CPVC/METAL/CPVC COMPOSITE PIPING SYSTEMS

Robert M. Frimel
Noveon, Inc.

ABSTRACT

For more than twenty years, CPVC compounds have been used to produce single-layer, all-plastic tube and pipe for the Plumbing, Fire Sprinkler, and the Industrial Piping markets. Due to market changes, expansions, and the inherent limits to the single-layer product, a completely new, engineered piping system had to be developed to augment Noveon’s product portfolio. Incorporating the properties of CPVC tube and pipe with the advantages of metal tubing, a CPVC/Metal/CPVC Composite Piping System proved to meet the marketing demands and the testing requirements.

This paper will present technical aspects in the development of the composite pipe engineered system. Equipment challenges, such as modified die channels and specially designed cross-head dies, to meet the thin wall CPVC tubing requirements and the shear sensitivity of the compound will be discussed. Metal forming and welding equipment had to be identified and demonstrated for the strict standards needed with the CPVC tube. Various types of equipment and system differences will be explained. Experimentation and product development optimizing multi-layer dimensions were balanced to accommodate testing and market requirements.

While continuing with the development of the CPVC/Metal/CPVC pipe, the engineered system had to include incorporation of the solvent cement fitting. New designs for the fitting system will also be presented. Discussions will concentrate on physical property data of the composite pipe, long-term stress rupture data, and testing requirements for assembly systems.
INTRODUCTION

All-plastic CPVC piping systems have been in the market since the 1960’s. The typical markets have been hot and cold potable water for residential and commercial dwellings, the light/hazard fire sprinkler application, and the industrial piping segment where chemical resistance for the piping is a requirement. These markets were satisfied by developing and improving various aspects of the physical properties of the CPVC compounds, such as impact resistance, processability, and fusion. Most of these improvements were accomplished by modifying the polymer chain or adjusting the compounding ingredients. Requirements of bendability, increased hanger support spacing, and improvements to linear expansion demanded more than chemically altering the polymer or compounding ingredients. These requirements demanded an engineering system solution to the product. Incorporating metal into the CPVC pipe addressed all of the market requirements, along with some additional unexpected benefits. By developing a CPVC/aluminum/CPVC composite pipe, one set of requirements for the plumbing market could be met and CPVC/steel/CPVC composite pipe could satisfy the fire sprinkler segment. Both markets demanded the continual use of the all plastic CPVC fittings.

The approach used for this development began with adhesives that could bond the CPVC to the aluminum and steel. After preliminary studies proved that the bond strength was sufficient for the required testing, dimensions of the inner CPVC layer and the outer CPVC layer were defined, along with the metal thicknesses for the specific targeted market. Equipment needed to be developed and designed to satisfy the dimensional specifications of the composite pipe. Finally, a new fitting design was needed to satisfy the requirements of the new engineered piping system.

DEVELOPMENT OF THE COMPOSITE SYSTEM

Adhesives

Having limited access to equipment for the development of composite piping systems, a method to determine the bond strength of various adhesives had to be designed. Many adhesives would be screened before taking the most promising through the equipment for producing composite pipe. CPVC plaques were produced and assembled on to either aluminum or steel coupons with the experimental adhesives. A low pressure applicator, a 1-kg. roller, was used to uniformly “press” the CPVC plaque to the adhesive and metal.

In the beginning, the development of the adhesive centered on thermoplastic materials. Co-polyester compounds proved to offer the most likely candidates to bond CPVC to metal. Many co-polyester compounds performed adequately at room temperature. The bond strength quickly failed as temperatures approached the required testing temperature, of 150°F or 65.5°C for the fire sprinkler piping and 180°F or 82°C for the potable water piping. Due to the softening point of the adhesives tested, the bond strength was inadequate as the temperature increased.

Thermoset materials showed the most promise in the temperatures needed for the optimum bond strength. Epoxied resins having activation temperatures close to the melt temperature
of CPVC gave the greatest bond strength. Once the thermoset was adequately activated, the testing temperatures did not weaken the sufficiently high bond strength.

**Dimensions**

Optimum dimensions for all materials of the composite system had to be achieved for the engineered system to meet the requirements, with each market dictating a different set of requirements. The plumbing market required all of the piping and assembly testing as the all plastic system – PPI approval, NSF approval, standard 61 testing, assembly testing and bendability at a minimum of 8 – 10 times the diameter as a bending radius. The fire sprinkler market required all of the approvals as the all-plastic piping system but with extended hanger spacing from 6 feet to 15 feet between hangers with less than a ¾ inch deflection in the center of the span, including the weight of water.

CPVC pipe is very rigid. A balance had to be developed between a thin layer of CPVC on the inside of the composite pipe, a thick layer of aluminum to maintain a bend with the two CPVC layers, and a thin layer of CPVC on the outside of the composite pipe. But, the CPVC layers had to be thick enough to react with the solvent cement of the fittings. A study was conducted to determine the wall thickness needed for solvent cement to penetrate, yet keep the integrity of the joint and piping system. This study found that consistent testing results occurred as the wall of CPVC approached 0.040 inch or 1.00 mm. Once the layers of CPVC were determined, the optimum balance for the aluminum thickness was analyzed to maintain a bending radius. Studies were done using .008 inch or 0.2 mm up to .016 inch or 0.4 mm wall thickness of soft aluminum. It was determined that the wall thickness could vary by 0.004 inches or 0.1 mm, depending on size of the plumbing pipe. The decision to standardize on one wall thickness of aluminum for all plumbing sizes was made for ease of production. The nominal 0.016 inch or 0.4 mm wall thickness of aluminum met the required bending radius for all pipe sizes.

A different approach for the various dimensions of the composite pipe was used to satisfy the fire sprinkler requirements. Different wall thicknesses of metal pipe were used in the determination of the 15 foot or 5 meter hanger spacing requirement. The various pipes were hydraulically filled with water. The middle of the span was accurately measured for each pipe, taking into account the added weight of the inner and outer CPVC layers. Again, for uniformity in the production arena, the 0.040 inch or 1.00 mm wall thickness steel pipe satisfied the requirements for the various sizes of composite pipe needed.

**Die and Extruder Requirements**

Due to the high shear sensitivity of the CPVC compound, die designs for pipe heads producing all-plastic, thick wall CPVC pipe have special requirements of small inventory, smooth transitions, and low shear. The challenge was to modify the CPVC pipe die for the inner CPVC layer adequately to produce CPVC pipe with a wall thickness of about half the wall thickness of all plastic pipe. The normal compaction ratio for CPVC pipe dies was changed to accommodate the small gap of the thin wall CPVC pipe. The land length had to be shortened as well due to the excessive pressure that the small gap produced.
Large capacity counter-rotating twin screw extruders that could produce reasonable rates for single wall CPVC pipe were over capacity for the thin wall CPVC pipe and produced excessive pressures for the newly designed die heads. A smaller extruder, having the required screw geometry and needed motor torque for CPVC was found in a 45 mm extruder. This smaller version of the typical production, counter-rotating twin screw could develop the CPVC compound, yet have enough motor torque to convert the electrical energy to mechanical work. Refinements of the die helped to provide extended run life for the material.

For the outer CPVC layer, modifications to crosshead die standard designs were required. The flow channels for the CPVC entering the die at 90° to the center line of the pipe had to be completely redesigned. This redesign included larger flow channels with multiple split streams. Both pressure tip and non-pressure tip dies were investigated. The pressure tip had the advantage of accommodating higher bond strength with the adhesive due to the pressure increase at the point the CPVC and metal/adhesive meet. The advantage of the non-pressure tip die design was the reduction of back pressure in the die. As the development of the bond strengths of the adhesive became greater, the non-pressured die tip became the preference. This improved run life for the outer CPVC layer. The extruder requirements for the outer CPVC layer were almost identically matched to those of the inner CPVC layer. The 45 mm, counter-rotating twin screw with the higher torque motor was the recommended machine.

**Metal Forming and Welding Equipment**

Many American and European manufacturers of metal forming and welding equipment were investigated as the requirements for the CPVC/metal/CPVC composite system became better defined. The American suppliers were limited to equipment that only produced all metal tube products, either aluminum or steel, at extremely high linear rates and large beads of weld that needed to be scarfed on the butt seam. The high linear rate of these machines was unacceptable for the rate limiting step of the CPVC extrudate and the quality requirement of a completely smooth (almost seamless) weld seam. This aspect was critical for the joining method of the CPVC fitting and the critical outside diameter of the composite pipe.

The European equipment suppliers had the converted metal forming and welding equipment of the wire and cable industry and metal profile industry. These suppliers had already begun transitioning their equipment into the composite pipe market for the PEX/aluminum/PEX multilayer metal pipe.

There were four basic differences with the types of equipment used in the manufacture of composite pipe: driven or non-driven metal formers and TIG (Tungsten Inert Gas), using electrodes, or LASER using high power light, welders. The driven metal formers could more than adequately form the 0.040 inch or 1.0 mm steel, but were over designed for forming the 0.016 inch or 0.4 mm soft aluminum. Concerns about the driven metal formers with maintenance in a production environment, along with the down time to change the entire tooling system for various pipe sizes, led to development of the CPVC/aluminum/CPVC composite on the non-driven metal forming technology. The LASER welding offered more flexibility to options if changes to the thinner wall aluminum were to develop.
As the trials on the various manufacturers’ equipment proceeded and the aluminum and steel wall thicknesses had extreme requirements with the pulling torque for the non-driven metal formers, larger pipe pullers with higher torque were being used for the product. Out of a concern for the higher torque machines, especially as the steel pipe sizes approached 2 inches or 50.8 mm, the patented split clamp caterpillar of an equipment manufacturer guaranteed an adequate system for the size of pipe needed with the CPVC/metal/CPVC composite product.

**Testing and Agency Approval**

Once samples of the CPVC/metal/CPVC composite pipe began to be produced on the defined equipment and the adhesive bond strength maintained its strength across the testing temperature ranges, pipe samples were put on long-term stress rupture testing. See Figure 2. Only the CPVC/aluminum/CPVC composite pipe was tested. The CPVC/steel/CPVC did not fail at elevated temperatures and pressure so there was not any regression line generated.

![CPVC-Aluminum-CPVC multilayer pipe at 180°F (82°C)](image)

Figure I

Three temperatures were selected for various lots of produced samples to generate data needed for PPI approval.

By testing at elevated temperatures, such as 203°F or 95°C, data could be submitted to PPI after 2000 hours of testing. Samples tested at 180°F or 82°C could be submitted after 6000 hours. Under ASTM F1281, various testing requirements have been outlined for adhesive bond strength, ring tensile test to measure the strength of the butt welded seam, burst pressure for pipe strength at room temperature, and sustained pressure for pipe strength at
elevated temperature. Again, using CPVC/aluminum/CPVC composite pipe samples, all samples met and exceeded the requirements (see Table 1).

<table>
<thead>
<tr>
<th></th>
<th>Adhesion</th>
<th>Burst Pressure Pass/Fail</th>
<th>Sustained Pressure Pass/Fail</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>lb f/inch</td>
<td>½ inch &gt; 880 psi</td>
<td>½ inch 395 psi @ 180°F or 82°C for 4 hours</td>
</tr>
<tr>
<td>Room Temperature</td>
<td>46.7</td>
<td>½ inch &gt; 880 psi</td>
<td>½ inch 395 psi @ 180°F or 82°C for 4 hours</td>
</tr>
<tr>
<td>140°F or 60°C</td>
<td>26.2</td>
<td>¾ inch &gt; 580 psi</td>
<td>¾ inch 395 psi @ 180°F or 82°C for 4 hours</td>
</tr>
<tr>
<td>180°F or 82°C</td>
<td>16.1</td>
<td>Actual pressures &gt; 1800 psi</td>
<td>Actual pressures &gt; 1800 psi</td>
</tr>
</tbody>
</table>

One of the most significant property improvements for the CPVC/metal/CPVC composite pipe product was in the coefficient of linear thermal expansion. The all-plastic CPVC pipe COLTE averaged about 70 e\(^{-6}/°C\). The coefficient of linear thermal expansion for the CPVC/aluminum/CPVC composite pipe reported at 38.9 e\(^{-6}/°C\) and the coefficient of linear expansion for the CPVC/steel/CPVC composite pipe reported at 18.7 e\(^{-6}/°C\).

**Fittings**

To complete the engineered system design of the CPVC/metal/CPVC composite pipe, a new fitting system had to be developed. Various themes for designs incorporating an inner sleeve as an all-in-one fitting proved to be cumbersome, unreliable, and expensive to modify standard fittings molds. The system that met all requirements and the least expensive to produce was a separate internal bushing with a lip to cover the cross-section of the five layers of pipe. This internal fitting, along with the outside standard fitting, comprise the complete system for the CPVC/metal/CPVC composite pipe. Not only did the assembled samples pass the hydrostatic sustained pressure test of ASTM D2848 for the CPVC/aluminum/CPVC composite pipe, but also the CPVC/steel/CPVC composite pipe assembly passed long-term hydrostatic pressure test of UL1821 (see Table II).

<table>
<thead>
<tr>
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<th>CPVC/Aluminum/CPVC Composite Pipe Assembly</th>
<th>CPVC/Steel/CPVC Composite Pipe Assembly</th>
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</thead>
<tbody>
<tr>
<td>Hydrostatic Sustained Pressure</td>
<td>6 samples out of 6 must pass</td>
<td>Long-term Hydrostatic Pressure Test</td>
</tr>
<tr>
<td>6 minutes @ 551 psi (37 Bar) and 180°F (82°C)</td>
<td>1000 hours @ 370 psi (24.8 Bar) and 150°F (65°C)</td>
<td></td>
</tr>
<tr>
<td>4 hours @ 403 psi (27 Bar) and 180°F (82°C)</td>
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Even though the internal bushing reduced the inside diameter of the pipe at the fitting, all composite pipe systems significantly exceed the International Plumbing Code water distribution system design criteria required capacity at fixture supply pipe outlets.
Conclusion

The development of the CPVC/metal/CPVC composite pipe engineered system presented a challenge not only in the development of the materials, but also in the design of the equipment. The thermoset epoxied resin adhesive had the greatest bond strength across the required temperature range. This adhesive allowed all five layers of the pipe to perform as one single layer. The aluminum and steel had to be defined for each targeted market and their respective requirements. The CPVC compound needed to be adjusted for processability through high shear dies. The modifications to the die designs were developed for the thin wall CPVC requirements. The metal forming and LASER welding equipment were developed for the entire product range for both thin wall aluminum and thick wall steel. Finally, the fitting system had to be optimized to pass the stringent requirements of the agencies and the standard that govern the pipe industry. Currently, the CPVC/aluminum/CPVC composite pipe for ½ inch and ¾ inch sizes has an NSF SE listing. A project to modify an existing standard has been initiated in ASTM. The CPVC/steel/CPVC composite pipe will begin to be tested through the agencies for the fire sprinkler market.
Key Words for CPVC/metal/CPVC Composite Piping Systems
Composite
CPVC
Bendable
Noveon
Multi-layer