Butt welding of polyethylene pipes

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1. Introduction

Butt welding is often used to connect polyethylene pipes in systems for the transport of natural gas, potable water, and heating water.

Though butt welding is already a well-established technique for connecting PE pipes, renewed interest in this process was raised by the introduction of the newer PE types. The welding conditions prescribed in the various national and international specifications were laid down years ago for the older PE types. The newer PE types, however, have a different welding behaviour, which may affect the welding conditions to be used.

Therefore in the past years a lot of research on the butt welding of PE pipes has been done in the UK, Germany, the Netherlands, and other countries. This research focussed on welding of the rather thick-walled PE pipes used in gas and water distribution systems, but some work was also done on the butt welding of the thin-walled PE casting pipes used in district heating systems.

In this report the results of research on the butt welding of PE pipes performed by VEG-Gasinstituut in the last years will be summarized.

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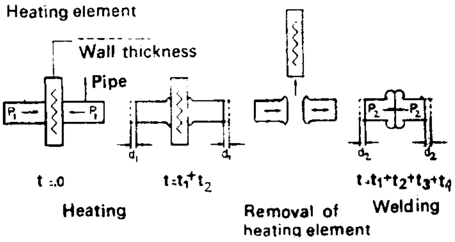

Fig. 1. Different stages in the butt welding process.

2. Description of the butt welding process

The process is basically simple : the faces to be joined are brought up to a heating plate and heated for some time, the plate is withdrawn and the two faces are then pressed together. A small bead will form on the inside and outside surfaces and this will give us some indication of the weld quality.

In the butt welding process four different stages (fig. 1) can be distinguished :

2.1. *Preparation of the surfaces to be welded*

The two pipe ends must be in complete alignment and the ovality of the pipes should not exceed certain limits. Moreover, the pipe ends have to be cut and cleaned in such a way that they are flat and square and free from grease and dirt.

2.2. *Heating of the pipe ends to be connected by welding*

Usually the heating is carried out in two steps. During the first stage the pipe ends are brought up to the heating plate under a certain pressure and held there until a bead of a certain size has formed. This heating stage under pressure is followed by a non-pressurized heating period.

2.3. *Removal of the heating plate*

After the pipe ends have been heated for a sufficient time, the heating plate is removed carefully and shortly after that (after a certain change-over-time) the pipe ends are pushed together.

2.4. *Welding and cooling under pressure*

The heated pipe ends are pushed together at a certain pressure and during a specified period.

Though butt fusion jointing is basically a simple process, many welding parameters play a part, like :

T_1 = the heating plate temperature (welding temperature)
t_1 = the heating time under pressure
t_2 = the heating time with no pressure applied
t_3 = the change-over-time of the heating plate
P_1 = the heating pressure
P_2 = the welding pressure
t_4 = the welding time under welding pressure

Many combinations of welding parameters are possible, so establishing the allowable range of welding conditions is usually a laborious task.

3. Test methods for weld quality determination

The quality of a product cannot usually be established by only one test method, a number of different tests being normally necessary. This also holds for butt welds. In the literature a lot of test methods to determine the quality of butt welds have been described. An evaluation of some of these test methods has recently been made by VEG-Gasintituut and presented as a paper at the International Conference "Welding and Adhesive Bonding of Plastics' 83" in Dusseldorf, FRG, October 1983 (Ref. 1). The main conclusions of this evaluation will be described below. Four short-term and two long-term test methods to characterize butt weld quality were evaluated. The various short-term methods were the bend test, the tensile test, the tensile impact test, and the bend impact (Charpy) test. All these tests were carried out on samples axially taken across the butt weld and at ambient temperatures (20±2°C).

For plastics short-term strength is only of limited significance ; long-term strength should be established as well. Therefore some long-term test methods were also evaluated. These were sustained internal water pressure tests of complete pipe samples and static tensile load tests of samples axially taken across the butt weld. It was found that the usual short-term tests had only limited significance. Very poor butt welds were clearly detected, but welds of a doubtful quality were often not found. By removing the weld bead before testing, the selectivity of the short-term tests was improved. Especially by tensile testing of samples from which the weld bead had been removed. Poor, moderate and good quality welds could be distinguished.

Differences in weld quality can be more clearly distinguished by long-term testing.

A disadvantage of the sustained internal water pressure tests is, however, that the tangential wall stress is twice as high as the axial wall stress. Consequently, in this test, the weld is loaded only in a restricted way in its most critical direction, i.e. axially. This is why this test is not suitable for determining the optimum weld quality, only poor welds being distinguished from good-quality welds. However, quantitative differences in weld quality can be found by performing long-term static tensile loading tests at 80°C in a detergent. These tests can be performed within acceptable periods (some hundreds of hours).

On the basis of this evaluation of test methods it is recommended to determine butt weld quality in the following way :

a) Tensile testing of samples with the weld bead left on. Very poor welds break in a brittle way in these tests.

b) Static axial loading of samples, where the weld bead is left on, at 80°C in a 5% detergent up to failure. Poor welds break in rather short times and in a brittle way. Good welds have much longer failure times.

A lot of these tests, and in particular the tensile test and the long-term static load tests, have been used to establish the optimum welding conditions.

4. Determination of the optimum welding parameters

In Section 2 it has already been remarked that many welding parameters are involved in the butt welding process, such as heating plate temperature, heating time and pressure, removal time of the heating plate, and welding pressure and time.

Optimization of the butt welding parameters and determination of the allowable range of welding conditions therefore usually takes a lot of experiments.

The number of experiments can be restricted, however, if the physical processes occurring during butt welding are better understood. Knowledge about these physical processes can be obtained by performing temperature and displacement measurements during welding.

Tiny thermocouples were built in at different spots in the pipe wall and the temperature as a function of time was measured.

Measurement of the displacement of the pipe ends occurred simultaneously and is indicative of the process of bead formation during butt welding.

An example of the results of such measurements is given in fig. 2. Butt welding of a 160×9.1 mm PE pipe was performed at a heating plate temperpture of 200°C and a welding pressure of 0.18MPa. In this case the pre-heating stage lasted about 45 seconds. In this time, t1, a displacement d1 of about 0.4 mm for each pipe end occurred. The. temperature of the welding interface was then about 185°C.

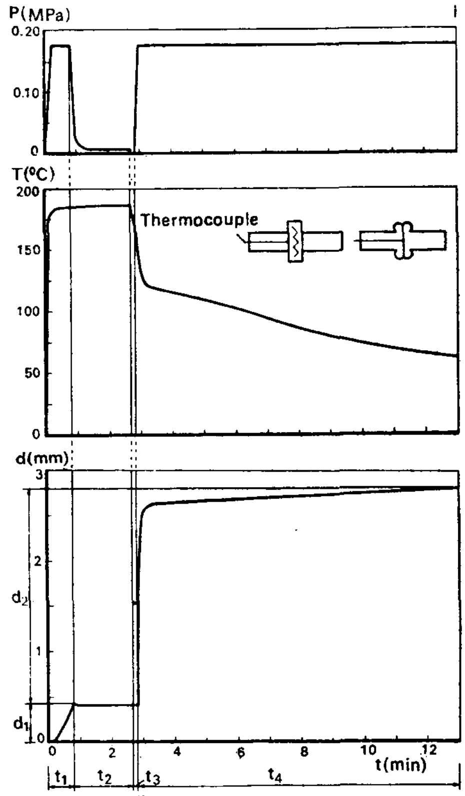

Fig. 2. Pressure displacement and temperature as a function of time during the butt welding proccss.

During the second heating stage at zero pressure the temperature on the interface only slightly increased to about 187°C and the displacement was almost constant. During the second heating stage of about 90 seconds the heat flow from the heating plate into the material only served to melt a certain layer of material.

In the removal time, t_3, of the heating plate, which was about three seconds, the temperature of the interface decreased slightly to about 170C°.

The two pipe ends were then pressed together and the weld bead formed. This formation of the weld bead was clearly indicated by a considerable displacement of the two pipe ends. For the main part, this weld bead formation process took place in a few seconds and the temperature of the welding interface decreased sharply to about 120°C, almost equal to the melting temperature of PE.

Afterwards only a gradual and small displacement took place, which can be ascribed partly to thermal shrinkage effects. The temperature in the middle of the pipe wall gradually decreased to about 60°C at the end of the welding process.

By performing such measurements with various sets of welding parameters, it was found that the physical processes during welding were almost the same in a rather broad range of temperatures and pressures.

Welding displacement always occurred within a very short time interval, which means that the weld bead was formed rapidly. After this quick welding displacement the temperature on the welding interface was always about 120°C. It was found that almost all melted material formed in the heating stage was pushed outward to form the weld bead. Variations in the heating stage, e.g. by changes in temperature and time, therefore only affected the amount of welding displacement and so the size of the weld bead. But the physical processes leading to bonding on the interface (e.g. diffusion) were almost unaffected.

Butt welding can be considered as a kind of self-correcting process. Surplus molten material is pushed out to form the weld bead. The size and geometry of the bead, of course, may affect the weld quality, but the quality of the joint is primarily determined by bonding on the welding interface. The conditions for good bonding on the welding interface proved to be almost equal in a broad range of welding temperatures, welding pressures and heating times. It is therefore expected that the weld quality will be almost constant in this range of welding parameters.

By these tests it was confirmed that butt welds of a good quality are obtained at welding temperatures between 180°C and 260°C and welding pressures between 0.1 and 7.0 MPa. These conclusions were based on results of experiments of various PE types used for gas and water distribution systems. Almost all of these PE types can be welded at the same set of welding parameters.

These extensive investigations (Ref. 2), in which butt welds were made at many sets of welding parameters, pipes of various diameters and wall thicknesses were welded and tested, and different PE types (resins) were used, resulted by the end of 1983 in a draft specification for butt welding of PE pipes and fittings, in which the allowable welding parameters are carefully prescribed (Ref. 3).

At the right combination of welding parameters and under proper conditions, as described in the draft specification, butt welds of a high quality will be obtained having no detectable defects and with mechanical strength properties that are approximately equivalent to those of the parent pipe material.

If, however, butt welding is not carried out in a proper way, substandard joints may be obtained. For instance :

- Poor equipment may cause misalignment of the pipe ends.
- Voids may be introduced in the weld zone due to shrinkage on cooling if the welding pressure is too low.
- Excessive change-over-times of the heating plate may result in incomplete adhesion.
- By improper cleaning of the pipe ends inclusions may occur in the weld zone.

In this way the mechanical strength of the weld can be reduced considerably.

In conclusion, it can be stated that butt welding is a reliable jointing technique, provided that the right set of welding parameters and proper welding equipment are used, and welding is performed by a well-trained welder.

References

1. M. Wolters, B. Venema, "Evaluation of test methods for characterization of the weld quality in PE pipe systems. Paper presented to the International Conference "Welding and adhesive bonding of plastics" Dusseldorf (FRG) 12—13 October 1983.

2. M. Wolters, B. Venema, Mechanical quality of welds in polyethylene pipe systems. Paper presented to the fifth Plastics Pipes Symposium, York (UK) September 1982.

3. "Specification of welding method for butt welding pipes and fittings of polyethylene with a density equal to or greater than 939 kg/m³, Dutch draft specification, November 1983.