JOINTING METHODS FOR PE CASING PIPES OF DISTRICT HEATING SYSTEMS

F.J.M. Alferink, D.G. Blom, B. Venema and M. Wolters,
Material Research Department, VEG-GASINSTITUUT n.v., Apeldoorn, The Netherlands

Joints in PE casings of district heating pipelines are made by extrusion welding, butt welding or sleeves in which sealing is obtained by an adhesive. To set up guidelines for making these joints a lot of research has been performed, part of which is described in this paper.
Joints of a good quality are obtained if extrusion and butt welding are performed under the prescribed conditions using good equipment. In some tests in which the effects of soil conditions on the joint are simulated, welded joints proved to be better than joints containing an adhesive.

INTRODUCTION

District heating is a system by which the required heat for room heating and hot tap water is distributed by pipeline. The heat for this system is obtained from the generation of electrical energy, industrial processes, incineration of domestic waste, and central combustion of fuels. The heat is usually transported and distributed in steel carrier pipes at temperatures between 100 and 140 °C and pressures of 10-16 bar. To avoid excessive heat losses this steel pipe must be insulated. There are several ways to install the system either above ground or underground. In the Netherlands normally underground systems are used.
To ensure reliable distribution with a buried pipe system attention should be paid to protection of the insulation against mechanical damage and water ingress. This is often done by means of a PE casing pipe. In most of the systems polyurethane rigid foam (insulation) bonded to a PE casing pipe is used. The system is built up of prefabricated pipe lengths of 6, 12 or 16 metres each, and fittings like bends and branches.
For the straight pipe lengths an uninterrupted casing is used. But for the fittings the casing is mostly composed of several parts (segments) jointed by butt welding prefabricated in the factory.
To connect the prefabricated pipe sections and fittings steel welds are used for the carrier pipes, while the outer casing pipes are often jointed by means of sleeves and tightened by welding or using an adhesive.
By direct burial of the bonded steel - PUR - PE system, the soil friction is used to reduce the thermal expansion of the pipe system. Small parts of the system still move in the ground. To withstand these movements jointed casing pipes shall have sufficient strength to resist axial movements and water pressure. To obtain a watertight and strong PE joint, butt welding is normally used for fittings while extrusion welding is used for the connection of the prefabricated parts.
This paper reports on research carried out to define the conditions by which acceptable butt welds in fittings and extrusion welds in joints are obtained. In extrusion welding a distinction is made between fillet welds using a sleeve and V-shaped groove welds (Fig. 1).
The aim of the investigations performed was to set up a standardized procedure for making butt welds in fittings and extrusion welds in joints.

EXTRUSION WELDING

Description of the extrusion welding process

In the extrusion welding process the parts to be jointed are usually heated by hot air to a temperature exceeding the melting temperature of the PE pipe material. The groove is filled by a filler material which has also been heated to above the melting temperature. The plasticized filler material is pressed into the groove and is formed by a smoother. The extrusion welding process is a continuous process (Fig. 2).

The extrusion welding procedure can be divided into 5 stages:

1. Selection of the materials.
2. Preparation and positioning of the sleeve and/or the pipe. The surface to be welded must be machined and positioned in such a way that a predetermined gap is created. After positioning and machining the weld zone shall be cleaned.
3. Welding of the parts to be jointed by heating and filling the groove with melted material.
4. Cooling of the weld zone to a sufficiently low temperature ($< 40^{\circ}C$).
5. Visual inspection of the finished weld.

In the next paragraph these stages are dealt with in more detail.

Determination of the acceptable welding conditions

In the extrusion welding process many parameters play a part, such as the way of preparation, the geometry of the groove, the hot air temperature, the temperature of the filler material, the speed of filling, etc.

This study has shown that in making the extrusion welds the following items are of prime importance:

Selection of materials. Pipe, sleeves and filling material shall be made from the same raw material to ensure that the melt and flow properties of the materials are similar, and that the thermal stabilization systems of the materials are compatible.

Preparation of the welding area. To enhance fusion the surface of the pipe shall not only be cleaned, so that it is free from dirt and grease, but also its outer layer may be machined off, because this layer may have a structure deteriorated by the extrusion process (e.g. oxidation). It has been found that removal of a thin layer by sandpaper or scraping is insufficient. To obtain a good weld the surface should be machined removing about 0.5 to 1 mm of the material. In making the V-groove this is done automatically. For the fillet weld, however, special care must be taken to remove a layer of sufficient thickness.

Welding process. For the welding process itself the temperature of the hot air and the extruder, the heating time and the welding pressure are important parameters. Optimization of the extrusion welding parameters usually takes a lot of experiments. It is wellknown that a sufficiently high temperature of the polyethylene in the weld zone during the welding process is of prime importance for the weld quality. To enable recording of the temperatures in the weld zone small thermocouples were built in at different spots, and temperature as a function of time was measured. By performing such temperature measurements at different sets of welding conditions the welding process was optimized. Variations were applied, for instance, in the temperature of the hot air blowers, the distance between the two air blowers and the temperature of the plasticized filler material. The temperature measurements also provided information about the effects of the weld gap and the angle of the groove. For the V-shaped groove the weld opening shall be 3 to 4 mm, the pipe ends being chamfered to an angle of 30° each. When the gap is too narrow the hot air and the filler material will not be able to penetrate to the bottom of the groove. For the fillet weld, the sleeve shall be chamfered in such a way that the angle between pipe and sleeve edge is about 80° and the gap between sleeve and pipe shall again be 3 to 4 mm. For both the fillet weld and the V-shaped weld provisions shall be made to prevent the plasticized filler material from flowing away and to ensure that the material can be welded under pressure. To enable this the pipes for the V-shaped welds shall be internally supported and for the fillet weld the gap between sleeve and pipe shall be filled up with a strip. The support and strip shall be made from a material that does not melt and adhere to the weld and is a good thermal insulator. In cases where the above-mentioned conditions, regarding weld gap and support of the filler material were not fulfilled, the welds were of poor quality, caused by the presence of notches in the weld zone.

After laboratory studies to determine the welding conditions for V-shaped and fillet welds, experiments have been carried out to determine the effects of weather conditions to which the welding operation will be exposed on site. The material to be welded shall have a temperature of at least 130 °C during the welding operation which is 10 °C above the melting temperature of almost all HDPE types. By means of temperature measurements in the welding zone and in the filler material it was found that certain limits should be set to the wind velocity, the outside temperature and the presence of water.
It appeared that with the equipment used welds of a good quality were obtained at wind velocities up to 4 m/sec and outside temperatures above 0 °C. Moreover, water in the welding zone is not allowed.

The strength of the V-shaped extrusion joints has been determined by bending tests, bending-impact tests, tensile tests and constant tensile load tests at elevated temperatures (80 °C). For fillet welds the test methods are restricted by the geometry of the specimen. Only tensile testing and constant tensile load testing at 80 °C are suitable. In general it can be stated that by the bending test and the tensile test only very poor welds are detected. For the V-shaped weld the bending impact test very clearly showed the influence of notches. Constant tensile load testing at 80 °C enables finer distinctions to be made. Dumb-bell test bars cut across the V-shaped weld were tested at 3 MPa and 80 °C in a 5% detergent solution resulting in times to failure between 300 and 2000 hours. For specimens taken from a virgin PE pipe failure times of about 2000 hours under the same conditions were found. For fillet welds times to failure of between 700 and 1000 hours were found at a tensile stress of 3 MPa and 80 °C again, but now tested in water. The times to failure of the fillet welds are difficult to compare with times to failure for specimens taken from a virgin PE pipe, because of the added bending moment (caused by the geometry of the test specimen) in the fillet weld specimens during testing (resulting in a different stress situation). However, these times have a reasonable level as compared with times to failure given by Lüke and Krahl (1), namely 3-30 hrs at 4 MPa/80 °C in water.
Cooling of the weld zone. To ensure that the optimal strength of the weld is attained the temperature of the weld zone shall have cooled to between 30 °C and 40 °C before stressing the joint.
Visual inspection. The weld shall be smooth and uniformly shaped.

Conclusions

Concludingly, it can be stated that extrusion welding is a reliable jointing technique, provided a proper selection is made of the base materials and adequate surface pretreatment, complete root penetration of the weld and a sufficiently high welding temperature are realized. Furthermore, it is of prime importance that proper welding equipment be used and welding be performed by skilled welders.

BUTT WELDING

Introduction

Butt welds in PE casing pipes for district heating pipelines are widely used in fittings like bends, tees and valves. These welds are made in the factory or workshop. The casing pipes are rather thin-walled.
For the rather thick-walled PE pipes, as used for gas and water distribution systems (pressure applications), a lot of research on butt welding has been performed in the last few years in various countries, a.o. in the Netherlands by Wolters and Venema (2, 3). This has resulted in a welding specification, in which the welding conditions to be used are prescribed (4).
The conditions under which the rather thin-walled casing pipes are to be welded were, however, still unknown. Therefore VEG-GASINSTITUUT performed research to set up guidelines for making butt welds in thin-walled pipe segments of fittings in district heating pipelines.
Due to the presence of a steel pipe inside the PE casing pipe and the fact that sometimes mitre joints are to be made, special welding equipment is necessary. At VEG-GASINSTITUUT such equipment is not standard available. Therefore most of the butt welds needed for the investigations were made with the usual welding equipment, by which the centrelines of both pipe ends are in line with each other (so-called square butt welds).
The optimum welding conditions and the effects of small variations in the welding conditions on the weld quality have been determined using these square butt welds. By means of tests on a limited number of mitre welding joints, the results on square joints have been verified.

Optimum welding conditions

To determine the optimum welding conditions for these rather thin-walled pipes, it was verified, first of all, whether the physical processes occurring during butt welding, were about the same for thin- and thick-walled pipes. To this end temperatures at various spots in the weld zone and the displacement of the pipe ends during butt welding were recorded (2). The geometry and appearance of the weld beads were also examined. From these measurements it appeared that the physical processes during butt welding of thick- and thin-walled PE pipes were almost equal.

Hence, the optimum welding conditions for thick-walled pipes were taken as a basis for the welding conditions to be used for the thin-walled casing pipes. Various welds were made under these and slightly varying conditions and the quality of these welds was assessed by means of short-term tests (tensile test, bending test, tensile impact test) and long-term tests (constant tensile load test, internal water pressure test) (3).

It was found that butt welds of optimum quality were obtained when welding was performed using a heating plate temperature of 210 °C and a welding pressure of 0.2 N/mm^2, i.e. the same conditions which hold for thick-walled pipes.

In short-term tests these welds did not show brittle fracture, but failure preceded by yielding (plastic flow). In long-term testing the strength of these welds was nearly equal to that of the parent pipe material.

Mitre welded joints

Basically the butt welding process of mitre joints is as simple as that of square pipe ends. However, notice should be given to the fact that the fixed and movable clamps are built on a common foundation of the welding machine in such a way that the movable clamp moves according to the common centreline.

The mitre jointed butt welds (30°) showed an optimum quality at the same conditons of temperature, time and pressure as with square butt welds. In tensile testing fracture was again preceded by yield (plastic flow). In constant tensile load testing (at 80 °C in a detergent) failure times obtained for mitre joints were only slightly shorter than those for square butt welds (Table 1), which could be ascribed to the presence of additional bending loads during testing.

TABLE 1 - Results of long-term constant tensile load tests in a 5% detergent at 80°C (Ø 160 x 3.9 mm)

Weld	Time to failure (h) at $\sigma = 5$ N/mm^2		Time to failure (h) at $\sigma = 4$ N/mm^2	
	min (95%)	average	min (95%)	average
Square	13	23	25	46
Mitre 1	14	22	16	24
Mitre 2	12	20	19	40

In internal water pressure testing failure always took place in the weld zone, contrary to square butt welds, where failure always occurred in the pipe itself. This may also be caused by the additional bending loads in the mitre joint butt welded samples. Still the obtained failure times are rather high (97 to 233 hours at $\sigma = 5$ MPa/80 °C).

Influence of the welding conditions on weld quality

In the preceding paragraphs it was concluded that butt welds made under the prescribed welding conditions have a very good quality. A decrease in quality occurs, however, if these conditions are not observed.

Extensive investigations in the laboratories of VEG-GASINSTITUUT have shown that the heating plate temperature (180-260 °C) has only a minor effect on quality. The effects of welding pressure were also limited, provided that a certain minimum level (0.1 N/mm^2) was passed. The change-over-time is a critical welding parameter; wind and other atmospheric conditions also have a strong effect.

Good planing (flat, square) of the pipe ends is essential for a good quality, as well as a limit to the allowable misalignment. In other words, good welding equipment should be used.

Conclusions

It is concluded that butt welding of thin-walled pipes is a reliable jointing technique, provided that welding is performed under the prescribed conditions, good welding equipment is used, and welding is performed by well-trained operators. Draft guidelines for butt welds in fittings for casing pipes of district heating pipelines have been issued recently in the Netherlands.

JOINTING OF THE PE CASING BY OTHER MEANS

Introduction

As stated before the PE casings can be jointed by means of butt welding or extrusion welding but there are quite a few other ways of jointing the casings together. In many cases an outer sleeve made of steel or aluminium is applied. Sealing between sleeve and jacket is obtained by means of an adhesive (mastic or kit). Besides extrusion welding the joint can be made by means of so-called electroweld strips or electroweld sockets. These components (sleeve, adhesive weld) should also be strong enough to resist external loads and should be watertight.
Since the proper performance of the system largely depends on the watertightness of the joint and behaviour under soil movements, some test rigs were developed in which the entire joint is subjected to field conditions.

Axial movement test

In practice, temperature fluctuations of the fluid result in shrinkage and expansion of the pipeline. To imitate these displacements a test was set up in which the entire joint is axially moved in a bed of sand (Fig. 3). Dry sand was chosen to prevent tunnel formation. The sand pressure can be varied between 1 and 5 metres of sand head to imitate differences in backfill. Displacement speed can be chosen between 1 - 5 mm per minute and total displacement is 200 mm. The ambient temperature in sand during the test depends on the insulation value of the foam, the sand bed and the fluid temperature, which ranges from 120 to 140 °C. A requirement on the number of displacements which the joint must withstand has not yet been fixed. After a certain number of displacements the joint is subjected to a water presssure test at 0.5 bar overpressure. Water ingress is established by leak detection methods or by coloured water in the joint after finishing the test.

Bending test

In another test rig the pipe with joint is dynamically bended. As a result of traffic and soil subsidence the pipe system is subjected to dynamic bending loads. To get an impression of joint behaviour during bending a four points bending test was developed in which the entire joint is loaded with a constant bending moment (Fig. 4). The forces are exerted on points outside the joint. Bending frequency is chosen in between 0.1-1 Hz and displacement is between 1-15 mm. During the test the joint is surrounded by water to enable leak detection in case of failure. The surrounding water has a temperature of 60 °C, which was found to be the temperature occurring in practice as a result of soil insulation and heat losses of the pipe system. Elevated groundwater pressure is simulated by means of 0.5 bar effective pressure in the water tank. In imitation of traffic vibration a pulsating pressure of 0.2 bar with a frequency of 5 Hz is exerted on top of the 0.5 bar water pressure. Again, the required number of bending movements without failure, has not yet been fixed.

At the moment a few different types of joints have been tested. These tests have only been used to improve the test rigs and were not aimed at comparing different types of joints.
Nevertheless, it can be stated that in general a properly welded joint has a better performance in both test rigs than a joint containing mastic or kit.

Conclusions

Both test rigs give an insight into the quality of different jointing techniques concerning the behaviour under soil conditions. Work is in progress now on national and international level (CEN) to draft requirements for complete joints.

ACKNOWLEDGEMENT

Part of this work was sponsored by VESTIN (Dutch Association of District Heating Companies) and NEOM (Dutch Energy Development Company).

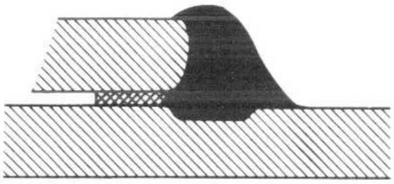
REFERENCES

1. Lüke, J. and Krahl, A., 1973, Kunststoffe 63, 772.

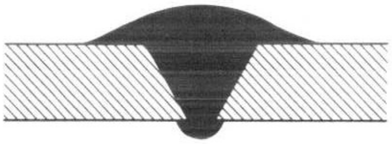
2. Wolters, M. and Venema, B., 1982, "Mechanical Quality of Welds in Polyethylene Pipe Systems", Proc. Fifth Plastics Pipes Symp., York, U.K., 26.1.

3. Wolters, M. and Venema, B., 1983, "Evaluation of Test Methods for Characterization of the Weld Quality in PE Pipe Systems", DVS Proc. Conf. Welding and Adhesive Bonding of Plastics '83, Düsseldorf, FRG, 56.

4. "Specification of Welding Method for Butt Welding Pipes and Fittings of Polythene with a Density Equal to or Greater than 930 kg/m^3", the Netherlands, 1983.



Fillet weld



V - shaped weld

Figure 1 Two types of extrusion welds

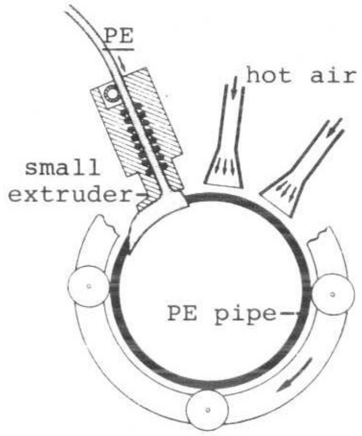


Figure 2 Extrusion welding process

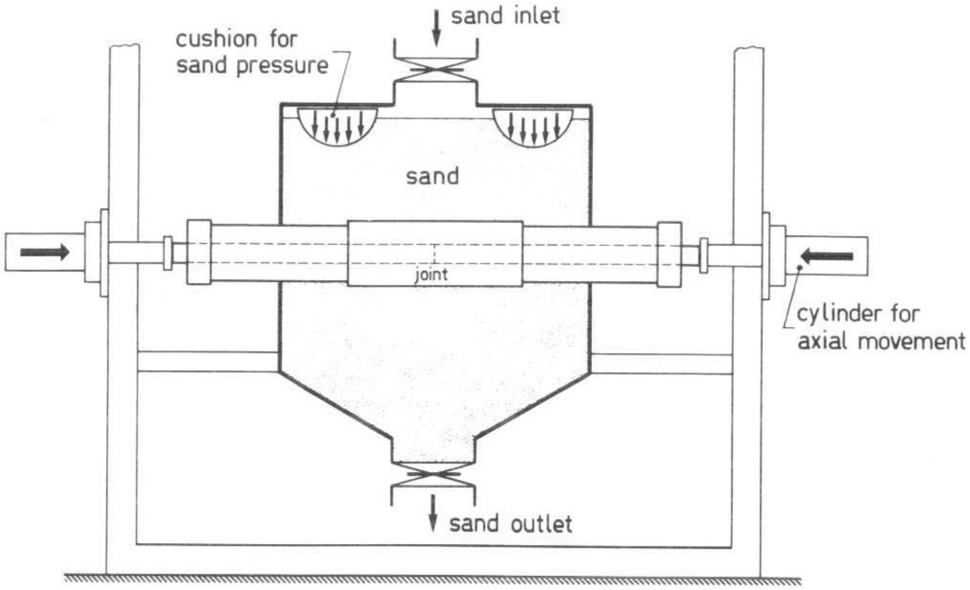


Figure 3 Test rig for axial movement test

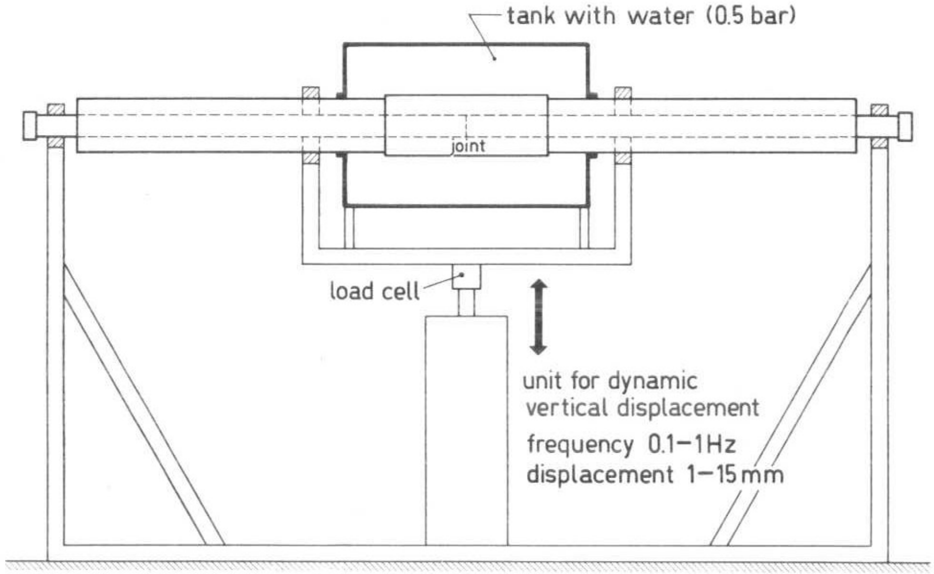


Figure 4 Test rig for dynamic bending