Proceedings of the 17th Plastic Pipes Conference
PPXVII
September 22-24, 2014 Chicago, Illinois, USA

PVC-O: EXPANDING IN TECHNOLOGY AND APPLICATION

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ABSTRACT

PVC-U is used around the globe for potable water supply and sewer applications. This is due to its strength and stiffness as well as to its excellent flow properties. PVC-U shows an excellent performance in protecting the potable water quality. And it is registered that failure rates of PVC-U pipelines are very low. PVC-U has proven that it is able to maintain these excellent properties in a predictable way exceeding 50 years. It is a very sustainable pipeline material.

To further improve the excellent properties of PVC-U, the Plastic Pipe Industry has developed a new generation PVC, called oriented PVC (PVC-O).

In the first part of this paper a summary of PVC-O and its outstanding properties will be presented. The continuous in-line biaxial extrusion process will be highlighted. It will be explained why water companies and contractors appreciate the application of PVC-O.

In the second part of this paper, attention will be drawn to the possibility of creating PVC-O BiAx pipelines with demountable tensile resistant joints. 3 types of joints for PVC-O BiAx pipe will be described. For 2 types, solvent cement is used whereas the 3rd jointing method concerns a mechanical coupling. Using cement jointed couplers in combination with PVC-O BiAx pipe will be illustrated and the sound use of it will be shown in a directional drilling case.

Finally a 400-mm PVC-O BiAx pipeline project in the Netherlands will be discussed. In this project, demountable solvent cement welded tensile resistant joints are applied.

I. INTRODUCTION OF PVC-O

Since the 1950's PVC-U pipelines have been used globally in abundance for potable water supply and sewer applications. Introduction of PVC-U was accelerated due to difficulties which were encountered with traditional pipeline materials such as cast- and ductile iron for pressure applications, as well as with clay and concrete pipe for non-pressure applications. These materials appeared to have a limited life-expectancy due to their susceptibility for corrosion, soil-settlement etc. Water companies wanted to have more sustainable pipeline networks with a performance of at least 50 up to 100 years.

PVC-U appeared to have a good strength and a sufficiently high stiffness and became a dominant material. Introduction of PVC-U was smoothened due to the excellent flow properties of this pipeline material as a result of its low hydraulic roughness, compared to traditional materials. And even more importantly, PVC-U showed that it could maintain its excellent properties in a predictable way exceeding 50 years. Furthermore, throughout the years it was registered that failure rates of PVC-U pipelines were much lower than those of traditional pipe-line materials. Another factor contributing to the success of PVC-U is its excellent performance in protecting the potable water quality as proven by several studies.

In their search to further improve the excellent properties of PVC-U, the Plastic Pipe Industry started to develop a new generation PVC called "oriented PVC" or "PVC-O". Yorkshire Imperial Plastics in the United Kingdom was the first to developed oriented PVC pipe in the 1970s. Orienting the molecular structure of an extruded PVC-U pipe at elevated temperatures resulted in a significant improvement of the physical and mechanical pipe properties. A considerable increase of the hoop strength and resistance against Impact were the most appealing improvements, as also explained by Meijering (lit 1) and Chapman (lit. 2)

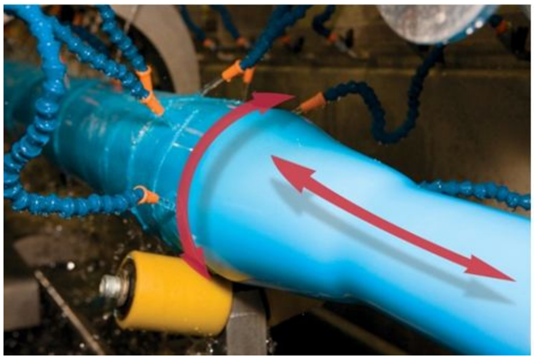

Fig. 1: *Bi-axial stretching process.*

Since the 1990's manufacturing processes were developed, such as mono-axial batch processes and bi-axial continuous in-line extrusion processes (fig. 1 and 2). The latter enhances both the radial and axial properties of PVC-O pipe and its overall pipe performance. In regard to bi-axial continuous extrusion, good quality PVC-O BiAx pipe manufacturing depends on four main aspects being the K-value of the resin, good mixing quality of the dry-blend, good fusion of the dry-blend in the extruder and a well-controlled bi-axial stretching process.

Fig. 2: *Preform with small diameter and large wall is stretched to large diameter and thin wall.*

To manufacture biaxially oriented PVC-O pipe, feedstock PVC-U pipe is stretched in two directions. During stretching, the diameter increases between 25 and 100% and the length is increased by 5 to 30%. This can be compared with a piece of rubber: when you stretch it, it will get thinner. The objective of biaxial orientation is to make the pipe stronger in two directions. Orientation takes place at the lowest temperature possible, just above the molecular freezing point. Figure 3 shows a model of a plastic molecule. This molecule can be stretched until it is completely straight, further stretching will result in rupture. If oriented PVC-O pipe is produced with the same thickness as a regular PVC-U pipe, then it can handle a higher internal water pressure. This also means that stretched PVC-O pipe can be made thinner for the same pressure application and therefore this results in considerable raw materials savings.

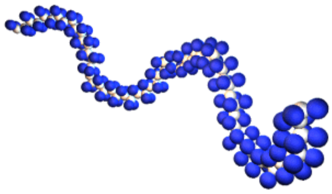

***Fig. 3:** PVC-molecule chain*

***Fig. 4:** PVC-O installation in Australia*

PVC-O pipe introduction in world markets took off, after international PVC-O standards (lit. 4, 5, 6) and reliable good extrusion equipment became available around 2000. From then on, PVC-O has proven itself globally as an excellent pipe line material for potable water, sewer and agricultural applications (lit 3). And currently several new applications such as directional drilling, above ground industrial usage and application in earthquake sensitive areas, are being investigated enabling possible introduction in new markets. Also PVC-O is advancing in higher MRS values, pressures and bigger diameters

Many water companies nowadays recognize that the development of new extrusion technologies for the manufacturing of PVC-O pipe has greatly enhanced the PVC pipe characteristics. PVC-O has up to twice the strength of regular PVC. It has a lower carbon footprint, a better resistance to slow crack growth and a much better cyclic fatigue and water-hammer resistance. Also does it have the same permeation resistance as conventional PVC-U.

Furthermore, contractors appreciate PVC-O pipe because it extremely robust, excellent in handling and therefore easy to install. This results in an increased speed of installation and hence significantly lower total installed costs. Furthermore, contractors acknowledge that PVC-O pipe is more flexible (fig. 4 and 5) and easier to use in case of bends in the pipe-line trajectory. Also is PVC-O pipe less susceptible to damage as it has an impact resistance which is 2.5 times higher than the resistance of conventional PVC-U to impact. These good impact properties of PVC-O remain also at sub-zero temperatures till -20C. As a consequence, contractors can continue installing pipelines under freezing conditions.

***Fig. 5**: Curved PVC-O pipe-line*

II. TENSILE RESISTANT JOINTS FOR PVC-O

In almost all cases, below ground PVC pressure pipe systems make use of rubber ring joints. At points of a change of direction, thrust blocks are used or reinforced soils to absorb thrust forces. This system has been used successfully for more than 50 years all over the world. In the Netherlands with its softs soils, tensile resistant joints have been developed and are used for more than 30 years. Three types of joints exist. The first two make use of collars which are cemented on the spigot end of the pipe and are locked by using a clave or circumferential wedge. The latest development is a tensile resistant joint which makes use of a stainless steel grab ring. All three tensile resistant joints are demountable.

The same tensile joints are used for PVC-U as well as for PVC-O. Studies have been performed to check if PVC solvent cement has a negative effect on the performance and strength of the PVC-O pipe. It turned out that even with a surplus of usage of PVC solvent cement, there is no effect on the mechanical performance of the pipe. Nevertheless the best solution is to make use of a narrow clearance or negative clearance type of joint. The joints to which reference is made in this paper indeed have a minimum or negative clearance. The collar is pulled onto the pipe spigot end with a special tool, removing excess solvent cement. On the contrary in PVC-U systems for plumbing we use of positive clearance in joints.

Three types of tensile resistant joint exist. Table I and figure 7 show the different types and their specifics. Type 5 is the latest development which uses a stainless steel grab ring to secure that the pipe connection is tensile resistant.

Table I: *Types of tensile resistant joints*

Type	Solvent cement	Mechanical	Full Plastics
Type 3	X	X	X
Type 4	X	X	X
Type 5		X	

In figure 6 the principle of the Type 3 coupler is shown. The collar is positioned and cemented on the spigot end. The seals take care of the tightness and the locking-rings secure the connection. In Type 3, the clave is a plastic strip which is pushed into the angular space between socket and collar. In Type 4, it is a ring which is pushed in the space between socket and collars. In both cases the joint is demountable.

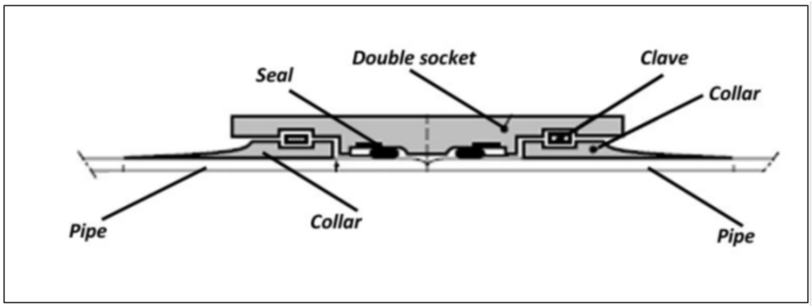

Fig. 6: *Principle of Type 3*

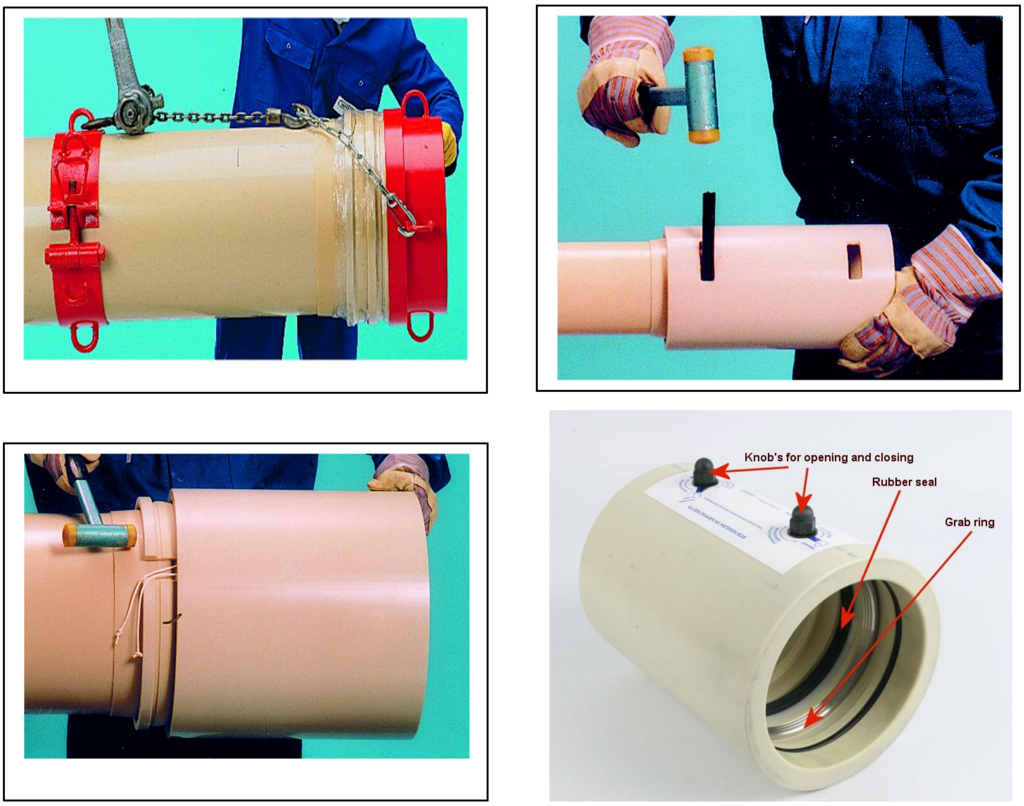

Fig. 7: *Assembly of the collar, assembly of Type 3, assembly of Type 4 and Type 5*

In addition to carrying out tests to find out the sensitivity of PVC-U and PVC-O pipe to solvent cement, also tests have been carried out to check the strength of the tensile resistant joint. The objective in this case is that the pipe should fail earlier than the joint. Testing was done by carrying out pressure tests aiming for 100 - 1000 hrs. In all cases the pipe failed whereas the joint remained intact. The joint appeared to be stronger than the pipe (see fig. 8 and 9). In paragraph III a case is shown where tensile resistant joints (Type 4) are used.

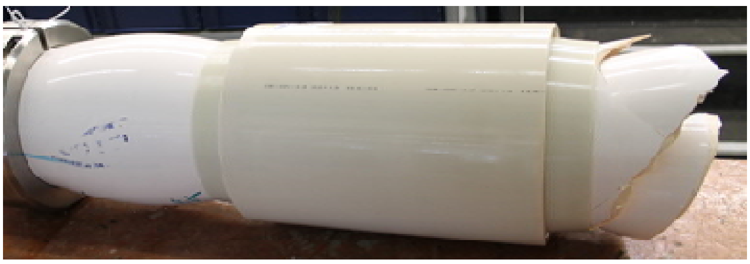

Fig. 8 and 9: *Test on tensile resistant jointed PVC-O pipe*

The use of PVC tensile resistant joints in combination with PVC-O pipe is very interesting for directional drilling applications using discrete pipes (fig. 10). Where this was not feasible with PVC-U, it is possible with PVC-O pipes, because PVC-O pipes are much more flexible. The length of the pipes can be chosen in such a way that they suit the required lengths for the project. The collars are already cement jointed in the factory. As a consequence, the time needed to connect two pipes at site is just a matter of a few minutes.

Fig. 10: *Directional drilling with PVC-O pipe*

PVC-O Pipe with pulling head just before entering the borehole

The pipes are delivered at site with collars mounted

Assembly of the next pipe

Receiving the pipe in the reciving pit

III. CASE STUDY: PVC-O PIPELINE WITH TENSILE RESISTANT JOINTS

The project:

In the Netherlands, water company WMD of the province of Drenthe, installed a 19 kilometer PVC-O BIAX pipeline (red line on map of fig. 11) from the city of Assen to the city of Beilen. All pipes had a length of 24 meter and were jointed with double couplers and with, in total 200 tensile resistant joints Type 4 (fig. 7). Furthermore 60 tensile resistant bends were installed (fig. 12).

Drinking water in the city of Beilen was not as soft as the municipality required. The water in the city of Assen however has the right hardness, because of the presence of a sophisticated water preparation plant. Having the right hardness of the water is important, both for regular consumers as well as for the industry, especially in regard to the lifetime and well-functioning of washing machines and other appliances where water is heated for private or industrial use.

In order to let the city of Beilen benefit from this, WMD water-company invested in a 19km, 400-mm PVC-O potable water transport pipeline. With this pipeline WMD resolved two problems: Firstly, drinking water produced in Beilen could be mixed with soft water from Assen; ensuring supply of good water quality to all the customers. Secondly, the pipeline secures water supply also in case of calamities. By connecting both cities, each city can supply the other city with drinking water in case of maintenance or extension of the network.

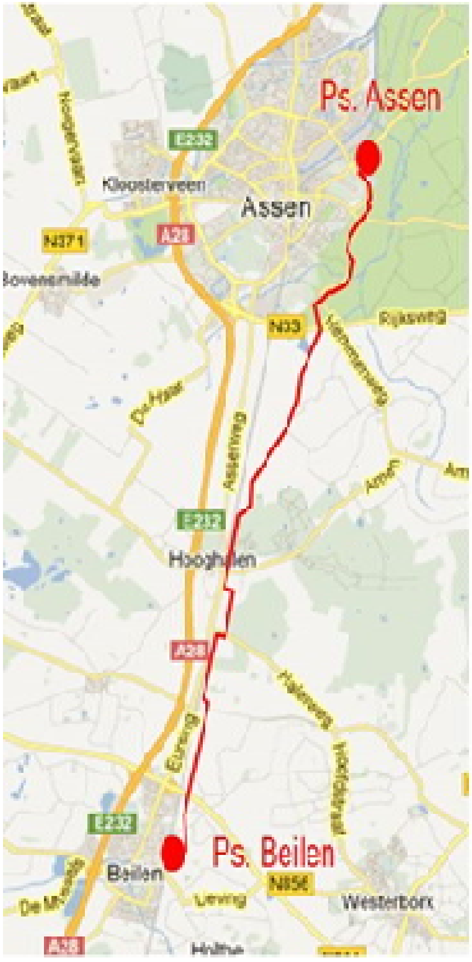

***Fig. 11**: Pipeline trajectory*

***Fig. 12:** Tensile-resistant bends*

***Fig. 13**: Double couplers*

Pipe-material selection:

The water-company selected PVC-O BiAx pipe because they have the experience that the quality of PVC-O pipe exceeds the quality of traditional pipeline materials. The biaxial stretching process reinforces the pipe-material and improves the properties as was earlier explained in this paper. For the WMD, especially the higher impact resistance, higher pressure resistance, lower installation costs and less pressure-loss were the main reasons to choose PVC-O. Other advantages WMD mentioned, are the significant lower meter weight compared to other materials, no need for welding and the ease of installation.

The WMD selected a 400-mm PVC-O pipe although a 315-mm pipe would have been able to do the job. The consideration was that in the longer term, operational costs (energy costs for pumping) could be kept lower due to the bigger pipe diameter as there would be less pressure-loss and hence less energy required to pump potable water from one city to the other. The second reason to choose an over-dimensioned pipe was to anticipate for future required additional capacity. Although the potential capacity of the pipeline will not be fully used now, it will however, in a couple of years. As the pipeline has a technical lifetime approaching 100 years, the water-company has chosen a more sustainable solution.

Production, storage and transportation

PVC-O BiAx pipes can be manufactured in any length required as manufacturing is done by an in-line continuous extrusion process (fig. 14). By being able to manufacture different lengths, tailor-made logistical and installation-friendly solutions can be offered for projects. In case of this project, the water-company selected plain-ended PVC-O BiAx pipe of 24 meters (!).

Figure 14: *Impression of manufacturing*

The big advantage of these long pipes for this project was fast installation. Although the installation costs of PVC-O pipes are amongst the lowest, by using the approach of using longer pipes, further significant savings on installation costs were achieved.

By using special lifting equipment with air-vacuum nozzles, the pipes were hoisted and installed in the trenches. Special permits were required for this exceptional transport (see fig 15).

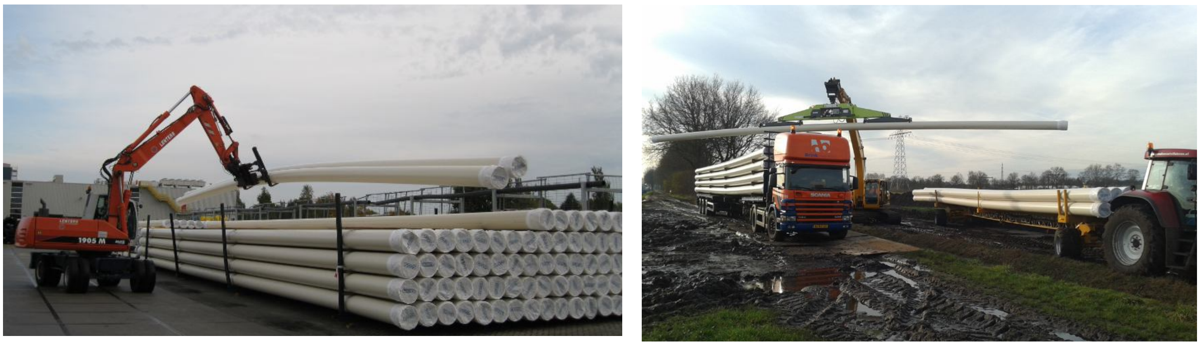

Figure 15: *Impression of storage and transportation*

The PVC-O pipes were manufactured in one continuous production run of several consecutive weeks and stored at the factory. Supply of the pipe on demand by the contractor was carried out in batches, matching the progress of installation.

Installation

The pipes were connected by 400-mm double couplers (fig. 13) and where the situation required this also by means of tensile-resistant bends and tensile resistant couplers (fig. 12 and fig. 7). Earlier, tensile resistant jointing systems (Type 1 and 2) preceded the development of Type 3, 4 and 5 joints. Type 3, 4 and 5 joints are nowadays very commonly used in the Netherlands.

Fig. 16: *19 km PVC-O BiAx pipeline 400-mm project with solvent cement tensile jointing.*

CONCLUSIONS

1. PVC-O is expanding in both, technology and in application. In regard to the technology, higher MRS values, higher pressure ratings and bigger diameters are realized.
   In regard to applications, PVC-O pipe can be used for directional drilling, (temporary) above ground applications, agricultural applications and pressure sewer. Furthermore PVC-O pipe is current being evaluated for the transport of gas and usage in earthquake sensitive areas.

2. Solvent cemented (demountable) tensile resistant joints can be used in combination with PVC-O BiAx pipe in a sound and proven way for above mentioned new and existing applications (such as potable water pipelines where previously thrust blocks or reinforced soils were required). Due to prefabrication in the factory and fast installation at site, considerable installation costs savings can be realized.

3. PVC-O pipe extrusion by means of a continuous in-line extrusion process allows for manufacturing of plain-ended PVC-O pipe of any length, from e.g. 6m up to 24m. Due to this continuous in-line process there are no pipe length limitations. There are big logistical advantages using long pipe lengths. PVC-O pipe installation costs are already amongst the lowest and by using longer pipes, further significant savings on the total installed costs are achieved.

ACKNOWLEDGEMENTS

- For extensive testing of PVC-O pipe with tensile resistant joints and subsequent discussions, Gert Nijeboer and Marc Bunskoek of Wavin T&I are greatly acknowledged.

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