



**Large Size Thermoplastic Lined Metallic Piping:
A New Solution for Old Piping Problems**

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Abstract

Metallic piping systems lined with thermoplastic materials have been widely used and proven in difficult process piping applications since their invention in the early part of the twentieth century. To date, they have been largely deployed in process piping “inside the fence line” at a variety of chemical, pharmaceutical and other process industries. The composite system has not been widely available in sizes larger than NPS 24” (DN600). There have been fundamental design constraints, even in smaller sizes, which limit the applicability and cost effectiveness of the composite system. These include, but are not limited to: spool length, configuration complexity and liner wall thickness. (The thickness of the liner wall is correlated to both vacuum and abrasion resistance.) Investment in product and process design has now enabled the production of much larger thermoplastic lined metallic piping systems up to NPS 72” (DN1800) and eliminated most constraints on length, configuration and liner wall thickness. Specifically, rotational lining in very large-scale equipment has been developed to address the specific limitations of traditional thermoplastic lined pipe and fitting offerings. A growing menu of polymers is available to custom tailor the system to the specific application.

These developments have significantly widened the application space for thermoplastic lined metallic piping. New applications include higher flow volume process lines, cooling water intakes from a variety of sources, and pipeline transportation between plants or terminals. In the case of pipeline transportation, long straight runs will continue to be lined or rehabilitated in-situ. Directional changes, elevation changes and accessories like pig launchers and catchers and manifolds can be opportunistically designed to utilize the newly developed processes and solve long standing issues in pipelines.

Thermoplastic lined metallic piping systems are now able to compete with incumbent solutions such as cement mortar lined steel piping, rubber lined steel piping and Fiber Reinforced Polymer (FRP) piping. Each solution has its strengths and weaknesses, but generally the rotationally thermoplastic lined metallic system is the most robust owing to its liners. These liners have user selectable physical properties and are mechanically bonded to the metallic housing.

This paper provides detailed discussion of the new process and product development. Perspectives will be given on specific application problems which can be addressed by large diameter rotationally thermoplastic lined metallic piping.

Rotational Molding and Lining Technology

Rotational molding and lining with thermoplastics evolved in the 1950's from earlier technologies. These included processes which involved uniaxial rotation of a mold such as spin casting of metal as well as biaxial rotational casting of various materials. Diverse lining materials were used ranging from cementitious mortars to thermosetting polymers. Sometimes, even foodstuffs, like chocolate, were used.

Today, rotational molding, or "rotomolding" is used to make an extremely diverse collection of hollow plastic articles and assemblies. Common examples are playground equipment, kayaks, trash cans and portable toilets. The basic process consists of filling a mold with plastic resin in a powder form. After the mold is charged, it is capped. Subsequently, the mold is rotated in two perpendicular axes while being heated in an oven. As the mold rotates, the thermoplastic resin charge inside tumbles around the interior of the mold and melts as the oven heat is transferred through the metallic mold shell. An analogous action for those unfamiliar with the technology, is the process of shaking flour in a cake baking pan to provide uniform coverage.

As the mold heats up, the plastic resin inside begins to melt and flow, assuming the shape of the mold. Because the mold is turning constantly, the molten resin remains on the mold walls. Eventually, the entire charge of resin is melted, and the mold continues to rotate while cooling. The resulting plastic shape mimics very closely the interior formation of the mold. The mold is designed to split apart at a parting line so the shape can be removed. Final finishing, de-flashing and assembly can be performed after molding.

Rotational lining or "rotolining" is a similar process. There are two key differences.

The first difference is that the plastic is molded into a housing from which it is not designed to be removed. This implies that more complex geometries can be created, as the designer is not limited to shapes from which the plastic can be removed. Thus, piping components with complex branching arrangements and molded in sealing surfaces become feasible.

The second key difference is that the plastic liner is intended to adhere or "melt bond" to the housing. This is a complicating factor for the rotational liner, as the shrinkage that occurs in all plastic as it transitions from liquid to solid states induces a residual stress in the liner plastic. Unrestrained, the plastic would be somewhat smaller than the housing. Adhesion limits and distributes this stress uniformly. Unadhered or partially adhered liners in rotolined articles can exhibit cracking and other stress related phenomenon.

A key development in the availability of large diameter rotolined piping has been the formulation of a new plastic with this adhesion component. For many years there was a limited selection of resins with proven ability to adhere to metallic substrates for rotolining. For piping components, primarily High-Density Polyethylene (HDPE), Polyvinylidene Fluoride (PVDF), Ethylene Tetrafluoro Ethylene (ETFE) and some Polyamide (PA) formulations were available. These are very useful plastics with specific applications. However, a performance gap in temperature rating as well as chemical resistance has been present in this conventional offering. In the next section, some key material properties will be discussed.

Traditional Rotational Lining Material Properties

- **HDPE** is a robust plastic for rotational lining. HDPE has a proven track record in lined piping for multiple types of water including fresh, brackish and seawater. It is also widely used in multiple chemical services and hydrocarbon applications. HDPE is known to swell, become softened (plasticized) and weakened by hydrocarbon adsorption, a phenomenon that is magnified at elevated temperature. Melt bonding formulations are readily commercially available. Generally speaking, it is best deployed in operating temperatures between -20°F (-29°C) and 180°F (82°C), although for hydrocarbons it should not exceed 140°F (60°C) due to the adsorption phenomenon mentioned above. Fuming Sulfuric acid, Methylene Chloride, Hydrofluoric Acid and a few other chemical species aggressively attack HDPE.
- **ETFE** is a very robust liner material. It is commercially available with proven melt bonding additives and can also be rotolined using either liquid or powder coat primers to achieve an adhered lining. Application temperatures range from -20°F (-29°C) to 302°F (150°C). As a partially fluorinated polymer, it provides near universal chemical resistance. (Although some chemical species require a reduced high temperature rating due to plasticizing effects).
- **PA** is widely used in hydrocarbon media. It is rated for use in the temperature range between -20°F (-29°C) and 180°F (82°C). Chemical applications that are not recommended are strong acids and halogenated compounds. Additionally, polyamides are hygroscopic, so water-bearing media mixtures can plasticize the liner causing alterations in the mechanical integrity as a liner.



ETFE FLANGE



POLYPROPYLENE FLANGE



HDPE FLANGE

TABLE: LINER DATA

Liner Data	Property	Polypropylene	ETFE	HDPE
	Service Temperature Range, °F	0 - 225	-20 - 300	-20 - 180
	Liner Color	Orange	Natural	Black
	Color of Identification Band	Orange with Black Lettering	Gray with Black Lettering	Red with White Lettering
	Coefficient of Thermal Expansion of Liner. (in/in/ °F)	4.8×10^{-5}	7.4×10^{-5}	6.7×10^{-5}
	Thermal Conductivity, (BTU-in)/hr-sq ft-°F)	0.8	1.65	Consult Factory
	Tensile Strength of Liner at Yield, (psi, min)	4000	6500	1760
	Elongation of Liner at Yield, (%)	10	275	400
	Compressive Strength of Liner	5500	2500	2000
	Specific Gravity	0.9	1.7	0.94
Durometer Hardness, (Shore "D")	72	72	70	

Recent Advancements in Rotational Lining Material

A primary topic of this paper is the development of a new rotolining plastic material. At the time of publication, an innovator in the field of plastic lined piping is launching a complete family of NPS 14” -48” DN 350-1200) flanged pipe and fittings lined with Polypropylene (PP). Additionally, complex piping shapes and vessels lined with PP can be provided in almost any desired configuration. This is a new development that was not available in the past. Polypropylene lined piping in this size range fills a significant temperature and chemical resistance performance gap between the current lower temperature rotolining offerings of HDPE and PA and the higher price/performance/temperature ETFE. Polypropylene with an adhesive quality provides robust chemical resistance between the temperatures of 0°F (-18°C) and 225°F (107°C). It is chemically resistant to all but a handful of common chemicals. Specific applications that are not recommended are those bearing free Chlorine and Sulfuric acid above 90% concentration.

The development of a viable PP resin formulation for rotational lining of piping components has long been an elusive goal. Despite its very desirable corrosion and temperature resistance, the resin’s natural release properties, high shrinkage and low elongation (on the order of 10% at yield and 30% at break), have combined to make existing commercial formulations impractical. In attempts to utilize existing formulations, designers encountered two distinct and interrelated failure modes associated with the inherent properties of the material. These failure modes are debonding and cracking. Several formulations exist with bonding additives, but these proved to be inadequate for all but very small piping configurations. The shrinkage that occurred during cooling in the housing imparted residual stress on the liner; a stress which is proportional to the length and thickness of the liner. No existing formulations were found which reliably bonded to the metallic housing in larger nominal pipe sizes (NPS). Bonding is vital for performance in piping applications as, in addition to the inherent residual stress from shrinkage, other stresses are imposed in actual service conditions. Among these are thermal cycling, bending and internal vacuum (external pressure). An unbonded liner will be subject to buckling

or cracking as the unrestrained stresses create strains beyond the ultimate elongation of the material. In some larger configurations, debonding and cracking were observed in uninstalled piping.

Two countermeasures had previously been deployed in attempts to produce large diameter PP lined piping. The first countermeasure was the use of very thin coatings. These can resist debonding and cracking somewhat better than normal industrial liner thicknesses due to the reduced tensile stress developed in the thin liner. The second countermeasure used two-part lining systems. A highly modified resin, rich in bonding agent, was first applied as a base or primer layer. This base layer could then be overcoated with a purer form of PP with the desired corrosion and temperature resistance. Neither of these countermeasures were practical. Thin coatings simply do not have long term stability due to effects associated with permeation. Two-part systems are both costly and ineffective for providing robust long-term bonding.

For these reasons, the development of a PP resin formulation that enables a single coat, thick lining of large piping configurations is a breakthrough. The technical team that accomplished this breakthrough used a combination of experimentation and predictive polymer material science to create both a unique formula and a unique application process. The team's innovations overcame the problems long associated with rotational lining of PP. Although the specific innovations are considered trade secrets, the below narrative describes the journey.

In setting out to develop this breakthrough technology, the research team first surveyed recent developments in PP performance enhancement in other applications. A variety of nucleating agents and impact modifiers have been shown to greatly improve toughness and reduce stress whitening (crazing) by improving elongation at yield by up to 20%. Ultimately, both these approaches were explored and utilized to some degree in the development of a robust single step rotoline grade PP. Additionally, careful control of the thermal cycle, from initial heat up through to final cooling, provides an additional "lever" which the design team utilized to optimize mechanical properties.

As materials change state from liquid to solid, nucleation is the first step as the molecules self-organize. A variety of additives known as nucleating agents are available which trigger this step. The intent of the additive is to exercise control over the size and number of nucleation sites. In polymer material science, nucleating agents typically serve as "seeds" for crystalline growth. By introducing a dispersed cloud of these seeds, some control can be gained over the size of the crystallites which form as the material solidifies. This is crucial as polymers comprised of many small crystalline structures tend to be less brittle than those comprised of fewer large crystalline structures. These particulate nucleating agents have a secondary effect in PP of increasing the overall strength of the plastic by impeding dislocation motion of individual molecules under stress.

Impact modifiers are effectively alloying agents with elastic properties. Used with caution they can significantly increase elongation at yield with a minimal effect on chemical or temperature resistance. The final generation of the PP development discussed here included a small dose of impact modifier.

And finally, by exercising thermal cycle control, the design team developed a semicrystalline polymer liner with beneficial attributes in toughness and elasticity. Specifically, a cooling cycle with increasing rate provides a polymer structure with a proportion of amorphous to crystalline regions in such a range as to optimize toughness, hardness and elasticity.

In addition to applying known polymer material science concepts, the design team utilized experimentation to evaluate the practical effects of the various combinations of formulation and process steps. They developed a unique test cell which could be efficiently rotationally lined, evaluated and recorded. Hundreds of these test cells were lined to arrive at the final optimal formulation and thermal cycle to achieve the goal of a well bonded, tough PP lined metallic housing.

Rotational Lining Materials Summary

Piping designers now have a robust suite of options for the rotational lining of pipes and fittings, components, vessels and other complex piping shapes. There are many materials and size ranges available. All commonly piped fluids, mixtures and many slurries can be conveyed in durable, low cost systems, providing countermeasures for many of the most common ills and shortcomings of traditional solutions. The newly developed PP formulation, processed in a proprietary rotational lining thermal cycle, produces a unique, cost effective and robust lining for metallic piping constructs. The following section will discuss application specifics, common issues and differences among the potential solutions.

Applications for Large Diameter Thermoplastic Lined Piping Systems

As already noted, high flow volume piping systems encounter many of the same problems as smaller piping. Many of these problems are magnified due to the physical size of the piping. Common incumbent solutions include rubber-lined piping, cement mortar lined piping, fusion bonded epoxy lined piping and FRP piping. Each of these has been developed to address a particular shortcoming or set of shortcomings of basic unlined steel piping. Some unique problems are associated with these incumbent solutions.

Process Piping

Large diameter process piping (larger than NPS 24") is relatively rare. This piping can be utilized for any of the six categories of service defined in the ASME B31.3 Process Piping Code. Piping lined with thermoplastics or any of the other solutions mentioned above are commonly used in five of the six service types defined in the ASME B31.3. (High Temperature fluid service is not applicable to lined piping.) For quick reference, below is a condensed definition of the five applicable service types in which lined piping or FRP may be practical. For full and complete definitions, please refer to the current version of the piping code.

- 1) Category D – Processes which involve fluids that are nontoxic and nonflammable, at pressures below 150psi (1035 kPa), and temperatures between -20°F (-29°C) and 366°F (186°C).
- 2) Category M - Fluids which are so highly toxic that a single exposure to a small quantity caused by leakage can produce serious irreversible harm to persons on breathing or bodily contact.
- 3) High Purity Fluid Service – Fluids with special fabrication, inspection, examination or testing requirements imposed for cleanliness or cleanability.
- 4) High Pressure Fluid Service – This is generally fluid service with pressure higher than those allowed by ASME B16.5 class 2500, but the special design considerations for high pressure may be applied to other pressure classes at the owner's discretion.
- 5) Normal Fluid Service – This is the most common service type and is fluid service to which the other categories do not apply. These can include quite toxic, flammable or corrosive fluids.

These definitions are provided to aid in understanding of the need for a lining material. For example, lined pipe can be specified in the relatively benign category D fluid service to mitigate either the long-term effects of stagnation or corrosivity of such media as brackish water. Category M services, in addition to being highly toxic, are very frequently highly corrosive and may require certain lining materials to mitigate corrosivity. In high purity fluid service, it is often the case that linings are specified to protect the fluid itself from contamination reactions with metallic piping. A great many highly corrosive fluids grouped into normal fluid service are widely used in process piping, including strong acids and bases. In these cases, piping is protected by corrosion resistant linings. Finally, high pressure

fluid services can also be corrosive. In these services, special metallic rings are generally added between flanged joints, located outside the sealing surface, to contain pressures higher than those that can be sealed by unsupported soft-liner materials.

Process Piping Applications for Large Diameter Nonmetallic Piping

As previously mentioned, it is somewhat unusual to have true piping larger than NPS 24" in process piping. However, piping with a need for lining is quite commonly connected to large diameter tanks, vessels and reactors. In these large components, robust corrosion resistance and high purity has previously been obtained using sheet lining with PTFE or, in rare cases, rubber.

These traditional solutions are marginal at best as both exhibit relatively high permeation rates. Ultimately, end of life is hastened by corrosive attack to the metallic housing, leading to thinning and reduction of the pressure containment safety factor. The permeation process is widely documented elsewhere and thus is not the focus of this paper.

A more subtle but widespread phenomenon is seam failure. In sheet lined components, sheets are welded using a variety of methods. These require a very high skill level to properly execute and are notorious for premature failure. In the case of rubber lining, raw rubber sheets are adhesively bonded to the component interior and overlapping seams are connected via vulcanization of the rubber. Properly done, the resulting seam is fully crosslinked and has integrity equal to the remaining sheet. However, airborne dust, grinding offal and other contaminants can weaken these bonds and predispose discrete seams to failure.

By contrast, rotationally thermoplastic lined process piping, tanks and vessels provide seamless, fully bonded, low permeability lining with corrosion resistance tailored to the specific fluid services.

Cooling Water Systems

In many types of plants, water is used in high flow volume applications to modulate process temperatures directly by heat sinking. Water is also used in evaporative cooling towers and condensers for distillation columns, steam power plants and other heat exchange systems. Because of the extremely high volume of flow in large scale systems, the water in these cases is typically untreated water from a nearby natural source. These sources include freshwater and brackish rivers, canals and lakes, wells and seawater. This presents a variety of unique piping challenges, as these sources vary in

corrosivity, solids content and biological content. Each of these variables is discussed in some detail below.

In some cases, in order to reduce consumption and environmental impact, cooling water is treated and recirculated. The treatment chemicals include acidic and alkaline media for pH buffering as well as biocides. This can enhance the corrosivity of the water and adds a layer of complexity to the material selection process.

Corrosivity – Corrosion is very complex. NACE International is an excellent resource for in-depth information on the topic of corrosion. A simplified explanation of the phenomenon is that virtually all forms of metallic corrosion occur through the action of the electrochemical cell. The basic components of the cell are the anode, cathode and a conductive fluid known as the electrolyte. The potential difference between the anode and cathode drives a flow of matter from the anode to the cathode, through the electrolyte. The elements of the cell can be microscopically small surface features, such as roughness or grains within the metallic crystal matrix or macroscopic features such as dissimilar metal pipes, atmospheric conditions and varying chemical concentrations.

Within a cooling water system, the electrical conductivity of the water, which acts as the electrolyte, can influence the rate of corrosion. In simpler terms, dissolved materials in the water, including mineral content or salinity, greatly affect the rate at which corrosion progresses.

Linings are considered the best line of defense against corrosion. Cooling water piping designers can select from traditional lining solutions such as fusion bonded epoxy, cement mortar and rubber. Fusion Bonded Epoxy lining is applied via spray coating and is relatively thin. It is highly sensitive to surface preparation. Holidays (pinholes) and scratches become sites for cell corrosion as all electrochemical energy is focused on these minor imperfections. Cement mortar linings have been reported to crack and spall for a variety of reasons, including water hammer and mechanical damage. Rubber lined piping exhibits high permeability to water which has been shown to cause delamination. Additionally, seams in rubber sheet liners can delaminate in high velocity flow situations.

The new product and process developments which are the subject of this paper offer a new menu of options for corrosion resistance. Within the temperature ranges listed above, HDPE, PP and ETFE rotationally lined piping offer near universal corrosion resistance with none of the weaknesses of the traditional incumbent solutions.

A less widely understood phenomenon in cooling water piping is that of Microbially Induced Corrosion (MIC). Even in situations where the user is fortunate enough to have a relatively non-corrosive fresh

water source with a neutral pH and low mineral content, waterborne microbes can create problems for metallic piping. This occurs when a small population of microbes collects on any surface imperfection. Weld seams in Electric Resistance Welded (ERW) piping as well as the interior of girth welds in butt welded systems are frequently sites where microbial colonies can take hold and begin to grow, eventually forming large gelatinous coatings and matt-like structures. This occurs in a surprisingly wide range of conditions. The phenomenon has been documented in water systems ranging from near ultra-pure to near saturated with salt and other minerals, and in flow conditions from stagnant to very high velocity. Both aerobic and anaerobic microbial life have been observed. There are multiple corrosive effects of these massive microbial colonies. The excretion of corrosive chemicals, including sulfuric acid, sulfurous acid, nitric acid and others is one corrosive effect. The generation of areas of electrochemical potential between the microbe and metallic piping that results in the acceleration of corrosion in the metal beneath the colony is another corrosive effect.

In this case, seamless thermoplastic liners offer the best-in-class countermeasures. The fundamental nonconductive nature of the polymer offers a primary line of defense as the liner prevents both the formation of an electrochemical cell as well as cathodic oxidation of the metal housing. However, some particularly aggressive microbial cultures have even been observed to metabolize and degrade polymeric linings. In these unusual cases, anti-microbial additives that can offer very stable long term anti-microbial properties can be blended into the polymer.

Solids content - Cooling water intakes are generally engineered to avoid pickup of solids such as mud, gravel and mollusk shells. Despite these efforts, there will be a fraction of continuous or intermittent solids content in the flow caused by changing river levels, storm surges and other natural phenomena. At these times, abrasion effects can become significant. Another related phenomenon is the growing occurrence of macrofauna clogging.

The abrasion of inadvertent solids intake, including sand, silt, small stones and shells, can affect unlined and thinly lined piping quite aggressively. Although lightly loaded in a traditional ppm sense, the relentless scrubbing of continuous high flow water can lead to premature piping failure. In these conditions, thermoplastic liners offer a sound solution as the resilient, hard polymer deflects most impingement. Many years can be added to a piping system life with the addition of a thick, seamless rotationally applied thermoplastic liner.

Biological Content –Macrofauna (animals large enough to be seen with the naked eye) buildup is a growing problem for cooling water intakes. Non-native invasive filter-feeding mollusks, such as zebra mussels, thrive in the intake zones of cooling water pipes at rivers and lakes. These species migrate to the pipe entrance and bond to it and the surrounding features with strong, root-like fibers. They benefit from the constant flow of their microscopic foodstuffs in the intake water. The problem arises when the

population grows to create a dense, hard mass of living and dead organisms, restricting or blocking the needed water flow.

A simple countermeasure is the addition of a biocidal dose just outside the intake point, via a counterflowing parallel pipe or hose. This discourages macrofauna growth. The biocide dose becomes entrained in the intake water and diluted to insignificance as it flows to the usage point. However, the biocide concentration can be high at the intake and for some distance downstream. In this area, liners are needed to provide a robust protection from the corrosive biocide.

Transportation Pipelines

Transportation pipelines potentially have the challenges of both process piping as well as cooling water systems. As they can transport almost any chemical, all the ills of any B31.3 fluid service, as well as the challenges of high flow cooling water systems, are relevant to pipelines as well.

End-users, designers and owners are cautioned to evaluate the service conditions for effects that could shorten service life or lessen safety factors and consider all potential countermeasures to ensure reliability.

Applications in Transportation Pipelines – As mentioned previously, transportation pipelines are typically lined or rehabilitated with an in-situ process in which long lengths of extruded thermoplastic liners are drawn through straight sections. Various strategies exist to ensure tight fit and monolithic performance of pipe and liner. Directional changes, inspection ports, instrumentation ports and branches are accomplished with fittings. These, as well as accessories with a need for corrosion resistance, are typically lined ex-situ, by a variety of processes. New polymer types and larger fittings and accessories in virtually any imaginable configuration are enabled by the rotational lining developments discussed in this paper.

Conclusion

Applied research and experimentation, coupled with significant investment in capital equipment, have dramatically widened the application space for thermoplastic lined piping, tanks and vessels. Unlimited configuration flexibility, larger sizes and a wide variety of polymers provide piping designers and owners new options for long standing, implacable problems.

Large diameter Polypropylene (PP) lined piping is newly available as a solution in this market. At a moderate price, it offers higher temperature capability, broader chemical resistance and enhanced abrasion resistance compared to many of the traditional competitive offerings.

References

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- 3) The Wikipedia - article on Rotational molding

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