Joining of PE-X-Pipes

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Crosslinked polyethylene (PE-X) pipes, successfully used for decades in house installations and heating systems, have found a new and growing application in buried gas and water supply systems, in recent years. The reason for the renewed success of PE-X is due to its unsurpassed resistance to notches. The use of sand bedding, usually required for PE pipe, can be eliminated with PE-X, owing to the notch resistance and other proven material advantages. The pipe can also be readily installed using trenchless methods (e.g. auger boring, hammer moles) without additional protective means or fear of damage. However, the decisive reason for the success of the pipe material is that there is a reliable connection method available, which works under site conditions, is simple and safe to handle, and of course also economical - electrofusion. When heated PE-X seems to have an elastomeric behaviour and in contrast with polyethylene it does not melt. This is the reason for PE-X in the past being considered not suitable for fusion jointing. The DVGW, German society for Gas- and Water distribution, awarded a contract for a research project to prove the fusion capabilities of peroxide crosslinked polyethylene (PE-Xa) with PE electrofusion couplers. In 1997 the positive results were published by GASTEC. Testmethods to prove the fusion characteristics of PE-Xa-pipes with electrofusion fittings made of PE80 and PE100 in general, and the fitness of purpose of the joints under site conditions shall be shown. An overview shall be given about latest research activities and results in fusion and butt welding of different PE-X types.

Introduction

Pipes made from cross-linked polyethylene have been applied for decades in areas affected by variations in temperature. PE-X pipes are used for floor heating systems, air conditioning pipe systems as well as for district heating systems. In addition to the user friendly advantages of the PE-HD pipe such as low weight and high flexibility, PE-X offers excellent resistance against notches and high resistance against rapid crack propagation at low temperatures. It is these two aspects which have tipped the scales in favour of PE-X in underground pipe systems for gas and water supply. The opportunity to manage without sand bedding can lead to cost saving dependend on regional conditions in spite of the distinctly higher cost for pipe material. The main area of application for PE-X is for service lines, however, mains up to d180 (ª8 IPS) are already being installed.

The crimping connection technique which is used mainly for domestic installations is not acceptable for underground pipe systems. The electrofusion method was hoped to provide an economic and reliable alternative as it was already an established jointing technique for PE-HD pipes. Cross-linked polyethylene was for a long time regarded as not suitable for welding as molten mass does not occur during the welding process. The material does not flow and its MFR value is practically nil. Due to the cross linked molecular chain the material displays elastic characteristics. Welding tests involving electrofusion fittings yielded good results

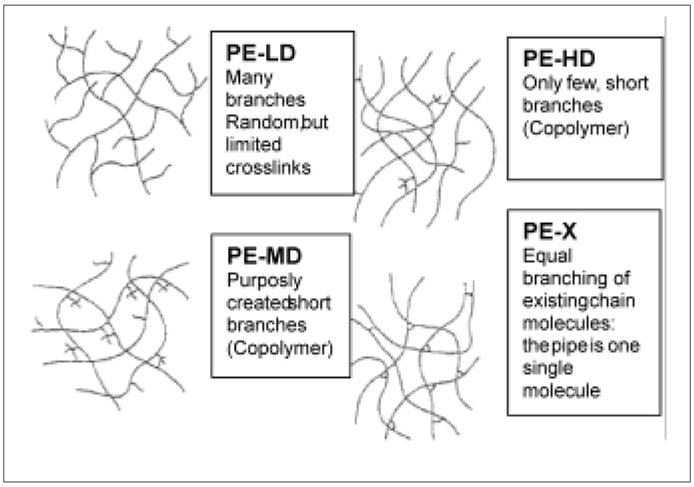

Fig. 1: Molecular structure of cross-linked polyethylene compared to LD-PE, MD-PE and HD-PE. Configuration of chain molecules in the amorphous ranges [1]

however and further checks were carried out. As well as the positive results, however, it was necessary to find a plausible theory which explains this apparent contradiction, in order for it to be applied in practice.

In 1993 the DVGW (German Society for Gas and Water distribution) commissioned the Netherland Institute "GASTEC" to test PE-X pipes for their welding suitability using the electrofusion procedure. The positive results were published in 1997. Since then the electrofusion technique has principally been regarded as a suitable procedure for the jointing of PE-Xa-pipes.

Cross-linked polyethylene (PE-X), methods for cross-linking

Figure 1 shows the molecular structure of cross-linked polyethylene compared to LD-PE, MD-PE and HD-PE. **Table 1** lists the most common cross-linking methods of HD-PE. It has been proven that welding suitability does not depend on degree of cross-linking, certainly as far as perodixically cross-linked polyethylene, PE-Xa, is concerned.

Cross-linking with peroxides

The peroxides used for cross-linking disintegrate under the influence of high temperatures. The resulting radicals tear hydrogen molecules from the polyethylene chains. Cross-linking is started by cross connection of the chain molecules [1].

Cross-linking with silicon hydride

Initially vinyl silicon hydride blends with polyethylene, with peroxide initiating the procedure. A final reaction causes siloxanic cross-linking groups to come about through steam or hot water in the presence of a catalyst [1].

Radiation cross-linking (nuclear radiation or electronic radiation)

A radiation source is the prerequisite for physical cross-linking. Most commonly electro-magnetic radiation is used here (γ-rays), which emanate from an isotope, or high energy electrons produced by an accelerator. Both procedures lead to the breaking out of hydrogen atoms from the chain molecules of the polyethylene. As this reaction takes place at room temperature, cross-linking takes place only in the amorphous ranges of the polymer material [1].

Theories for the weldability of polyethylene

In order to comprehend the weldability of PE-X it is necessary to look at existing theories of weldability of uncross-linked polyethylene. According to Brinken [2] there are four theories:

Adhesion theory [3]

The adhesion theory emphasises the importance of (almost) zero contact surface energy between two polymer materials. This condition is best met using two polymers of the same composition, as is the case when welding PE with PE. It may be expected that at least some types of PE-X differ so little in this respect from PE, that this condition may also be fulfilled when welding PE-X with PE. However, additives and impurities may affect the weld quality, depending on their type and concentration.

Diffusion theory [4]

Chains or parts of a chain must be diffuse between one material and another in order to achieve a satisfactory weld connection. Brinken concluded that diffusion in high molecular weight polymers is far too slow to justify the good welding properties of PE.

Flow process theory [5-7]

Brinken stresses the importance of the flow process theory, which is based on the work of Potente in Germany. It describes the strength of the weld increases with increasing welding pressure, until a plateau in the weld strength is reached and there is almost no further welding pressure effect.

Viscoelastic contact theory [8, 9]

The contact surfaces of the two parts to be joined are originally rough and quite small. They are increased by the effects of the welding pressure. Their strength also increases. This theory takes into account only place change procedures on a micro level. However, the effects of mechanical, macroscopic place change procedures are greater. The theory applies mainly to adhesion or ”welding” of rubber and does nothing towards explaining the welding behaviour of polyethylene.

Effects of applying these theories to the welding of cross-linked polyethylene in underground pipe system installation

The welded area must not be a weak link in the pressure pipe system of gas or water supply. Quite the contrary: it should display greater strength and long term durability than the pipe itself. Within the gas and water supply industry, pipe systems are expected to have at least 50 years‘ life expectancy. Therefore the time factor plays an essential part in determining the quality of a weld connection.

Long term strength of the material can be shown using the Lustiger model [10]: The Lustiger model shows, that the long term strength of a PE-material depends on the concentration of tie molecules in the material. Tie molecules are long molecules that interconnect the different crystals in the material and bind them firmly together.

This model is the basis for the mixed crystal hypothesis [11]. This hypothesis is used to explain long term strength at the PE/PE-X joining level: To explain the welding behaviour of PE-X with MD-PE and HD-PE, the model based on the

Tab. 1: Most common cross-linking methods of HD-PE

Pipe Description	Minimum degree of cross-linking [%]	Cross-linking procedure		
		Physically		Chemically
PE-Xa	75			Peroxide
PE-Xb	65			Silicon hydride
PE-Xc	60	electronic rays	γ-radiation	

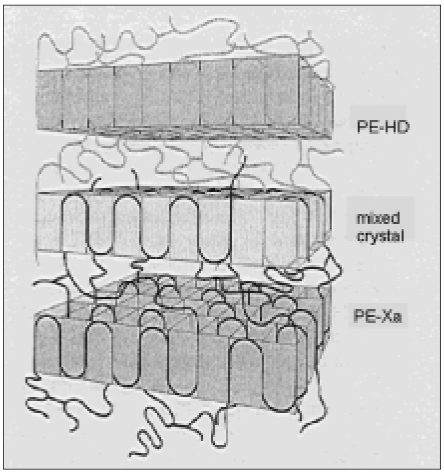

Fig. 2: Mixed crystal layer in the fusion zone between HD-PE and PE-Xa [11]

existing adhesion and flow process theories for uncrosslinked PE is completed by the mixed crystal hypothesis.

In order to achieve a long term durable welding connection between PE and PE-X, these connecting molecules in the weld area must combine not only the crystals in the PE materials, but also the crystals in the PE-X material. This means that after the mixed crystal hypothesis in the weld zone an additional layer of crystals is created which contains parts of the molecular chains of both the PE and the PE-X material (**Figure 2**).

These mixed crystals form the strong physical bonds needed to obtain a good long term weld quality [11].

This hypothesis is supported by microscopic examinations of the joints in PE-/ PE-X-welded areas [11-13].

In the meantime it has been possible to provide the evidence for the validity of the mixed crystal hypothesis. Further tests regarding butt welding of PE-X/PE-X led to the result that on renewed heating of the joining zone up to fusion temperature the transmission of force at joining level is practically nil. The physical joining strength of butt welded PE-X pipes depends exclusively on the physical fusions of the mixed crystals which occur during cooling times at about 115 °C. If this temperature is again exceeded, joining forces disintegrate almost completely [14].

Practical proof for the suitability of electrofusion technique for PE-Xa pipes

It was shown as part of the DVGW experiment ”Welding suitability and impact resistance of pipes made from cross-linked polyethylene” that pipes, fittings and tapping tees made from HD-PE pipes can be connected to peroxidically cross-linked polyethylene (PE-Xa) using the electrofusion method [13].

These findings are based on checks which had been completed successfully according to the standard checks for PE pipes, e.g. manuel fold/bend test or the long term internal pressure test.

In addition long term durability of a welded joint was tested using the long term tensile test and completed successfully. The break picture of the HD-PE/PE-Xa electrofusion joint is identical to the HD-PE/HD-PE and is therefore used as a factor in the assessment.

Extended findings for the fitting material HD-PE (PE 100, PE 3408)

Long term tensile test according to DVS-guidlines 2203-4 Addendum 1 [18] were carried out by FRIATEC in conjunction with Hessel Ingenieurtechnik, Germany, as part of the preparations for the changeover from the fitting material MD-PE (PE 80) to PE 100 (HD-PE). As well as carrying out standard material combinations using fittings and pipe PE 80/ PE 80, PE 100/ PE 80 and PE 100/ PE 100, fusions were carried out between PE 80/ PE-Xa and PE 100/ PE-Xa respectively [15].

The results are identical with those achieved under Figure 5.

During the long term tensile test there was no detection of any failure at the joining level. As was to be expected, the break invariably ran across the heating coil plane. The heating coils reduce the area which transmits strength on the test block and act as notches. This is why resistance against notches of the fitting material used is of utmost importance with regards to the long term test results.

Figure 3 shows the testing method of a long term tensile test. **Figure 4** shows the test sample from the electrofusion zone: tensile test of fusion zone between pipe and coupler. **Figure 5** shows a typical rapture in the coil plane – not in the fusion plane. **Figure 6** shows a photo of the result of a long term tensile test: Rapture of the joint between PE-Xa-pipe (white, left) and PE100-electrofusion coupler (black, right).

The Manual Folding/Bending Test

An easy method to proof the quality of electrofusion joints is the Manual Folding / Bending Test (**Figure 7** and **8**).

Additonal findings for fittings made of HD-PE (PE100) with PE-Xb-Material, ELTEX TUX100, gel content 80 %, was made under commision of ELTEX with GASTEC in September 2000. The testing

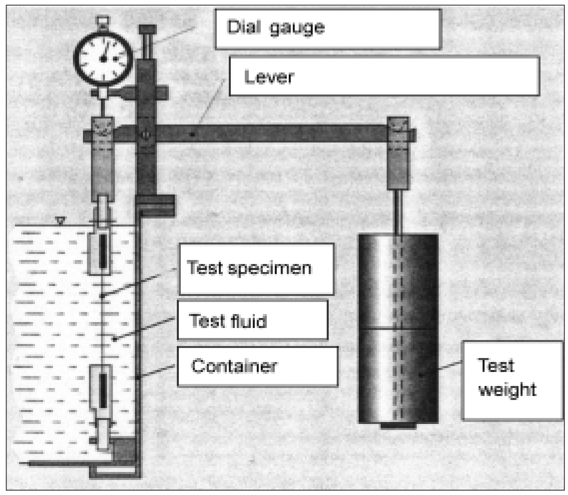

Fig. 3: Long term tensile test: Testing method

programm included electrofusion welding of couplers d 50 and d 110 (**Figure 9**), peel testing (ISO13954), infrared spectroscopy of the pipe material and electron microscopy of untested electrofusion welded specimens.

The tests shows very good electrofusion quality in the peel test according to ISO FDIS 13954. These positive results are supported by microscopical investigations.

Nevertheless long term internal pressure tests (prEN 1555-3) and long term tensile tests, e.g. DVS 2203-4, Addendum 1 are recommended to proof the fusability of new pipe material in pracitse.

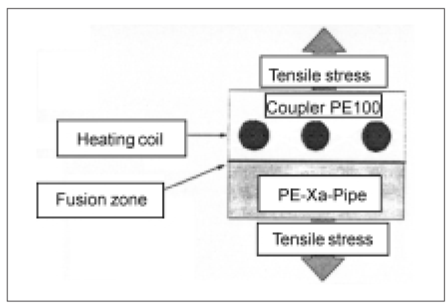

Fig. 4: Test sample from the electrofusion zone: tensile test of fusion zone between pipe and coupler

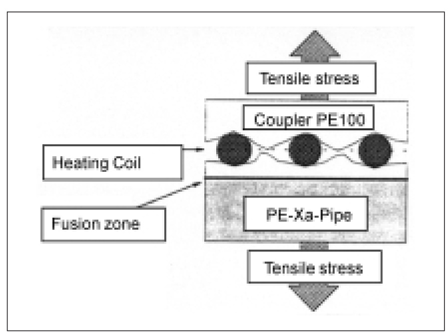

Fig. 5: Typical rapture in the coil plane – not in the fusion plane.

Fig. 6: Long term tensile test: Rapture of the joint between PE-Xa-pipe (white, left) and PE100-electrofusion coupler (black, right)

Practical Instructions

DVS-guideline 2207, Part 1, Addendum 1 (5/99)

In 1999, the draft for the DVS guideline 2207-1, Addendum 1: " Fusion of thermoplastics, electrofusion of pipes made from PE-Xa with fittings made from HD-PE" was published.

The application criteria are almost identical to the ones given for a standard PE electrofusion procedure, and are analogue to the welder's training.

The most significant differences are:

- ▷ Exclusion of butt welding
- ▷ *Scraper Tools*: Based on the tougher nature of the material, the use of rotating scraper tools is specified. Scraping off the surface with a manual scraper could mean insufficient removal of the oxidic layer and thus lead to imperfect weld quality.

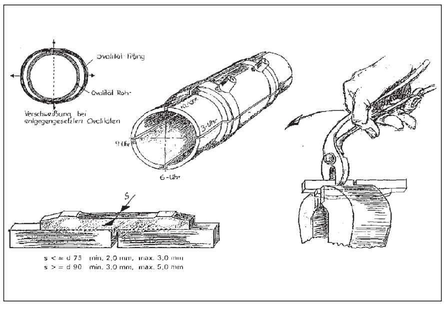

Fig. 7: Manual Folding/Bending Test

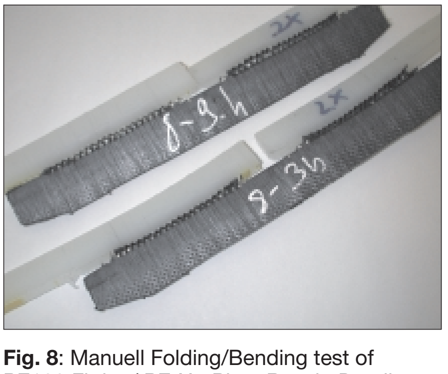

Fig. 8: Manuell Folding/Bending test of PE100 Fitting/ PE-Xa-Pipe: Result: Ductile break, high separating forces

DVGW – Worksheet G472

In 2000 the DVGW-worksheet G 472: "Gas pipe system up to 10 bar operating pressure made from polyethylene (PE 80, PE 100 und PE-Xa) - establishment" was published. It was the first German standard paper for the use of PE-Xa. The maximum operating pressure for PE-Xa pipes, SDR11 is 8 bar in this case.

Butt welding using PE-X pipes

Checks regarding best possible parameters for butt welding of PE-X pipes have been carried out using the following combinations:

- ▷ PE-Xa/HD-PE
- ▷ PE-Xa/PE-Xa
- ▷ PE-Xb/PE-Xb (cross-linked)
- ▷ PE-Xb/PE-Xb (welded first and then cross-linked)
- ▷ PE-Xc/PE-Xc (electronic ray)
- ▷ PE-Xc/PE-Xc (γ-radiation, high temperature)

Butt welding of PE-Xa/HD-PE

Internal stresses caused during manufacture are released when the pipe ends are heated and this can cause problems for the butt-welding of PE-X pipes. The dip of the pipe ends leads to a circular groove at the joint which has a negative effect on long term durability. This can be improved through repeated heating and then planing and cleaning the areas to be fused.

If these effects are minimised, short time welding factors of PE-Xa and HD-PE joints do achieve values which are comparable with HD-PE/ HD-PE-joints (fs = 0.9 up to 1.0)

The long term characteristics of PE-X/ HD-PE butt weld joints are not however anywhere near as good as those of pure PE butt welds [12].

The best results are achieved with standard PE weld parameters. Temperatures at the heating element are between 200 and 220 °C, joining pressure 0.10 to 0.15 MPa.

Whether the quality of the butt weld is linked with the degree of cross-linking of the PE-X pipe cannot be determined [12].

Butt welding of PE-X/ PE-X

The standard butt welding methods for PE yield poor results for both PE-Xa and PE-Xb.

Very good results were achieved when butt welding un-crosslinked PE-Xb pipes (as obtained on extrusion) with a gel content of 20-30 %). After butt welding, pipe including butt weld were crosslinked retrospectively in water measuring 95 °C. The test resulted in a high strength joint with ductile welds [16].

Additional testing is necessary.

Fig. 9: Manuell Folding/Bending test of PE100 Fitting/ TUX100-Pipe: Preparation – Test speciemen – Result: Ductile break, high separating forces

Summary

The electrofusion method has shown itself to be a safe, tried and tested jointing technique for pipes made from peroxidically crosslinked polyethylene, PE-Xa, in the gas and water supply industry.

Tests regarding the suitability of electrofusion polyethylene crosslinked with silicon hydride, PE-Xb, have yielded a satisfactory, equable result for this procedure. However, additional testing for practise is necessary.

Radiation cross-linked pipes, PE-Xc, are as yet insignificant in the practice of underground pipe systems. There are at this point in time no further test results.

The requested long term durability has so far not been positively proven in any butt weld joint, neither for the combination of PE-X / PE-X nor PE-X / HD-PE.

There are good prospects for weld connections in pipes which are cross-linked retrospectively after welding, either in a bain marie or using steam (PE-Xb). However, further tests are needed to make a fair assessment.

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