pipes (DN125-DN500) under such conditions, the study identifies stress factors due to mine subsidence, including longitudinal strains and their impact on pipe pressure ratings. Utilizing both open trench and Horizontal Directional Drilling (HDD) installation methods, the research employs numerical simulations to evaluate pipe-soil interactions and verify compliance with AS/NZS4130 standards. Results indicate significant stress-induced pressure capacity reductions, termed "capping reductions," which vary by installation method. The findings highlight the critical need for robust design strategies to mitigate subsidence effects, ensuring pipeline safety, serviceability, and economic repairability in challenging mining environments.

A-231

THE USE OF HDPE CORRUGATED PIPES IN MICROTUNNELING

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The integration of High-Density Polyethylene (HDPE) corrugated pipes and micro tunneling technology in sewage and storm water piping systems offers significant advantages in terms of durability, efficiency, and environmental impact. HDPE corrugated pipes are known for their high strength-to-density ratio, flexibility, and resistance to corrosion and chemical reactions, making them ideal for long-term use in harsh underground environments. Their lightweight nature also facilitates easier handling and installation, reducing labor costs and time.

Micro tunneling, a trenchless construction method, further enhances the benefits of HDPE pipes by minimizing surface disruption and environmental impact during installation. This technique allows for precise and controlled pipe placement, even in challenging soil conditions, and is particularly advantageous in urban areas where traditional open-cut methods would be impractical or disruptive. The combination of HDPE corrugated pipes and micro tunneling results in a robust, cost-effective, and sustainable solution for modern sewage and storm water management systems, addressing both current infrastructure needs and future demands.

This paper aims to highlight the perceived and actual advantages of using HDPE corrugated pipes in micro tunneling. To achieve this, it will present three different cases of HDPE corrugated pipes encased in concrete and installed via micro tunneling in various locations/projects in Abu Dhabi, the capital of the UAE.

The cases include a) Avoiding disturbance to a busy road leading to an industrial area, b) Preserving a beautifully landscaped residential area of villas where intervention is not allowed, and c) Connecting a residential island's expanding sewage mainline to Abu Dhabi's city-backbone sewage network.

In these scenarios, the trenchless installation of HDPE corrugated pipes proved to be the best, fastest, most reliable and ultimately the only alternative. These pipes were installed in challenging terrains, such as beneath a water canal at great depth, under busy roads at shallow levels, and in loose soil conditions. They were pushed through using No-Dig techniques, applying high loads and horizontal forces from manhole to manhole.

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100 YEARS LIFETIME OF POLYETHYLENE PIPES – A REVIEW

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The lifetime of plastic pipes has been a key topic of discussion over recent decades. For pressure applications, international standards typically define a design life of 50 years. In contrast, no such reference is provided in standards for non-pressure applications. Despite this, it is widely believed that the standards governing plastic pipes are intentionally conservative, which ensures safety and reliability under real operating conditions - Thereby, minimizing the risk of premature failures in both pressure and non-pressure systems. As a result, the actual service life of plastic pipes, in this study focused on polyethylene, may substantially surpass the 50-year design benchmark. This review study will explore the possibility for lifetimes of polyethylene pipes for up to, or even beyond, 100 years.

Based on the results of all examined studies and our judgment of the procedures used in those studies, the following can be concluded. As long as all steps in the process of design, manufacturing, trenching, and operating conditions follow currently valid EN and ISO standards for pipes, fittings and valves and installation of the plastic pipe systems, the actual lifetime of polyethylene pipes can be expected to be well above 100 years.

This contribution is based on a recent meta-study commissioned by TEPPFA (1), which examined existing literature to explore the possibility of extending the expected service life of plastic pipes to 100 years or even more.

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USING HDPE PIPE TO PRESERVE THE GREAT SALT LAKE

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The North Davis Sewer District (NDSD) collects and treats wastewater from the cities of Clearfield, Clinton, Layton, Roy, Sunset, Syracuse, West Point, and Kaysville. The current NDSD facilities treat up to 34 million gallons per day (MGD) prior to discharging into Farmington Bay of the Great Salt Lake (GSL). NDSD began investigating methods to meet stricter nutrient load requirements implemented by the State of Utah.

The pipeline consists of approximately 6.25 miles of 63-inch (1600mm) diameter High Density Polyethylene (HDPE) Diameter Ratio (DR) 26 pipe, three stainless steel (SST) air vents, one SST access manway, a buried SST tee for potential future connection to Ogden Spur, a concrete outfall and energy dissipation structure, and a rip-rap channel. Effluent will be discharged to the GSL via a new outfall located approximately 5.5-miles from the entrance to Antelope Island State Park on the north side of the causeway. This outfall location was selected to provide mixing with the main body of the GSL and prevent unmixed water from flowing back into Farmington Bay through the causeway bridge. Design considerations, corrosion mitigation, geotechnical evaluations, as well as pre-construction, manufacturing and shipping coordination.

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THERMOPLASTIC BOXES: THE EVOLUTION OF POLYPROPYLENE STORMWATER RETENTION AND DETENTION SYSTEMS

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Climate change has led to more intense and frequent significant weather events that has stressed our current infrastructure systems. The on-site retention or detention of the runoff from these events has made it imperative to minimize the impact of flooding to communities and on the roadway, facilities serving them. These systems can also retain water to provide necessary irrigation and groundwater replenishment during droughts. Historically, these systems have been manufactured using either concrete or metal materials. With the greater use of thermoplastic materials for underground piping and storage, a new opportunity has opened for these applications. Thermoplastic polypropylene boxes or crates, as they are known in some parts of the world, provide the maximum storage capacity for the least amount of structure. They do, however, present unique challenges for design, testing and manufacturing that have typically not been associated with pipe products used for these applications. Polypropylene boxes have the greatest historical use in Europe, but their expansion worldwide has been met with some level of apprehension in areas still dominated by more traditional materials. This paper will present the design and manufacturing basis of these products as specified in the ISO and EN standards and the challenges that still remain on expanding their adoption in other parts of the world. By addressing the concerns that have been raised by other standards organizations, specifically in the Western hemisphere, the uniform acceptance of these products worldwide can be achieved. Ideally, the same requirements for design, testing and manufacturing of these systems would serve the users with a consistent product and one that can easily be manufactured anywhere in the world.

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ANALYSIS OF NARROW TRENCH IMPACTS ON POLYETHYLENE PIPELINES

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In the construction industry, it is common practice to adhere strictly to published minimum trench widths1 without consideration for the option and potential advantages of narrower trench dimensions. This paper aims to illustrate the design parameters and benefits of installing pipelines in narrower trenches. It addresses key design considerations including reduced deadloads on pipes through optimized trench width1, the use of resilient soil modulus options for backfill materials, and effective methods for backfill placement. Installing pipelines in narrow trenches can be particularly advantageous in scenarios involving utility conflicts, high backfill costs, accelerated construction, and the minimization of haul-off operations.

To assist individuals considering the design and installation of pipelines in narrow trenches, this paper reviews the historical context of trench width, identifies circumstances in which narrow trenches should be utilized, provides methodologies for calculating the combined soil modulus (Msn/Msb)3, discusses suitable materials for narrow trench applications, and outlines techniques for backfill placement. Additionally, the paper will examine existing standards that specify minimum trench widths and offer recommendations for improving these standards.

A-240

INTERNATIONAL ROUND-ROBIN TESTING OF NON-DESTRUCTIVE TEST METHODS FOR POLYETHYLENE BUTT FUSION JOINTS

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The development of reliable non-destructive testing (NDT) methods for polyethylene butt fusion joints has become a necessity to ensure the integrity of PE pipelines. The industry has been working on developing the inspection capability of phased array ultrasonic test (PAUT), time of flight diffraction (TOFD), and microwave imaging (MI) tests in assessing flaws in the joints for many years. All these efforts lead industry experts to develop ISO standards for these NDT methods for polyethylene electrofusion and fusion joints within the scope of ISO/TC138/SC5/WG17.

Results of a worldwide ISO round robin study on phased array ultrasonic non-destructive test for electrofusion socket joints were published at PPXX in Amsterdam. It has significantly contributed to the development of “ISO/TS 16943:2023 Thermoplastic pipes for the conveyance of fluids — Inspection of polyethylene electrofusion socket joints using phased array ultrasonic testing”

In order to support development of “ISO/TS 22499:2024 Thermoplastic pipes for the conveyance of fluids — Inspection of polyethylene butt fusion joints using phased array ultrasonic testing”, a worldwide inter-laboratory round-robin test on PAUT, TOFD, and MI was carried out at ISO/TC138/SC5/WG17 working group using polyethylene butt fusion joints containing normal weld, particulate contamination, and cold weld, following single low pressure (SLP), dual low pressure (DLP) and single high pressure (SHP) welding procedures. NDT test results were compared with several destructive test methods, including the waisted tensile test (WTT), high-speed tensile impact test (HSTIT), low-temperature tensile test (LTTT), modified side bend test (mSBT), and guided side bend test (GSBT). Results of this round robin work have significantly contributed to setting the requirements of non-destructive testing procedure qualification.

This report contains the results of this round-robin work, comparing the performance of each non-destructive and destructive test methods in capturing flaws in butt fusion joints.

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SUSTAINABLE POLYOLEFIN FEEDSTOCK FOR VARIOUS PIPELINE PROJECTS

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A key future challenge is the reduction of CO2. Therefore, the target is to keep the fossil energy carriers like coal, oil and gas in the ground and avoid further increase of global warming through the use for transport, heating and in the chemical industry.[1],[2]
Oil derived from naphta and natural gas from the purified gases ethane and propane are currently the main feedstocks for the Polyethylene and Polypropylene production. The Polyolefin industry has identified at least two workable solutions:

Renewable natural feedstocks for the polymer production can come from used cooking oil, residues of the vegetable oil production which are not suitable for consumption, by-products of the pulp industry or from direct CO2 capture.

The second alternative for feedstock is recycling. Especially chemical recycling plays a crucial role to provide recycled feedstock for demanding or high purity applications. Various plastics are collected, sorted and fractions which cannot be mechanically recycled like multilayer films, crosslinked or heavily contaminated materials enter the pyrolysis process which can be carried out using green energy.[3],[4] In the pyrolysis process the polymer chains are broken down and converted back to gases, which can be separated into ethylene, propylene and other chemical components still usable for the chemical industry.

In both cases the feedstock for the production of polyethylene and polypropylene does not differ from the fossil sourced C2 and C3 molecules.

The paper describes various pipeline examples where utility companies for water and gas were interested to establish first demo and evaluation cases. They are in request to reduce their CO2 footprint and one way is to use sustainable pipe systems for their projects. The presented examples are from the pipe industry, but the use of materials based on renewable feedstock or chemical recycling is applicable to other polymers as well as other industries and applications such as packaging, automotive or medical.

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UNDERSTANDING THE IMPACT OF THE NEW DRINKING WATER DIRECTIVE

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Directive (EU) 2020/2184, known as the “drinking Water Directive” (DWD), entered into force on January 12, 2021 following a recast of the original 1998 Drinking Water Directive. This directive aims to protect human health against the harmful effects of contaminated water and to improve the access to drinking water. Article 11 of the DWD sets out the framework for minimum hygiene requirements for materials in contact with drinking water by means of three Implementing Decisions and three Delegated Regulations published in the Official Journal on 23 April 2024.

The European Chemicals Agency (ECHA) is supporting the European Commission in this work by preparing:

- European positive lists of starting substances, compositions and constituents that are authorised for use in the manufacture of materials in contact with drinking water that can be found in Commission Implementing Decision (EU) 2024/367. The development of the EU positive list is performed on the basis of substances authorized according to Reg. (EU) 10/2011, the “4MS-Initiative” (4MSi) list and EU national lists. New requirements or more stringent limits might appear.

- Procedures for updating European positive lists through an application process described in Commission Delegated Regulations (EU) 2024/369.

- Risk assessment methodologies for reviewing starting substances, compositions and constituents that could be added to the positive lists.

After the first EU positive lists were published, ECHA will continue to keep these lists up to date by adding new entries and amending or removing existing entries. It will also be the responsibility of the producer of the substances to provide the adequate information on time via the ECHA IUCLID6 tool in order to maintain their substances on the positive list.

This presentation will focus on some of the key challenges from the DWD on the organic materials and more specifically on PVC products in drinking water applications. A survey performed by the Vinyl Industry highlighted that most of the substances used for the manufacturing of DW products are listed, though some crucial substances are either not listed or might have to be petitioned on a short notice. Additionally, some substances have been given much stricter requirements than in previous national legislations and adequate analytical methods might not be available. Proactivity and good communication across the operators of the vinyl industry will be needed to guarantee full compliance.

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THE NEW EU CONSTRUCTION PRODUCTS REGULATION (CPR) - WHAT IT WILL ENTAIL FOR PLASTIC PIPES?

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In the European Union, construction is subject to the subsidiarity principle: Works regulations (including buildings) are under the sole competence of Member States, through their national building codes while the common market for construction products is solely regulated at European level.

The existing EU Construction Products Regulation (Regulation (EU) 305/2011) has been recently updated by Regulation (EU) 2024/3110 of the European Parliament and of the Council of 27 November 2024. The regulation, published in the EU Official Journal on 18 December 2024, marks a pivotal step toward a sustainable, efficient, and harmonised construction industry in Europe. Although the text will enter into force on 7 January 2025, most provisions will only apply one year later and only progressively for all construction products, based on a prioritisation under the CPR Acquis Process, with a maximum transition period until January 2040 for the new CPR 2024 provisions to apply.

The EU Commission is working on a 1st CPR Working Programme (2026-2028) which will incorporate the list of construction product families for which harmonized technical specifications (hENs or EADs) will have to be developed in priority, based on Standardisation Requests either through the CPR Acquis “normal” route or through the “Fast-track” one.

According to the CPR Acquis Process, the main standardization Mandate for pipes (plastic, concrete, …) M131 has been prioritised by EU Member States as #31 out of 34 product families. Hence the system of voluntary EN & EN ISO standards for plastic pipes is still valid: plastic piping systems can still be specified, sold & used under existing approvals to recognised product standards in all EU Member States. The new provisions of the CPR 2024, including CE marking, will only apply to plastic pipes and pipes made of competing materials covered under the same Mandate, when harmonised technical specifications will be developed and cited in the OJEU (in an expected timeframe of about 7-10 years).

The paper will present the main novelties of CPR 2024 and what this will entail for plastic pipes when the CPR 2024 will be applicable to our product families. The CPR 2024 will be applicable to all construction products under its scope but does not cover hygienic requirements that are regulated under the EU Drinking Water Directive.

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MOBILE EXTRUSION TECHNOLOGY - A SUSTAINABLE CASE STUDY IN THE PRODUCTION, JOINING, AND INSTALLATION OF LONG LENGTHS OF HDPE PIPES IN A MINING APPLICATIONS

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At the 2021 PPXX Conference in Amsterdam, the concept of mobile extrusion technology was introduced into the North American pressure pipe market as an innovative means of HDPE pipe supply in regions of high demand. This technology which was owned by a New Zealand company at that time was subsequently sold to an American mining company which utilizes this technology to produce various lengths and sizes of HDPE pipe that are used in the production process. The technology services over 300 miles (>485km) of active mine piping and other process water pumping. Some of the conveyances are abrasive which requires frequent replacement. The unique mobile extrusion technology provides several benefits to the operation: production and deployment of long lengths of HDPE pipe requiring less fusion joints, quicker deployment, lower cost through vertical integration, transportation savings and economical substitution of steel pipe.

This paper/presentation describes the compliments of mobile extrusion technology to production, logistics, joining, installation, conveyance and sustainability of HDPE pipes' beneficial solutions for phosphate mining applications as well as solutions over previously used steel piping. This paper will contrast the positive solution and experience of HDPE piping systems since pilot testing began in 2021 as compared to some of the issues previously encountered when using steel piping systems for these demanding applications.

Furthermore, case studies with insights from the end user will be presented which examines specific mining projects in central Florida where 48" SDR 21 and 48" SDR 26 HDPE pipes (1200mm) were produced and installed for water conveyance and 30" SDR 11 HDPE pipes (760mm) for tailings conveyance. Also addressed is the planning, coordination, mobility and efficiency of site set-up of three production lines which service the expansive land mass of three integrated mines.

Finally, the sustainability vision is reviewed through processes of harvesting worn pipe and the introduction of greater re-grind material into the final pipe product.

A-249

IMPROVING ELECTROFUSION (EF) PEEL DECOHESION WELD TEST INTERPRETATION THROUGH COLLABORATION AND EDUCATION

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Electrofusion has been used since the 1970s and has grown in popularity. Millions of electrofusion joints are installed worldwide each year, making it a critical technique for maintaining the integrity of PE piping systems.

In Australia over 150,000 tons of PE100 pipes are installed annually. The electrofusion process is used and when executed correctly results in a safe, reliable, and cost-effective means of joining and connecting to PE piping systems.

Assessment of EF welding reliability commonly requires destructive testing to be undertaken to evaluate weld integrity by accredited laboratories. This is typically done using the method detailed in ISO 13954 *Plastics pipes and fittings — Peel decohesion test for polyethylene (PE) electrofusion assemblies of nominal outside diameter greater than or equal to 90 mm*. Visual inspection of a fracture surface is required to determine if adequate fusion has been achieved across the weld interface.

Globally it has been recognized there is insufficient guidance on correct evaluation of the different fracture surfaces. This has sometimes led to misinterpretation of peel decohesion results by testing laboratories. In Australia, false negative test results reported by some testing laboratories has led to the condemnation of good welds. This has been a contributing factor in both welding contractors and water asset owners losing faith in the EF welding process and specifying alternative means of jointing.

Revision of ISO 13954 is currently underway and is expected to address some of these concerns. However, in Australia the industry needed to act with greater urgency because the national accreditation body was concerned that laboratories delivered different results for the same test pieces.

The industry association developed a guideline to assist with the interpretation of the peel decohesion test. This resulted in the publication of POP020 *'Principles of polyethylene (PE) electrofusion welding and assessment'*. In addition, a collaborative education programme between the industry association and national accreditation body was delivered nationally to laboratories accredited for EF peel decohesion testing.

This paper describes the development and implementation of industry guidance for EF weld assessment to re-build confidence in electrofusion.

A-250

COMPARING THE ENVIRONMENTAL IMPACTS OF DIFFERENT PIPING SYSTEMS

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Life Cycle Assessment (LCA) studies and Environmental Product Declarations (EPDs) for building products, including pipes, are becoming increasingly available as suppliers recognize the need to understand the environmental impact of their products.

EPDs provide transparent and independently verified information about the environmental impacts of these products. As users become more familiar with EPDs, the ability to select products that contribute to reducing the carbon footprint of a project becomes one of the drivers of sustainable procurement. However, the complexity of the information means that making meaningful comparisons can be problematic.

The plastic pipes industry association in Australia needed to understand how plastic pipes compared to alternatives and the significance of the differences. This included having the ability to communicate these impacts and importantly put them in context for a wider audience who may not have the level of experience with EPDs and their environmental indicators. To do this an independent third party was engaged to use published EPDs for different piping materials to compare the relative performance over commonly identified impact categories.

Systems that were studied included stormwater drainage pipes, water reticulation systems and pipes in buildings, comparing piping systems commonly used in Australia.

After considerable effort, comparison reports for drainage and infrastructure have been finalized. While some adjustments were required to align different EPDs, these documents provide valid and meaningful comparisons of pipe alternatives. Unfortunately, the comparison report for the built environment had to be shelved pending availability of better data as too many assumptions would have been required.

This paper describes the development of the pipe environmental comparisons and highlights some of the key outcomes. Whilst this work applied to various plastic pipe materials this paper focuses on polyethylene (PE) pipes.

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CIRCULARITY OF PLASTIC PIPES IN AUSTRALIA

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In both Australia and globally, there is an increasing emphasis on sustainability, with a strong push toward transitioning from a linear to a circular economy. However, despite the growing focus on this shift, many stakeholders still lack a clear understanding of what a circular economy truly entails.

A circular economy is not merely about improving waste management; it's about eliminating waste from the system altogether. Rather than simply recycling more, it is about maximizing the value of materials through reuse, repair, and refurbishment, ensuring they remain in circulation for as long as possible. Recycling should be seen as a last resort.

At present, policymakers are heavily focused on the recycling aspect, which has led to sustainable procurement practices favoring products with defined recycled content percentages. However, this approach overlooks the core principles of a circular economy. For the plastic pipes industry, this narrow focus on recycled content poses a significant risk, as it could lead to the de-selection of these products in certain projects.

Plastic pipes are specifically engineered for long service lives, and the majority are still in their first lifecycle. As a result, the volume of post-consumer plastic pipes available for recovery is currently limited. This highlights the need for greater education within Australian governments and industries about the circularity of plastic pipe systems. In response, the industry association launched a research project in collaboration with a university and an independent national not-for-profit organization focused on Australia's transition to a circular economy.

The primary objective of the research was to better understand the materials, applications, recyclability, and circularity of plastic pipe systems in Australia, while also providing context around the use of recycled materials in these systems. This required mapping the circularity of plastic pipes in Australia, including the material flows for different pipe applications and an assessment of current industry practices concerning the recovery of materials. The research also aimed to identify challenges, barriers, and opportunities to further close the loop.

Using a Material Flow Analysis (MFA) methodology, the research outlined the current state of plastic pipe circularity, focusing on existing uses and pathways. The final recommendations are based on leading practices from both Australia and internationally, alongside insights gathered from key stakeholders. Whilst this work applied to various plastic pipe materials this paper focuses on PVC pipes.

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CASE STUDY OF A PE-PIPELINE WITH MANHOLES DN/ID3500, JOINTED BY INTEGRATED ELECTROFUSION IN THE PHILIPPINES.

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As climate change accelerates and populations in Southeast Asia continue to grow, urbanization leads to increasing surface sealing, intensifying flooding issues. Addressing this challenge requires innovative and effective drainage solutions, such as large-diameter pipe systems. This case study focuses on a DN/ID 3500 flood control project in the Philippines, situated in a densely populated, earthquake-prone area along the Pacific Ring of Fire. The project involved the installation of a 1-kilometer-long HDPE pipe system, locally manufactured and designed to ASTM M55 standards, with a hydraulic capacity of Q = 26 m^3/sec. The pipes, transported through narrow urban roads and installed amid heavy traffic, were joined using an integrated electrofusion system, with manholes placed at 50-meter intervals. Compared to the alternative of reinforced concrete box culverts (RCBC), the HDPE pipe system offered both technical and commercial advantages, proving to be a superior solution for the client and the project's structural requirements. This paper explores the production, transportation, and installation of these large-diameter PE pipes, presenting solutions to logistical and technical challenges. It highlights how HDPE pipes can provide practical, competitive alternatives to conventional materials, particularly in demanding environments, and emphasizes their growing role in the flood control and drainage market.

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STRESS RELAXATION-BASED LIFETIME ESTIMATION OF UNPRESSURIZED POLYETHYLENE PIPES CONTAINING RECYCLED MATERIAL – REVISITING THE JANSON STRAINABILITY APPROACH

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Buried polymer pipes play an essential role in modern communal infrastructure and find application in water, gas, sewer, and drainage systems. Nowadays, issues such as environmental protection, sustainability, recycling, and resource efficiency are becoming increasingly important in the polymer pipe industry as well. This leads to a growing trend towards the use of recycled materials in polymer pipe systems, especially in unpressurized applications. While various studies have shown that the properties of pipes made from modern virgin polyethylene grades easily exceed the requirements of the applied loadings and can achieve lifetimes of up to 100 years [1,2], the use of non-virgin and post-consumer recyclates may negatively affect the mechanical properties and subsequently the lifetime.

Due to the high durability of virgin polyethylene pipe systems, the knowledge about the exact long-term performance of unpressurized polyethylene pipe systems is limited. Additionally, most testing procedures for lifetime estimation do not reflect realistic loading conditions. A promising method is the already developed Janson strainability test [3], which simulates the primary load on these pipe materials in the form of deformation induced stress caused by the surrounding soil. However, the Janson strainability test has not yet gained broad acceptance due to high material usage and long testing times.

Building on the Janson strainability test, the current work aims to accelerate the established testing procedure to achieve feasible testing times and allow for a stress-relaxation based lifetime estimation. Although the focus is on polyethylene, the methodology could be adaptable to other polymeric materials, paving the way for broader application.

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ADVANCED MICROSTRUCTURAL INSIGHTS AND OPTIMIZATION STRATEGIES FOR ORIENTED PVC PIPES

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Oriented PVC (PVC-O) pipes are produced by aligning the polymer chains predominantly in the hoop direction. This alignment alters the material’s microstructure, resulting in significant improvements in its mechanical properties. The orientation also affects the failure mode, as conventional PVC pipes typically fail through radial cracking. In contrast, PVC-O pipes experience crack propagation along the hoop direction. These changes in both mechanical properties and failure behavior demonstrate the crucial role of polymer chain alignment in enhancing the performance of PVC-O pipes.

Microstructural characterization of PVC-O pipes has been relatively underexplored in the literature, as most published studies focus on oriented PVC sheets rather than pipes1-3. This lack of research leaves a gap in understanding the specific microstructural features of PVC-O pipes, such as the degree of polymer chain orientation, stress distribution, and behavior under pressure. Additionally, there is limited understanding how these microstructural characteristics influence the long-term performance, fatigue resistance, and failure mechanisms of PVC-O pipes. Addressing these gaps is essential for optimizing the orientation process, improving material design, and fully maximizing the benefits of pipe manufacturing, ultimately leading to more efficient and durable piping systems for critical applications.

The primary objective of this study is to conduct a detailed microstructural characterization of a uniaxially oriented PVC pipe. This involves analyzing the orientation and distribution of polymer chains, identifying key microstructural features that influence mechanical performance, and assessing the degree of orientation achieved during the manufacturing process. Therefore, by understanding the relationship between the microstructure and mechanical properties, this study aims to contribute to optimizing PVC-O production methods and expanding knowledge of its technical performance.

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ADVANCING CLIMATE EFFICIENCY IN PIPELINE RENOVATION WITH NO-DIG TECHNOLOGY

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The renewal of aging pipeline networks is essential to maintaining reliable infrastructure. Traditional methods of pipeline replacement, which require extensive excavation, are resource-intensive and environmentally disruptive. These approaches generate significant carbon emissions and cause widespread surface disruption in both urban and natural landscapes. No-dig, or trenchless, technologies present a more sustainable alternative by enabling pipeline renovation with minimal excavation. This method reduces greenhouse gas emissions, preserves ecosystems, and minimizes disturbances in urban environments.

Building on decades of success with PVC as a durable, cost-efficient, and recyclable material, a key advancement in pipeline renovation is the introduction of bio-attributed PVC liners. These liners retain all the core benefits of PVC while significantly reducing reliance on fossil feedstocks and minimizing their climate impact. Furthermore, they meet the styrene-free requirements increasingly adopted by municipalities, offering a safer option for workers, nearby residents, and the environment. With their high abrasion resistance, PVC liners minimize particle release into the environment, ensuring long service life and reliability.

U-shaped PVC relining pipes are compact for transport and regain their original form during installation using steam, creating a precise fit within existing pipelines. The production process minimizes waste, as offcuts from installation are recyclable, and used liners can be removed and recycled at the end of their lifecycle.

Official approvals and assessments of the bio-attributed PVC solution are underway. It has already been officially approved in Denmark under the inspection scheme for pipeline renovation, demonstrating its compliance with stringent regulatory and environmental standards. In Sweden, it has received the highest rating in Byggvarubedömningen, following a comprehensive lifecycle assessment. Additionally, several projects in the Nordics have showcased its practical success in real-world applications. This method exemplifies a modern approach to infrastructure renewal, reducing the environmental impact of pipeline renovation and supporting circular material use. Ongoing evaluations will further highlight its contribution to improving infrastructure efficiency and environmental responsibility.

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30 YEARS OF DOUBLE WALL CORRUGATED PVC PIPING SYSTEM FOR SEWAGE APPLICATIONS

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Sewer pipelines and sewage treatment plants were a key revolution considering the deep impact they had in human society. On one hand wastewater could be conveyed away from populated areas, with the deep improvement in health, and on the other hand that effluent could be properly treated and, as a result, drastically reduce environmental impacts. Traditionally, only rigid materials had been used for these pipelines, so the innovation and technical development in much lighter plastic materials, mainly PVC, resulted in very important improvements not only in the longer lifetime of sewage installation because of much better chemical resistance, lack of corrosion, behavior to abrasion and flexibility, but also in higher hydraulic capacity and much better watertightness.

Specific circumferential stiffness is the key factor in the design of a buried pipeline for a non-pressure application for sewage, especially in long-term behavior. The challenge was to be able to achieve a competitive high stiffness plastic pipe, due to lower elasticity modulus compared to rigid materials. So, in the earlies nineties of the last century, an engineering process based on a double wall PVC pipe was developed, with a smooth inside surface and corrugated outside one, which increases the moment of inertia and therefore stiffness, but keeps the total raw material consumption, and so pipes weight, at a very competitive value. What is more, due to the low creep of PVC E-modulus compared to other materials, long-term high stiffness also remains. This property, along with a carefully designed sealing system which prevents any leakage, enables a maximum hydraulic capacity with a high inside diameter and smoothness, resulting in low power consumption and lower CO2 emissions in the total cycle of life, resulting in a life expectancy over 50 years.

The wide diameter range of corrugated PVC pipes is complemented by a large range of fittings and watertight manholes which are easily installed on site with elastomeric seals that can be adapted for different applications, such us siphon waste boxes and grease separators, among others.

All these properties are part of the double wall corrugated PVC pipeline in a complete system for sewage applications. This paper reviews more than 55,000 kilometers of installed double wall corrugated PVC pipelines and the work is applicable to other materials. A case study will also be discussed that examines the evolution of double walled corrugated pipes and explains the main characteristics and field applications of the whole system, including design and technical development.

A-260

ARE MICROPLASTICS A PROBLEM FOR THE PLASTIC PIPE INDUSTRY?

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Polyethylene (PE) was first introduced in 1933 as an alternative material for pipes due to its cost effectiveness in manufacturing, installation, and transportation.2,3,6 It also provided a distinct advantage over other piping materials like concrete and steel, as it does not corrode, thus extending the service life.4 Despite these positive attributes, PE and other plastic materials have the potential to abrade into macro, micro, and nano plastics that are prevalent in aquatic and terrestrial environments. Microplastics (MPs), 1 to 5μm in diameter, and nano-plastics, <1μm, are highly mobile and can be found in remote areas, like polar regions and the Marianna Trench,1 as well as in processed beverages and the skins of fruits and vegetables.5 Competing industries and advocate groups have targeted the plastic pipe industry as contributing to the MP pollution issue. However, there is currently limited published research to support these claims, and additional research is needed to quantify the types of MPs that could be potentially generated by the plastic pipe industry as well as the potential impact of the plastic pipe industry to MP pollution.

The research presented in this paper involves a study of the abrasion rates of high-density polyethylene (HDPE) pipes used in storm sewer applications and their potential to generate microplastics. The study includes a laboratory test utilizing a slurry mixture inside of a rotating pipe to abrade the pipe materials, and the separation, quantification, and qualification of the various MP particles that are generated. The wall thickness of the pipes will be monitored throughout the test and the abrasion rates recorded. The abrasions rates in the laboratory study are then correlated to actual measured rates of abrasion observed in a field study in the U.S. Additionally, stormwater samples will be collected at various locations in the U.S. to determine the types and quantities of MPs present and to assess whether or not any of them could have been produced by plastic pipes based on the assessment of abraded materials collected in the laboratory study. Finally, the total potential contribution of the plastic pipe industry to MPs will be quantified based on various abrasion rates. Research is currently underway and expected to be completed by June of 2025.

A-261

EDUCATING THE NEXT GENERATION OF PLASTIC PIPE EXPERTS

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Educating the next generation of civil engineers to rebuild infrastructure with sustainable and resilient materials is essential for addressing global environmental challenges and ensuring long-term societal benefits. Most civil engineering curricula focus solely on traditional materials such as concrete, steel, and wood. Engineering students are well trained on the properties of these traditional materials as well as how to use these materials to design structures. However, traditional materials like concrete and steel, while reliable, contribute significantly to carbon emissions and resource depletion. This is not sustainable, and the rebuilding of our infrastructure should prioritize the use of more sustainable and resilient materials so that future generations can enjoy the same quality of life that we have experienced. Plastics and composite materials offer a significant environmental benefit to our society and would make an excellent solution for rebuilding our infrastructure, yet current civil engineering curricula do not adequately address the use of these materials for our infrastructure design.

A transformative education strategy must prioritize integrating sustainable plastics, composite materials, and other innovative solutions into civil engineering curricula. This requires a comprehensive approach that combines theoretical foundations with practical applications, focusing on material science, lifecycle analysis, and environmental impact assessments. Students must gain a deep understanding of the properties, durability, and sustainability potential of advanced materials, along with exposure to their real-world applications in structural design, transportation systems, and urban development. Additionally, hands-on experiences, such as laboratory experiments and field studies, should be paired with industry collaborations to provide students with cutting-edge insights and practical expertise.

The University of Minnesota – Duluth and the Advanced Materials Center has developed a new curriculum to instruct students on the material and design properties for advanced materials such as plastics and composites that can be used to rebuild our crumbling infrastructure. This paper will focus on some of those key materials and design principles and will provide a framework for educating the next generation of civil engineering students to be better prepared for solving our complex infrastructure problems with more sustainable and resilient materials such as those used by the plastic piping industry. It will also provide some practical tools for the plastic piping industry to employ to help engage with universities on educating the next generation of engineers.

A-264

PE100 MATERIAL SUPPORTS SEA WATER COOLING PROJECT IN JAZAN – SAUDI ARABIA

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The Sea Water Cooling Project in Jazan, Saudi Arabia, offers an example of a sustainable solution for seawater cooling systems. This project involved constructing a seawater cooling system for Jazan City for Primary and Downstream Industries (JPCDI). It includes building two seawater pipelines, four hypochlorite pipelines and a pumping station. In this system, seawater is pumped through a heat exchanger and used to cool the industrial cooling water being carried in a closed loop.

The project's geographic location presents technical challenges. Seawater cooling systems are essential for industrial applications but come with unique difficulties, especially in designing and operating seawater intake structures. Common issues include corrosion, biofouling and the harsh marine environment's impact on materials. Traditional intake systems often face durability concerns and high maintenance costs due to exposure to saline water and fluctuating temperatures.

To address these challenges, HDPE PE100 was selected for the structural wall pipes (DIN 16961-1:2018, DIN 16961-2:2018). This proved to be an ideal solution as the harsh surrounding environment excluded most conventional piping materials. Additionally, seawater cooling systems, combined with durable and corrosion-resistant HDPE seawater intake lines, offer a sustainable solution by utilizing an abundant natural resource. This approach significantly reduces freshwater consumption, energy usage and the environmental impact of industrial applications.

Given the requirements for the 6.7-kilometer HDPE structure-walled seawater intake pipelines with an ID of 3,230 mm, PE100 material was chosen for its excellent processability and mechanical properties (ISO 9969:2016). This made it the ideal material for producing spiral wound pipes that met the project's requirements.

High-Density Polyethylene (HDPE) PE100 pipes provide an innovative solution to these challenges. With their exceptional corrosion resistance, flexibility, and longevity, HDPE pipes can withstand the demanding conditions of seawater intake applications. Their smooth internal surface minimizes biofouling, thereby reducing operational downtime and maintenance requirements. Additionally, the ease of installation and jointing techniques for HDPE pipes make them an ideal choice for both onshore and offshore applications, ensuring a reliable and cost-effective seawater intake system.

A-265

A REVISED NCLS TEST METHOD TO PREDICT SERVICE LIFE FOR STRUCTURE-WALLED PIPES

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The Notched Constant Ligament Stress (NCLS) test method as specified by ASTM F2136 is currently used in the corrugated and structure-walled pipe industries and several other industries to evaluate the stress-crack resistance of the materials used in these respective applications. The current test method involves the notching of dog-bone test specimens and the immersion of these specimens in a solution containing 10% Igepal CA-630 surfactant (octylphenolethoxylate) and 90% deionized water. The test bath is heated to 50 degrees C, and a load is placed on the test specimens to generate a constant stress across the un-notched portion of the ligament. Current pipe standards require minimum failure times ranging from 12 - 33 hours, depending on the application and other parameters. These minimum failure times were established based on empirical data and are not tied directly to service life.

In recent years, Igepal has come under scrutiny due to its toxic nature and is in jeapordy of being banned in several countries. As such, the need for a new test method that does not use this surfactant is imminent. Crossroads Engineering Services and the University of Minnesota - Duluth have conducted research to replace the Igepal solution in the current NCLS test with a 100% deionized water solution, similar to what is specified in the Un-notched Constant Ligament Stress (UCLS) test specified in ASTM F3181. Conducting the test in a 100% DI water solution offers several advantages. First, this test bath is non-toxic and can be used in any laboratory. Secondly, since the UCLS test already utilizes a 100% DI water solution, the same test equipment could be used for this revised NCLS test. Thirdly, and perhaps most importantly, conducting the test in 100% DI water will allow the test results to be shifted utilizing traditional methods such as Popelar Shift Factors and the Rate Process Method to extrapolate the data to service conditions. As such, the test can be used to predict service life.

Several materials have been tested to validate the methodology, and a round robin is currently underway involving multiple materials and multiple laboratories. The analysis will be completed by May of 2025, and the results presented in this conference. A relationship between the revised NCLS test and service life in various conditions will be shown.

A-266

REDUCING EMBODIED CARBON THROUGH THE USE OF PLASTIC PIPE IN INFRASTRUCTURE

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With the increased focus on the reduction of Embodied Carbon in Infrastructure projects the focus is typically on large ticket items such as ready-mix concrete and asphalt. Engineers often overlook simple opportunities such as storm sewer and culverts for carbon reduction opportunities. This paper will outline some examples of how the selection of thermoplastics materials over traditional materials can provide a significant carbon savings. The savings for carbon can be demonstrated across the value chain from single use plastics to durable pipe goods. The paper will also review the recent project from NIST showing the environmental impacts of diverting recycled plastics materials to single use plastics vs durable pipe product. Recent infrastructure projects will be used to demonstrate the potential savings from construction perspective when using plastic pipe materials vs traditional materials. Calculations for carbon comparison will be bases off of a comparative LCA for drainage products that was completed in accordance with ISO standards.

A-267

PLASTIC PIPE MARKET DEVELOPMENT AFTER ECONOMIC CHANGE IN 1989 IN POLAND

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In year 1989 in Poland the base of economics has been changed from planned economy to market economy. In that time Polish market has been opened to new developments in general as well as in piping business.

Poland has begun to catch up in the development of water supply and sewer networks. This was also related to the urban development of urban and rural areas. This paper deals with the development of the infrastructure market and catching up in the supply of drinking water and sewage disposal. An important element of the changes is the change in the material structure of the constructed water supply and sewer networks, where plastic pipe solutions have begun to play an important role. The recorded increase in the number of water supply and sewer house-connections (laterals) is not without significance. Thus, Poland is quickly catching up in the degree of saturation with water supply and sewer networks. The support of development funds from the European Union is not without significance.

Common production of plastic pipes is based on product standards or national approvals. During last decades, Polish standards as well as technical approvals has been evolved. It was discussed in which direction it should evolve. When Poland joined European Union (EU) in year 2004, it was clear that standardization should follow European Standards.

Similar changes are taking place in other countries of Central and Eastern Europe (CEE).

A-270

SURVEY OF EXPERIENCE WITH MORE THAN 50 YEAR OLD WATER SUPPLY POLYETHYLENE PIPES IN JAPAN

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Japanese Industry Standards (JIS) related to polyethylene water supply pipes were published in 1959 and classified LDPE for soft pipes and HDPE for rigid pipes.

Water supply pipes are composed of PE pipes and mechanical fitting and metal elbow components under nominal inside diameter of maximum 50mm. They are mainly used for smaller supply lines that supply a street or a group of buildings from the header pipes.

After more than 50 years the leakage of pipelines for water supply is gradually increasing. The Japanese public foundation for water works technology promotion and Japan Polyethylene Pipe System Association started to survey the performance of aged polyethylene pipes in 2021. The research laboratory of Yamagata University joined the project a year later. The document will include -field failure mode of smaller PE potable water pipes used over 25 years in 10 cities (Fukuyama, Higashi-Osaka, Ishikari, Nagoya, Saitama, Sapporo Sendai, Tokushima. Prefecture: Kagawa, Kanagawa) in Japan in2022.in Japan. Average life of LDPE and HDPE pipes was 42 years and 49 years respectively and lowest lifetime was 30 years and 41 years respectively. The failure mode of more than 300 pipes investigated was classified as a “Brittle creep fracture” by observation of appearance and their fracture surface of the pipes.

Based on the direction of crack growth observed three modes were classified, i.e., axial crack, circumferential crack and mix mode of those inclined crack. Cracking mode was dependent on the material types used for the pipes. Most of LDPE pipes showed axial cracking failures, on the other hand the cracking mode of HDPE pipes showed half of them were axial crack and the rest were circumferential crack and mix mode. There was, however, no significant difference of the failure life of the pipes even if the mode of cracking was different. Most of axial cracks occurred by the point loading due to rock impingement in the onsite installation filled with soil. Non-axial cracking for HDPE pipes occurred near the rigid mechanical fittings. It suggested that excess bending and /or torsion during an installation of pipes remained after being buried in the soil. This would easily occur in HDPE pipes that have a relative long relaxation time.

Another analysis reported the dispersion state of carbon black for aged pipes and the depth profiles of Carbonyl Index for oxidation near the surface of the inside wall also of aged pipes. Both results showed no significant impact on the initiation and growth of creep crack.

A-271

SURVEY OF UNITED STATES DEPARTMENTS OF TRANSPORTATION: PRACTICES TO ENHANCE RESILIENCY OF EXISTING ROADWAY AND EMBANKMENT CULVERTS

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This synthesis is prepared for the National Cooperative Highway Research Program (NCHRP) of the Transportation Research Board (TRB) under the sponsorship of the American Association of State Highway and Transportation Officials (AASHTO) and in cooperation with the Federal Highway Administration (FHWA). Culverts were identified as vulnerable components to extreme weather events and climate change during a 2013-2015 pilot study (FHWA-HEP-16-079). Extreme climate and weather events can accelerate culvert failures and shorten expected design lifetimes, leading to costly repairs, rehabilitation projects, or full replacements. This synthesis summarizes current management and maintenance practices employed by state Departments of Transportation (DOTs) to enhance the resiliency of their existing roadway and embankment culverts. It also documents common failure modes of culverts and challenges in implementing resilience strategies. The synthesis was developed through a literature review, a survey sent to 52 transportation departments of transportation including all 50 state DOTs, the District of Columbia, and Puerto Rico, and case example interviews with DOT staff from select respondents. Case study interviews were conducted with five state DOTs representing geographic diversity, a wide representation of culvert types and materials installed and specified in their states, and variety of potential threats that could impact resiliency, including floods, hurricanes, severe storms, and wildfires.

A-272

A SUSTAINABLE 100 YEAR DESIGN LIFE WITH HDPE PIPE

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With the challenges of today's aging water and wastewater infrastructure in North America it is more important than ever to utilize limited funding in the most efficient and cost-effective way to arrive at a long-term sustainable solution. Properly designing these piping systems to fully utilize key performance properties of each type of material is important to achieving a true 100-year solution. Couple this with the array of installation options, such as trenchless methods, and the social disruption and overall carbon footprint can be minimized.

There is no "one" perfect solution for all piping installation and operating conditions. For each material it is important to understand what failure mechanism(s) are most likely to cause end-of-life and to design for those to assure that each potential mechanism is mitigated for a minimum of 100 years or more. While at the same time, it's important to take into account performance advantages so as to not needlessly over-design the system which increases the cost of the project overall. For all piping systems the potential failure mechanisms are similar – pressure, corrosion/oxidation, surge, cyclic fatigue, and effects of concentrated stresses (e.g. SCG for HDPE). Typically, one of these mechanisms will be the overriding factor causing effective end-of-life of the system.

This paper will look at how a design life is different than an effective service life. Also, examine how the key performance properties for HDPE PE4710 compounds being used today evolved over the years to extend the service life, and how to use these properties to design in the most efficient and sustainable manner. In addition, with reduced weight for transportation and the options for trenchless installation the cost for social disruption and the overall carbon footprint of the project is minimized providing a beneficial ESG – Environmental, Social and Governance - solution for a true 100-year design life.

A-273

A NOVEL ELECTROFUSION WELDING TECHNIQUE FOR LARGE DIAMETER PRESSURE CLASS PE PIPELINES: MECHANICAL ASSESSMENT, AND CASE STUDY

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This paper aims to introduce a groundbreaking method for welding PE pipes, featuring an innovative incorporation of electrofusion wire directly on the pipe wall. The focus of this paper is twofold, it assesses the mechanical reliability of these new joints and presents the potential of this technique through a comparative case study. We showcase the potential advantages of this welding solution on a 37KM (1200mm Pipes SDR 17) pipeline project executed in Malaysia, in which both the conventional PE pipes jointing methods were used: electrofusion and butt fusion, versus the use of such novelty.

Our approach included structural integrity tests, joint strain tests, and long-term creep behavior under varying conditions, benchmarked against traditional techniques. The meticulous procedures ensured a thorough understanding of the proposed method's feasibility and effectiveness. the Pengerang Johor project executed in Malaysia has served as an example for our cost benchmark study. The ecological component being of equal importance, a qualitative assessment of the solution's carbon foot print is presented as well. Mechanical testing revealed promising results. Demonstrating the robustness and efficacy of the electrofusion wire-incorporated connection. Strain tests showed the technique's suitability for relining projects, maintaining 82% of maximum pipe pulling force under traction. Pressure tests confirmed its reliability for full-pressure applications. The pipe end profile geometry enabled stress-free onsite welding with minimal human influence. The case study demonstrated economic benefits, including reduced installation time, labor, and logistics costs.

In conclusion, this innovative technique presents a viable solution for enhancing pipeline construction efficiency, particularly in projects requiring large diameters.

This paper presents novel insights into pipeline construction by introducing a pioneering approach to PE pipe connections. Incorporating electrofusion wire represents a paradigm shift in the industry, offering enhanced reliability, efficiency, and cost-effectiveness. The findings contribute significantly to advancing the state of knowledge in infrastructure, providing a valuable addition to literature and practices.

A-276

REVOLUTIONISING PLASTIC PIPE HANDLING: A REUSABLE SYSTEM FOR SAFER, EFFICIENT LOGISTICS

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The plastic pipe industry supports critical sectors such as plumbing, agriculture, construction, irrigation, and telecommunications. However, traditional logistics methods, particularly single-use timber frames, have proven inefficient and hazardous. Issues such as structural failures during transport, worker injuries from manual handling, and community accidents during unloading underscore the urgent need for sustainable and innovative solutions.

This presentation introduces a reusable pipe framing system, a transformative approach to improving plastic pipe logistics. Grounded in five core principles—**safety, efficiency, practicality, suitability, and sustainability**—this system redefines standards for transport, storage, and handling.

The system's development followed an intensive R&D process, including:

- **Material Innovation:** Testing materials such as rHDPE and glass-fibre PE to achieve durability, lightweight properties, and cost-efficiency. The product is designed to be produced with recycled PVC material, primarily from pressure pipe and fitting compound waste, and byproduct from production processes.
- **Design Optimization:** Using Finite Element Analysis and lab testing to create a modular design compatible with pipes of various lengths, diameters, and materials, ensuring structural integrity under transit forces.
- **Prototyping and Field Testing:** Real-world trials in Australia, New Zealand, and the UK validated performance across scenarios such as loading, unloading, and road transit.

Real-world deployment delivered significant benefits:

- **Transport Efficiency:** Optimized stacking and load distribution increased vehicle capacity utilization, reducing costs, trips, and carbon emissions.
- **Storage Optimization:** Improved vertical and horizontal stacking enhanced warehouse throughput without requiring expansions.
- **Safety and Operational Savings:** Streamlined handling processes reduced labour demands and significantly improved safety for workers and communities.

Customer trials confirmed the system's effectiveness, with end users praising its ease of use, waste reduction, and seamless integration into existing workflows. A cost-benefit analysis reveals substantial savings within the first year of implementation, driven by lower logistics costs and reduced waste.

Case Study

Future iterations will include IoT-enabled sensors for real-time frame tracking, automation in loading processes, and eco-friendly material upgrades. The system aligns with global legislative requirements for sustainable packaging disposal and recycling, offering a forward-thinking solution to the industry’s environmental challenges.

By addressing longstanding inefficiencies and safety concerns, this reusable pipe framing system sets a new benchmark in logistics, delivering safer, more efficient, and environmentally sustainable supply chains.

A-278

THE 100-YEAR LIFETIME OF PE100/PE100RC PIPES – AN INDUSTRY ASSOCIATION'S PERSPECTIVE

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The reliable working lifetime of polyethylene (PE) pipelines is essential for managing long-term investments in infrastructure for water, natural gas, and hydrogen supply systems, as well as evaluating their environmental sustainability compared to traditional materials. While design life is typically 50 years for PE80 and PE100 class pipes based on current standards, the actual service life can be much more than this due to factors such as lower operating pressures and temperatures, and safety factors applied during the design stage.

The manuscript explains fundamentals of extrapolated lifetime calculations from pressure test data, the currently accepted standard way of calculating design life, the difference between the design life and actual service life of PE100 /PE100RC pressure pipe systems. The paper also discusses the development of PE100-RC materials, which offer enhanced resistance to slow crack growth, which significantly extends the lifetime of the PE100 pipe systems.

Furthermore, it critically evaluates findings from field experiences, corporate and academic research from the viewpoint of technical experts from PE100+ Association from a wide range of geographic locations. It indicates that PE pipelines can achieve a reliable working lifetime exceeding 100 years, with predictable failure modes such as ductile rupture, slow crack growth, and oxidation. It emphasizes the importance of understanding these failure modes to ensure effective long-term predictions. Additionally, it explores alternative methods of implementing a design life of 100 years in future applications, considering the current and future standardization landscape.

A-282

INDUSTRY INSIGHTS, BEST PRACTICES/TRANSITIONING FROM TRADITIONAL MATERIALS LESSONS LEARNED TRANSITIONING FROM DI TO HDPE WATER MAIN

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Lessons learned in transitioning a municipal water company from DI to HDPE water mains and services. In general, the water company installed 8” water mains and 1” service line. The transition to 8” HDPE DR13.5 and 1” DR9 was ultimately successful though the transition was not without its challenges. The HDPE industry came together to provide the necessary support for this transition. This presentation will go in detail into the component pieces needed to successfully transition to HDPE water mains and service lines. The materials, training and testing to facilitate this transition will be covered from a lesson learned perspective of a public water company with 80,000 water customers in the Midwest that installs gas and water together in the same trench.

A cooperative and cohesive approach is needed for all involved in the process of transitioning to a new material. From the design engineer to the field installation crew, everyone needs to be supportive of the change process. For the design engineer to specify the use of 8” HDPE water main and services they need to know a few things such as the operating pressure of the water system and the chemical make-up of the water[1]. Field crews need to be trained and equipped with the tools required to install HDPE. The engineering facts and tooling needs are straightforward to figure out. However, predicting and navigating the acceptance of the material change by management and the education of the field crews is much more difficult. In the example presented, as engineers began designing HDPE as the new water main material, the field crews resisted and refused to install the materials designed. As the benefits of HPDE were explained and experienced by the entire water utility, eventually, the attitudes of crews were changed, cooperation was obtained, and the transition was successful.

1: MAB-3 (2024) – Model Specification for PE 4710 Buried Potable Water Service, Distribution and Transmission Pipes and Fittings

A-283

DETECTION OF ARVIN SUBSTANCES IN WATER SAMPLES AND PIPE APPLICATIONS

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TEPPFA has approached Eurofins Product Testing in Denmark for assistance and for being the leading laboratory for an interlaboratory comparison test of measuring the substances, listed in table 4 in the annex of in the Commissions Delegated Regulation 2024/369. The substances are degradation products of stabilizers with a phenolic structure, also known as the Arvin substances.

The purpose of the study was to investigate and document the performance of the analytical test methods used for quantification of the degradation products migrated into water from pipes used for drinking water installations.

11 laboratories, located in Denmark, Germany, The Netherlands, Italy and Austria were invited to participate in the interlaboratory comparison test. 10 of these laboratories participated.

A two-fold interlaboratory comparison test was organized. In the first interlaboratory comparison test analysis was carried out on spiked water samples. These samples are used to evaluate the analytical measurement technique (preconcentration, instrument analysis and quantification etc.) used by the participating laboratories. The second test includes water migration and water analysis from two different pipe materials provided by TEPPFA.

The participating laboratories were asked to provide detailed method information such as: analytical technique, quantification principle, detection limit and measurement uncertainty. Semi-quantitative results were not included in the consensus value.

Test results showed an RSD (Relative Standard Deviation) between 12% and 46% for the spiked samples and a slightly higher RSD for the test of pipe samples.

An overall conclusion of the study is that a standardized and accredited method for measuring these substances is needed.

The paper will go in detail with the findings of the study and highlight the variations coming from different methodology and technique in the extraction, concentration and detection.

CURRENT LIST OF ACCEPTED ABSTRACTS FOR POSTER PAPERS

A-178

EVALUATION AND QUALIFICATION THROUGH TESTING OF THICK-WALLED EXTRUDED PP-RCT PIPE WITH UNEVEN WALL THICKNESS

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Polypropylene is a semicrystalline thermoplastic that differs significantly from many other thermoplastic pipes in that when it is extruded in thickness over 30mm in thickness (approx. 1.2 inches), it tends to sag due to the effects of gravity. This sagging results in a wall that is egg shaped (thin at one point and thicker at another). This doesn't happen to other common thermoplastic materials, such as HDPE, until pipes with significantly greater thicknesses are extruded. There are some diameter and wall thickness combinations of PPR and PP-RCT pipes that are listed in standards, and others which are being commercially offered in which the wall thicknesses are as much as 45mm in thickness (approximately 1.75 inches). When the wall is really thick, the difference between the thin and thick portions of the wall can be as much as a 50% difference.

One dilemma this presents is that when measured according to ASTM D2122 and eight points are measured, this wall thickness of such pipes are usually still within tolerance for those pipes that have the diameter and thickness listed. This is the case even when the wall thickness at the thinnest point is less than the minimum required wall thickness. Even though this difference is significant, butt welding can still be accomplished if the misshapen walls are properly aligned.

We have performed a variety of tests in the past to validate the long term and short-term pressure and mechanical integrity of pipes having this characteristic. As such, we know that despite not passing the eye test, the odd egg shape actually results in a pipe structure which can be greater than a perfectly round pipe. For these reasons, the authors have undertaken a more formal study involving a number of tests performed at an independent outside lab to compare the strength of such misshapen pipes and the welds made from such materials to what is normally required of the materials.

The study will involve multiple sizes of multilayer PP-RCT pipes, including 12" (315mm) SDR 7.4 pipe, 20" (500mm) SDR 11 pipe and 24" (630mm) SDR 17 pipe. Various tests will be performed, including 1,000 hr. hydrostatic testing at 95°C, burst testing at elevated temperatures and tensile testing. The testing will be performed on both sections of pipe that include a butt weld, as well as unwelded sections. A comparison will be made of the results of the tests as compared to that which is required and expected for pipes that are exceptionally round in other sizes and lesser thicknesses. The paper would summarize and present these findings.

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THE IN-LINE PRODUCTION PROCESS OF BI-AXIALLY ORIENTED POLYOLEFIN PIPES WITH OPTIMAL PERFORMANCE

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Bi-axially oriented polyolefin pressure pipes have shown outstanding improvement over the whole property range as reported in our last presentations at PPXX and PPXXI (1,2). The performance of these pipes is a consequence of the starting resin used, in combination with the successive steps of preparing a thick-walled starting pipe, deforming the pipe under controlled conditions regarding temperature and stretch ratio and, finally, relaxing the residual stresses. During the early development of this technology laboratory scale batch-type equipment was used. Decoupling of the successive steps offered precise control over the complete process, but rendered it labor-intensive and slow, in other words, not suitable for a production environment.

To translate the early research to a commercially viable process, a full-scale continuous production line was constructed, based on the learnings from the batch process. Coupling all three steps and significantly increasing the speed of the process were identified as key requirements. With this, significant changes to the rate of heating and cooling and the speed of deformation were introduced as well as to the time available for stress relaxation. To address these challenges the team could no longer rely on visual observations and manual corrections and thus more advanced process control and modeling had to be applied.

In this paper we will highlight the latest developments in processing and online data capture for the process and quality control to develop a robust in-line process for the preparation of bi-axially oriented polyolefin pipes. Temperature control from melt to crystallization and reheating to the desired draw temperature uniformly to enable homogeneous biaxial stretching and stretch ratio control are most critical parameters for ensuring optimal performance of the resultant pipes. To optimize the process conditions thermal profile simulations were carried out and implemented in practice. The paper will discuss these key developments.

A-201

ROLE OF DIFFERENT INFLUENCING FACTORS ON THE REACTION OF PEX

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Coupling effects of peroxide and antioxidant, and influence of the concentration of peroxide and processing temperature on the cross-linking reaction of PEX were studied. The results show that, the torque and viscosity of polyethylene with different concentration of peroxide are different for the whole reaction period.

At the initial stage, HDPE mainly shows a transition state from solid to melt, and the viscosity of the polymer, as a whole, shows a decreasing trend, and at this stage, the viscosity decreasing speed is not affected by the concentration of peroxide. With increasing in melting time, the viscosity with different concentration of peroxide changes differently. For lower concentrations of peroxide, the initial time for viscosity to increase is about at 19 seconds, while the increasing speed is relatively slow. For higher concentrations of peroxide, the initial time for viscosity and torque to increase is advanced to 15 seconds, and the increasing speed is also faster.

In addition, increasing in the concentration of peroxide could improve the cross-linking degree, but not shorten the whole cross-linking period of the system. At the temperature employed in this work, the time for HDPE to complete the cross-linking reaction is about 80S regardless of the concentration of peroxide, and then the cross-linking reaction basically ends when the torque is balanced. Further, without antioxidant, the greater the concentration of peroxide is, the greater the balance torque and the higher the cross-linking degree of PEX is, while the oxidation induction time remains unchanged.

The addition of antioxidant can significantly improve the oxidation induction time of PEX system, and with the increase in antioxidant, the oxidation induction time of PEX shows an increasing trend. However, the selection of antioxidants is significant to avoid the conflict between antioxidants and peroxide, improve the thermal oxygen aging performance of the material, and maintain sufficient cross-linking degree and physical strength of the material. Within the temperature range of 210-230 ℃, with the increase in temperature, the cross-linking degree of the system fluctuates within a small range, and even decreases slightly. During actual production, choosing the right production process is very important for energy reduction, production efficiency and product quality.

A-204

THE EFFECT OF HIGH-PRESSURE HYDROGEN ON PLASTIC PIPE MATERIAL

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To maximize the safety and efficiency of hydrogen energy systems, it is essential to gain an in-depth understanding of the material property changes critical components, such as piping, undergo in high-pressure hydrogen environments. The plastic pipes offer various advantages, including lightweight, corrosion resistance, flexibility, and cost-effectiveness, presenting the potential to replace conventional metal piping. Plastic pipes, being lighter than metal, allow for easier transportation and installation, while their corrosion resistance ensures long-term stability. It is expected that plastic pipes can be used as hydrogen pipes instead of metal pipes because of these advantages. in this study, in order to evaluate the safety of plastic hydrogen transport pipes, damage and changes in material properties after high-pressure hydrogen exposure were evaluated for polyethylene materials, which are mainly used as gas piping materials. When exposed to 96.3 MPa hydrogen for 24 hours, in the case of LDPE, serious damage occurred and hydrogen permeability was significantly reduced, but in the case of HDPE, almost no damage occurred and permeability was just slightly reduced. Also, the mechanical properties and fracture mechanism of polyethylene materials was changed because of high-pressure hydrogen. Therefore, the evaluating the effects of high-pressure hydrogen on plastic pipes is critical for its application in hydrogen transport systems.

A-223

DISCUSSION ON THE CHARACTERISTIC DIFFERENCE AND APPLICATION OF ASME B1.20.1, B1.20.3 AND B1.20.7

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This paper deeply studies the differences among ASME B1.20.1 (general pipe thread), ASME B1.20.3 (dry seal pipe thread) and ASME B1.20.7 (hose coupling thread). This article is applicable to any materials that can be used to make threads. Firstly, the research background and purpose are introduced. It is pointed out that with the improvement of thread connection requirements in industrial development, these three standards play an irreplaceable role in different fields and scenarios. Then, the ASME standard system is expounded, including its development history and application fields, emphasizing the importance of ASME standards in multiple fields such as mechanical engineering.

Afterwards, the three standards are analyzed in detail respectively. ASME B1.20.1 general pipe thread has good universality and interchangeability. Its conical thread shape and various size parameters meet different connection requirements. The specification of flat crest amount improves the tightness and stability of connection. ASME B1.20.3 dry seal pipe thread adopts a unique sealing mechanism and can achieve good sealing performance without sealant. It has excellent reliability in harsh environments such as high pressure and high temperature, but its high manufacturing precision requirements increase the cost. ASME B1.20.7 hose coupling thread fully considers the special needs of hose connection.

It adopts parallel thread structure and specific size design. The sealing by gasket or O-ring ensures the reliability and tightness of connection. It has flexibility and certain compatibility with other standards. Finally, the research conclusions are summarized. It is pointed out that the appropriate standard should be selected according to engineering requirements. And the future research directions are prospected, including material innovation, intelligent thread connection technology, environmental sustainability and thread standards, and international cooperation and standard unification.

A-229

USE OF HIGH-PERFORMANCE CONSTRAINED GEOMETRY CATALYST LLDPE TO IMPROVE MECHANICAL PROPERTIES IN MICROIRRIGATION TAPES

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Irrigation pipes, like drip tapes and plastic tubes, are frequently utilized in agriculture for their cost-efficiency and effectiveness in watering crops. These pipes usually have a nominal diameter ranging from 16 to 22 mm, wall thickness from 5 to 40 mil (or 0.13 to 1.00 mm) and maximum working pressure up to around 3.0 to 3.5 bar (depending on the pipe wall thickness). The main function of such drip tapes or tubes is to deliver water, fertilizers and herbicides directly to the ground or close to the roots of plants. Polyethylene is widely used to produce such pipes due to its suitable balance in strength and flexibility besides its good chemical resistance. Pipes are manufactured via melt extrusion process, often using a mixture of different types of polyethylene, such as MDPE, LLDPE and LDPE. The drip irrigation industry is constantly looking for ways to optimize resources by reducing the cost per linear meter of its products, often using less expensive raw materials in the fabrication of the drip tapes and tubes. However, this strategy usually results in compromised tube performance such as loss of strength, low surface quality, and reduced extrusion output. Alternatively, such cost reduction can be achieved by reducing the thickness of the tubes using high-performance polymers without compromising their properties.

In this paper, the authors explain how substituting a traditional Ziegler-Natta LLDPE (I2: 1.0 g/10 min, ρ: 0.920 g/cm³, Mw/Mn: 13.5) with an improved constrained geometry catalyst (CGC) LLDPE (I2: 0.85 g/10 min, ρ: 0.918 g/cm³, Mw/Mn: 3.5) that was initially developed for superior abuse resistance in packaging, in a formulation for drip irrigation pipes, could result in up to a 15% reduction in wall thickness while maintaining the pipe's stiffness and burst strength. Due to unique molecular design, evidenced by narrow molecular weight distribution (MWD), formulations containing 36 wt.% of such high-performance LLDPE showed 15% higher burst strength, increasing from 6.5 to 7.5 bar, measured over extruded pipes according to NBR ISO 9261 when compared to incumbent formulation at same pipe wall thickness. Interestingly, the results indicated that reducing the wall thickness by 15% led to an equivalent 6.5 bar of burst strength, while also achieving a higher tensile secant modulus and yield stress (at 23°C with a crosshead speed of 50 mm/min). Despite its narrow MWD compared to ZN-LLDPE, the CGC LLDPE demonstrated good processability at high pipe extrusion speeds of 170 m/min.

A-238

A SMART NON-METALLIC PIPELINE ELECTROFUSION JOINT WITH EARLY DAMAGE WARNING FUNCTION

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This paper presents an innovative smart electrofusion joint for non-metallic pipelines with an early damage warning capability. We discovered a critical phenomenon in short carbon fiber-reinforced polyethylene (SCFPE) pipes: the transition of resistivity changes from linear to exponential growth before failure. Based on this finding, a novel method for pipeline failure warning was developed, leveraging resistivity changes as an early indicator. This approach enables independent tuning of SCFPE pipes' mechanical and electrical properties, resulting in a strain self-sensing SCFPE pipeline. The system effectively provides early warnings when the applied load reaches approximately 90% of the failure strength, enabling reliable monitoring of potential failures such as leakage or cracking. This technology has been successfully applied in mountainous water supply projects in Hubei, China, where it accurately detected joint damage caused by pipeline displacement before catastrophic failure occurred.

A-262

COILING OF MEDIUM PIPES SIZES (PE PRESSURE PIPES)

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The growing demand to obtain coils out of the medium pipe diameters (90 to 180mm or 3 to 6”) of Smooth PE pressure pipes up to 250mm or 10”, lead us to develop further the larger coilers suitable for the purpose.

Producing long coils present several advantages at different stages:
It helps the logistic inside the pipe manufacturing site to work on a continuous production instead of making straight pipes, eases the installation of a long piping sections, reduce the installation time, reduce the number of welded joints, therefore the entire piping installation results quicker and cost effective.

The process to obtain coils out of 160, 180 and 250mm (6 – 10”) must take into account important aspects as: the full control of the pipe and proper securing of the coil.

To achieve the above targets, the coilers are designed with the following main features:
Automatic width adjustment and semi-automatic coil ejection with Round Pipe System, features one haul-off on board that reduces the ovalization of the pipe yet optimizes the coiling process. Automatic Strapping systems with one or two strapping heads increases the performance of the coiler making the machine safer to operate

The coils sizes obtained are optimized for transport purposes, to fit the type of trailers and then unwinders suitable for the pipe installation. The trailers are designed to allow the safer unwinding operation, releasing the residual stored energy of the pipe and, the intermediate straps applied at the end of each layer of the coil, allow to keep he coil together while dispensing the pipe until the end of the coil.

Using coils instead of straight section of pipes eases the piping installation (fewer joints and joints welding etc.). While, the long section of pipes installed without interruption or junctions increases the piping reliability. The faster installation of the piping means less time on site, reducing carbon footprint.

In the end the use of the coils brings great cost efficiencies from faster installation compared to straight section of pipes.

A-269

ASSURING A SUSTAINABLE FUTURE OF OUR INDUSTRY'S WORKFORCE – SOME NORTH AMERICAN RESOURCES FOR THOSE INTERESTED IN PLASTICS PIPING SYSTEMS

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"Education is our passport to the future, for tomorrow belongs to the people who prepare for it today."

Whether you are a novice to this industry, an experienced piping system professional, or one who is approaching retirement and has experienced the benefits of being in this industry, it is of utmost importance that resources are available to educate and train the next workforce generation on the various aspects of plastics piping systems and the opportunities available.

This paper/presentation provides some insights on available North American resources for one who may have an interest in this industry from a general perspective of standard development organizations or industry association programs such as the ASTM Emerging Professionals Program and PPI (Plastics Pipe Institute) E-learning short course topics.

A-274

UV STABILIZATION OF PP USED FOR COMPRESSION FITTINGS AND CLAMPING SADDLES

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Compression fittings and branching saddles manufactured from PP-B are one of the most used fittings in Irrigation and water transportation projects. PP is a thermoplastic material made from propylene monomer that is durable, rigid and semi crystalline. Because of the presence of tertiary carbon atom in the structure of PP it is less resistant to photo-oxidation and photo-degradation compared to PE1. Because of chain session originated form photo-oxidation the mechanical properties of PP materials would be suppressed in outdoor applications[2].

Unfortunately, there is no weathering test for the material in the international norms ISO 178853 and ISO 134604 used for compression fittings and branching saddles production. Since these fittings are mostly used in outdoor applications, manufacturers normally using carbon black MB with or without UV MB having PP carrier in combination with PP-B natural grade to produce these types of fittings. The question is, if this would be enough to protect the PP-B material from photo-degradation or it need more advance stabilization. In this paper different scenarios of production and mixing of carbon black MB and UV MB were tried. In each case the 1500 hours UV weathering test applied and tensile properties in 0, 600 and 1500 hours inspected and reported. Further, the FTIR test was utilized to identify the carbonyl group, while the crystalline structure of the samples was evaluated using the DSC test. Finally, in the last part of the project a solution was offered and communicated with upper value chain and successfully developed a new material grade for this application.