Molecularly Oriented PVC Pipe (PVCO) for Water Transmission

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ABSTRACT:

Molecularly Oriented PVC (PVCO) is an improved material that has many potential benefits for large diameter irrigation projects. Its unique material structure gives it higher strength, improved impact resistance and higher toughness in cold weather conditions.

Recent advances in manufacturing technology have made larger diameters of PVCO possible, with 24" diameter recently becoming available in the North American market. This paper will briefly describe the molecular orientation process, the various manufacturing processes for PVCO pipe and the resulting improvements in material properties. Finally, the benefits of using PVCO for irrigation projects will be briefly discussed.

Introduction

PVC pipe has become one of the most commonly used pipes for large diameter irrigation projects. It's light weight and ease of installation, coupled with its dependability and long life span has made it the pipe of choice for the last 20 years in irrigation. In addition, new sizes and pressure ratings of PVC pipe up to 60" diameter have been developed within the last two years, giving engineers even more flexibility when designing irrigation projects.

Molecularly Oriented PVC (PVCO) pipes are the next generation of PVC pipes. PVCO is stronger, more ductile and more impact resistant that standard PVC pipe. These improved properties make PVCO pipes even lighter and easier to handle than standard PVC pipes, while carrying the same pressure rating. In addition, PVCO's improved impact resistance and toughness makes it less sensitive to installation deficiencies and rough jobsite handling.

While PVCO is a relatively new pipe material, its manufacture and testing is governed by well-established ASTM, AWWA and CSA standards.

This paper will briefly describe the molecular orientation process, the various manufacturing processes for PVCO pipe and the resulting improvements in material properties. Finally, the benefits of using PVCO for irrigation projects will be briefly discussed.

Molecular Orientation in Polymers

Thermoplastics are made up of long chains of molecules as shown in Figure 1. These molecules are made up of carbon, hydrogen and other elements. In some materials the chains are more organized and form what is called a semi-crystalline structure, while in others the chains resemble a plate of spaghetti, as shown in Figure 2[1]. PVC has this “spaghetti like” arrangement and is classified as an

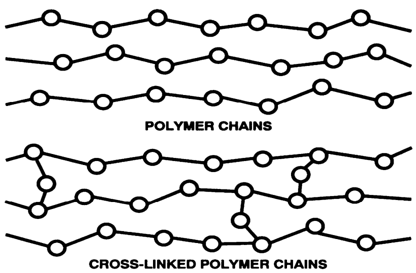

Figure 1 - Polymer Chains

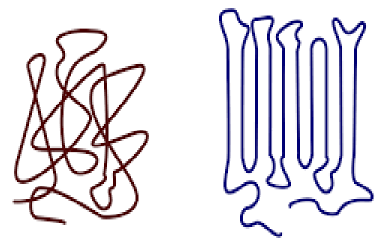
Figure 1 - Amorphous and Semi-Crystalline structures

amorphous polymer. When PVC is heated to its glass transition temperature T_g, and then stretched, those spaghetti-like chains tend to orient in the direction of the applied strain. The structure of the material itself changes, as the polymer chains “orient” in the direction of the stretching and form a lattice-like structure as shown in Figure 3[2]:

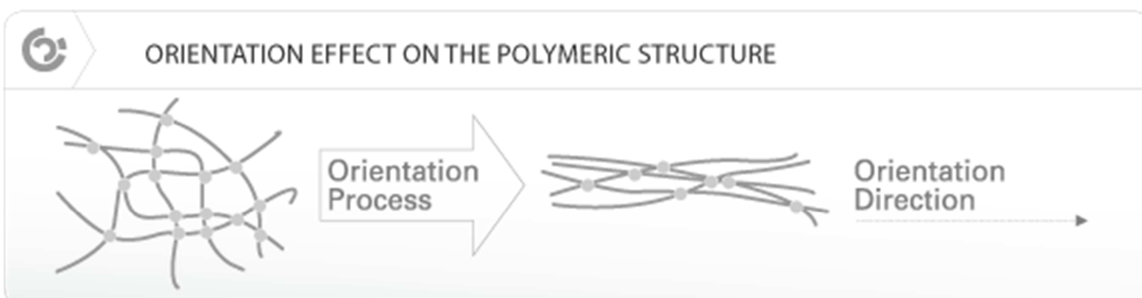

Figure 3 – Orientation Process

While all of this occurs at a molecular level, and is invisible to the naked eye, the effect on the material’s structure and properties are profound. The strength of the material increases in the direction of orientation, and the material develops a “layered” structure as shown in Figure 4.


Figure 2 - Layered Structure of PVCO

[1] https://en.wikipedia.org/wiki/Crystallization_of_polymers
[2] http://www.molecor.com/en/technology/molecular-orientation

Manufacturing of PVCO Pipe

While the beneficial effects of molecular orientation for PVC pipes have been known since the early 1970's, it was not until the 1990's that the first commercial processes were developed. These early processes were only marginally successful, and while they produced an excellent product, they tended to be prone to breakdown and production delays. As a result, PVCO remained a small "niche" product across North America.

However, with the advent of more advanced manufacturing processes in the early 2000's, manufacturing PVCO became more reliable and it became possible for larger diameters of pipe to be manufactured. While the industry was limited to 12" diameter pressure pipe 10 years ago, the pace of innovation continues to accelerate, and 24" diameter PVCO pipes are now commercially available, with 30" diameters on horizon.

The process for making PVCO is simple in concept but complicated in practice. PVC pipe is taken to a precise temperature and then stretched. Once stretched the pipe must be immediately cooled to "lock in" the orientation.

There are two distinct methods for accomplishing this. On-line processes stretch the pipe as a second step in the extrusion process. A pre-form pipe is extruded and farther down the extrusion line it is continuously re-heated and stretched over a mandrel. Once it is over the mandrel it is immediately cooled. Off-line or batch processes take discrete pre-extruded preform pipes and heat the entire pipe up to the required temperature and then expand them, using either air or hot water, in a large mold. Both processes can produce excellent results, and there are advantages and disadvantages to either approach.

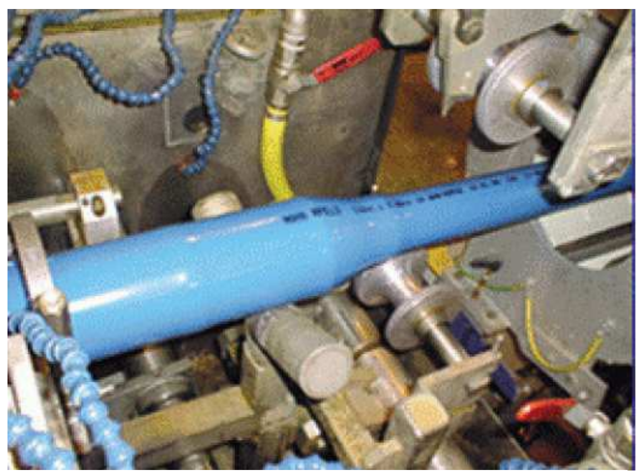

Figure 3 - On-line Orientation Process (Photo courtesy of Wavin Overseas B.V.)

Advanced Properties of PVCO

Strength – The stretching process dramatically increases the strength of the material. PVC and other plastic pipes are pressure rated based on their hydrostatic design basis (HDB), which is essentially the long term stress that the material can withstand for a minimum of 100,000 hours. PVC pipe meeting the AWWA C900/ 905standards has a long-term HDB of 4000 psi. The orientation process improves the long term HDB of PVCO to 7100 psi. This increased strength allows for increased inside diameters as less material can be used to achieve an equivalent pressure rating.

Toughness – PVCO has been proven to have much higher impact resistance than conventional PVC (Michel and Akkerman (2013)). While it exhibits improved impact strength across a wide range of temperatures, the difference becomes more pronounced as the temperature drops. This is illustrated graphically in Figure 6[3]. What is perhaps even more interesting is that the impact performance of PVCO appears to be unaffected by the presence of notches in the sample.

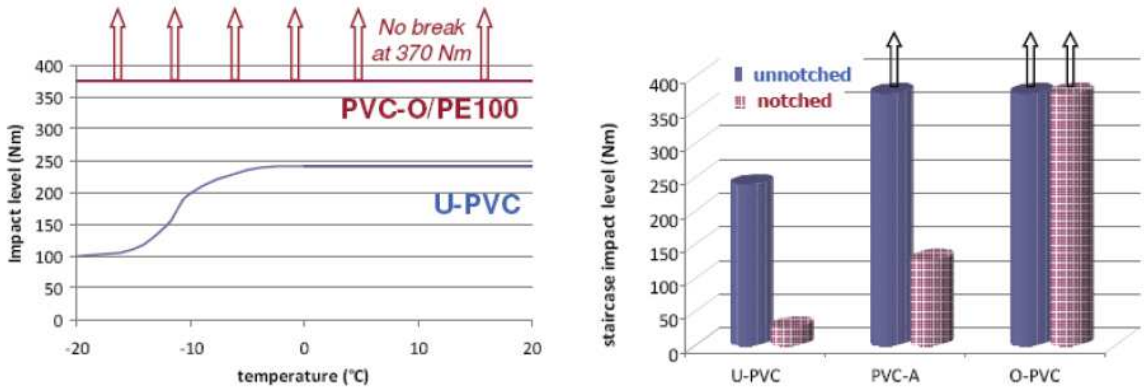

Figure 5 - Impact Resistance of PVCO

Failure Mode – The new structure created when PVC is oriented also gives the material a different failure made when compared to standard PVC Pipe. PVCO will exhibit a localized failure mode rather than a split. Figure 7 shows a 12" diameter in-service PVCO pipe that was struck by a crossbore. This type of localized failure is typical of PVCO as its layered structure tends to arrest any cracks and attenuate any propagation.

Environmental Footprint – Less material, lower weight and increased inside diameters equate to a lower life cycle cost for owners of PVCO systems. In addition, two separate studies have concluded that PVCO has the lowest embodied energy (a measure of environmental impact) of any commonly used piping material[4],[5].


Figure 4 - Crossbore Hit on PVCO

[3] Graphic taken from Catherine Michel, Johannes Akkerman; *"A Study Assessing the Performance of O-PVC in Pressure Pipes"* (2013)
[4] M. Ambrose, S. Burn; "*Embodied Energy of Pipe Networks*" (2005) CSIRO Manufacturing and Infrastructure Technology
[5] Baldasano Recio, Guererro et al; "*Estimate of the Energy Consumption and CO_2 Emission associated with the Production, Use and Final Disposal of PVC, HDPE, PP, Ductile Iron and Concrete Pipes.*" Universitat Politecnica de Catalunya, Environmental Modelling Laboratory.

Standards

The first North American standard for PVCO was ASTM F1483, which covered both CIOD and IPS outside diameters.

The majority of North American PVCO pipe is manufactured under the AWWA C909 standard (revised 2016) , which covers 4” and larger sizes.

In Canada, PVCO pipes are third-party certified to CSA B137.3.1.

Benefits for Irrigation Projects

Plastic pipes have tremendous benefits for water transmission projects: corrosion resistance, ease of installation, and excellent hydraulic properties. However, PVCO has a number of clear advantages for installers and operators of large irrigation systems:

1. Improved Cold Weather Impact Resistance – Many irrigation projects are completed during the cold winter months. As temperatures drop PVCO’s impact resistance remains extremely high, dramatically reducing the possibility of damage to the pipe during rough installation.
2. Improved Notch Resistance – Rocks and other debris in pipe bedding are far less likely to damage PVCO than any other material. In many cases this means that native backfill may be suitable many projects.
3. Improved Hydraulics – the larger inside diameters and glass like inside surface associated with PVCO pipes allowing for energy savings in pumped systems.
4. Failure Mode – in the event that a PVCO system is impacted by a crossbore or a heavy equipment strike, any damage is localized and can be easily repaired using readily available fittings.

With advances in manufacturing technology, the available diameters and pressure ratings of PVCO pipes will continue to expand. 24” pipe is currently available up to a 235 psi pressure rating, while 30” pipe rated at 165 psi will enter the market within six months.