

Analysis of a joint of steel and high-density polyethylene

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ABSTRACT

Purpose: The paper deals with a new design of a joint between a steel pipe and a PE-HD pipe, which is called a transition piece and is intended for transmission of liquid and gas media. As a pipe fitting it connects a PE-HD pipeline, which is usually laid underground, outside a building, and a steel pipeline, which is mounted in a building.

Design/methodology/approach: Paper gives some theoretical considerations on welding steel with PE-HD and other joining processes suitable for dissimilar materials such as metals and plastics. A production technology, stress calculations for the joint and an analysis of testing of the transition piece are described. An experimental research of a new “joint” between steel and PE-HD pipes is given.

Findings: The most important part in formation of a joint between steel and PE-HD pipes is played by an internal sleeve of high-alloy stainless steel, which expands the PE-HD pipe mounted in the interior of the expanded part of the steel pipe by elastic mechanical force. Theoretical stress calculations indicating the force required to tear the PE-HD pipe from the transition piece constitute an important part. An analysis of pressure and strength tests under different conditions, i.e. with different temperatures, moisture conditions, inner overpressures and underpressures, is given.

Research limitations/implications: The possibility of application of this research work for study an other of the transition piece, which are consisted of an other dissimilar materials.

Practical implications: Such joints, called transmission pieces, are possible applied to residential premises where the steel part makes the beginning of a steel fitting in the house and the PE-HD pipe the end of the outside pipeline network.

Originality/value: The paper presents a completely new design of the transition piece, which does not consist of any screw elements or seals made of materials susceptible to quick aging.

Keywords: Welding; Transition piece; Joint between steel and PE-HD; Stress calculations; Mechanical testing;

1. Introduction

Requirements to join dissimilar materials are more and more frequent in every day life. Consequently, in various research organisations in different countries, welding of dissimilar metals, of various clad materials, of ceramics to metals as well as welding of plastics to metals, particularly steel, are studied. All these studies have in common that dissimilar materials having different

physical and chemical properties are to be joined, and the joints themselves are based on different physical principles.

The kind of principle governing a joint between two elements made of dissimilar materials depends mostly on the kind of the material used and the extent of physical, chemical, and metallurgical differences between the two materials. The greater these differences are, the more difficult it is to produce a welded joint. In general, only a few principles are known which ensure a quality welded joint of two dissimilar materials having appropriate

mechanical, corrosion, and other properties. The most important are the principles based on interatomic, intermolecular, micro-mechanical, adhesive, cohesive, electrochemical, electrostatic, and other forces. There is certainly more than one principle simultaneously governing bonding of two dissimilar materials. In the case that the above-mentioned properties of the two materials differ to such an extent that a direct joint is not possible to produce, a third material compensating the differences to the largest possible extent is to be used.

Such a case is undoubtedly the joint between a synthetic material such as thermoplastics and a metal, particularly steel.

The paper treats a study of the welded joint between steel and high-density polyethylene (PE-HD). The workpieces had the form of pipes joined into a butt welded joint which should be fit to transmit various media such as water and gases. Such joints, called transmission pieces, are usually applied to residential premises where the steel part makes the beginning of a steel fitting in the house and the PE-HD pipe the end of the outside pipeline network.

The basic purpose of the transition piece is to ensure absolutely leakage-free transition of a medium in all transition (pressure, temperature) and ambient conditions (different moisture and temperature), and to withstand eventual dynamic loads in the building. The latter may occur particularly in houses near busy traffic roads due to heavy lorry traffic. The joint has also to withstand loads in the case of an eventual earth-quake.

Generally it may be stated that the joint between steel and PE-HD is based on several physical and chemical principles. In addition to adhesive forces acting between the two materials, there are mechanical forces due to the joint structure, and some others.

2. Review of welding literature

The majority of researchers dealing with bonding of synthetic materials with metals, including bonding of steel and high-density polyethylene (PE-HD), has applied chiefly two methods. The first and most commonly used method is adhesive bonding. The second is conventional mechanical bonding by screws, rivets, and other screw connections. Joining of polyethylene and a metal by adhesive bonding has been mostly studied.

Mechanical joining of two materials is most often used with pipe elements intended for transmission of liquid and gas media. Such a joint is most often used to connect two pipe systems. Natural-gas pipelines outside residential premises, for example, have lately been made of polyethylene pipes while inside residential premises they have been made of steel. The transition piece, as it is usually called, is located underground, particularly in the building wall.

This indicates that such a piece should be of the highest quality, to be capable of sealing at different temperatures and moisture, and to withstand mechanical loads due to an earthquake or other mechanical reasons.

Some cases of mechanical connection of a polyethylene pipe and a steel pipe are going to be described under heading 3.

Investigations of joining synthetic materials with themselves and with metals go back very far [1-4]. In these references, adhesive bonding with different adhesives, of differently shaped joints, of different materials and, for various purposes is described.

In reference [4], adhesive bonding of metal elements with metals clad with polymers is described. The metal materials used were steel, galvanised steel, high alloy stainless steel, pure aluminium, brass, and copper. In the study two different adhesives based on epoxy resins and one based on polyurethane rubber were used.

Two types of joints were studied. The first was a conventional lap joint and the other a butt joint. After adhesive bonding, the joints were tested in terms of strength using a tensile test and a shear-tensile test. The results obtained indicate that the strength of the joint between a metal and a metal clad with a synthetic material is primarily affected by properties of the adhesive applied. An appropriate preparation of the surfaces to be joined also has an important influence on the joint strength.

Welding, brazing, and adhesive bonding of various materials, including thermoplastics, with a metal are described in ref. [5].

Several authors [6-8] carried out quite extensive studies on bonding of plastics with metals. The majority of the studies were focused on adhesive bonding of lap joints on thin materials, i.e., those having thickness between 0.8 and 3 mm. Quite some time was spent on studies of an optimum preparation of the surfaces to be bonded on the joint strength. Five different methods were used for surface preparation of both materials concerned, i.e. steel and polyethylene. The most important conclusion drawn from the studies is that the surface preparation prior to adhesive bonding is of decisive importance to obtain a quality joint and that the method used affects strength properties of the joint as a whole.

Similar investigations were reported by some other authors [9]. Some researchers have studied a joining of the steel with the steel which was coated by HD polyethylene [10-11].

3. Description of the problem and possible solutions

As already mentioned, the objective of the investigation described was to join PE-HD to steel, particularly a PE-HD pipe to a steel pipe, while keeping the change of the outside pipe diameter as small as possible and the inside pipe diameter almost unchanged throughout the joint. In addition, the joint should be absolutely tight regardless of different ambient conditions (temperature, moisture) and show satisfactory mechanical properties and good corrosion resistance. One of the mechanical properties is also joint resistance to various dynamic loads. Although the joint is primarily intended to transmit liquid and gas media, and mainly located underground, such dynamic loads may occur. They may be due to an earthquake or busy traffic of heavy lorries and trains on nearby roads and railways respectively.

3.1. Is it possible to produce a joint between PE-HD and steel without a buffer layer of a third material?

Simple welding of the two materials concerned in a welded joint is not possible due to their different chemical, physical, and other properties. Some characteristics of the two materials are given in Table 1.

Table 1. Some basic physical and chemical characteristics of PE-HD and steel

	STEEL	PE-HD
Melting point (°C)	1530	130 - 135
Density at 20°C (g/cm ³)	7.8	0.95
Strength at 20°C (N/mm ²)	200 - 700	20
Strength at 80°C (N/mm ²)	200 - 700	5
Hardness (N/mm ²)	100 - 1000	50
Specific heat (J/kgK)	0.48 - 0.52	0.01 - 0.05
Heat conductivity (W/mK)	25 - 59	0.50
Toughness ISO-V	40 - 200	0.1 - 0.4
Young's modul (N/mm ²)	210·10 ³	800

Microstructures of the two materials are shown in Fig. 1. It is known that steel crystallises in regularly shaped cubic lattices which may be face- or body-centered. Ferrite steel, which is primarily used for steel pipes, crystallises in a body-centered cubic lattice. That is to say that atoms in an individual crystal grain are arranged in a regular geometrical shape. The boundary among individual crystal grains has an optional shape. In PE-HD, atoms form molecules, and the latter, in turn, chains, which give this material its characteristic properties.

If in iron, e.g. α -iron, the distance between atoms is to be increased, a strong force, i.e. high energy, is required. In the elastic zone this distance may be increased only for a few tenths of a per cent although the total elastic zone of steel is much larger. It depends on several factors, particularly the kind and quantity of alloying elements in steel and its heat treatment.

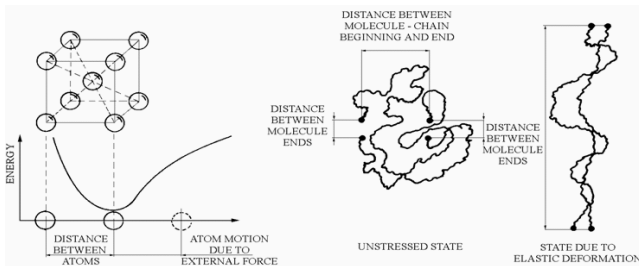


Fig. 1. Microstructures of PE-HD and steel, particularly arrangement of basic elements (atoms and molecules) in both materials: PE-HD (right) and steel (left)

With thermoplastics, particularly elastomers, a much weaker force is required for elastic deformation due to a particular connection of basic elements, i.e. molecules, into chains, the deformation thus being much stronger. With some types of thermoplastics it may increase by several hundred per cent. Fig. 2 schematically shows a difference between the metal and thermoplastics.

Following the data given in Table 1 and the schematic representations in Figs. 1 and 2 it is quite clear that the two materials concerned can not be joined in a conventional way, irrespective of the procedure.

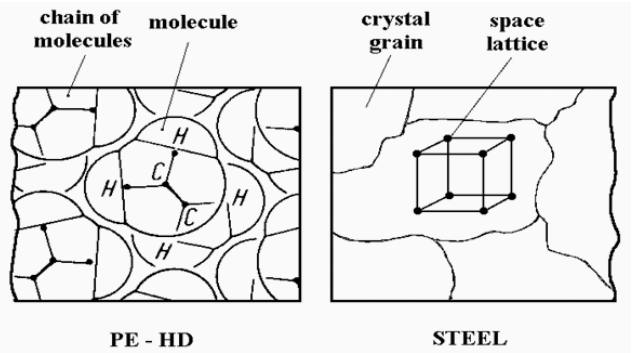


Fig. 2. Schematic representation of connection among basic elements in iron, i.e. atoms, and in polyethylene, i.e. molecules

Fig. 3 gives rise to further considerations. Why could not a crystal lattice of steel and a PE-HD molecule be bonded, if not metallurgically or chemically, at least mechanically? All which is to be done is to “insert” a PE-HD molecule among crystal lattices or among crystal grains, and a welded joint will be obtained. The question, however, remains open how to carry out such an operation, and particularly under which conditions and at what cost.

Under certain conditions such a joint may certainly be produced. Yet economic considerations do not justify R&D studies in this field, particularly since the demand in such joints in the market is low.

Generally, certain conditions (vacuum, temperature, shielding atmosphere) and energy are required for welding of the materials. The energy may be electrical, chemical, which changes into thermal, or mechanical (ultra sound, friction, compression). Fig. 4 shows three methods of direct welding and one method of indirect joining.

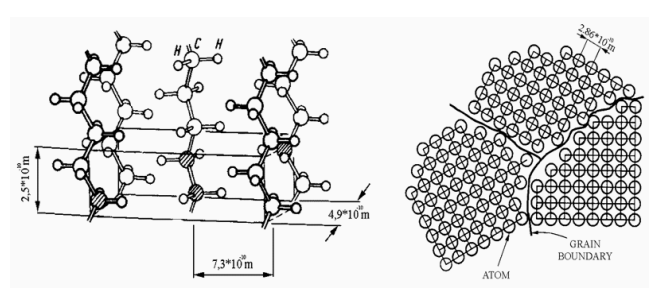


Fig. 3. Schematic representation of PE-HD and steel workpieces and their microstructure

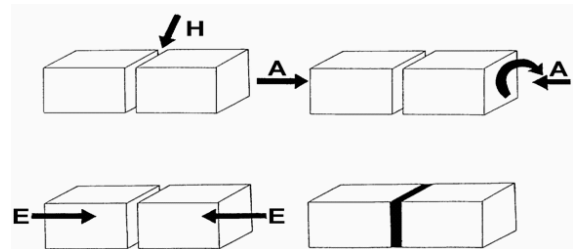


Fig. 4. Four different methods of joining materials

The first method makes use of thermal energy (H), the second mechanical energy (A), the third electrical energy (E), i.e. electric resistance, and the fourth a third material being an adhesive or a material clad on the metal by spraying, evaporation or electrochemical process (PVD, CVD). When ceramics is deposited on a metal or on PE-HD, the two workpieces may be joined in different ways. Some of the techniques are described in various articles [12-16].

3.2. Transition piece

The basic function of the transition piece has already been described. It is schematically shown in Fig. 5. The connection between the steel and PE-HD pipes may be produced in different ways, such as mechanical, electrochemical, physical. The basic task of the joint is to be absolutely tight and show satisfactory mechanical strength. Some known cases of the mechanical connection of the transition piece are described under heading 3.3.

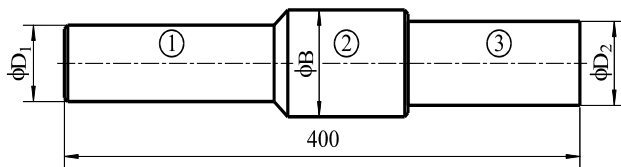


Fig. 5. Schematic representation of the transition piece

3.3. Description of individual solutions regarding production of the transition piece

Some particular uses of the transition piece have necessitated the development of some versions which are complicated, time- and space-consuming when integrated in a main system. Fig. 6 shows a transition piece without an expandable sleeve acting as a screw joint. The steel socket (1) with a male thread is intended to be connected to a pipe with a female thread for a screw cap (3). The joint includes also a connecting ring (2), a seal (4), a thrust ring (5), and a PE-HD pipe (6).

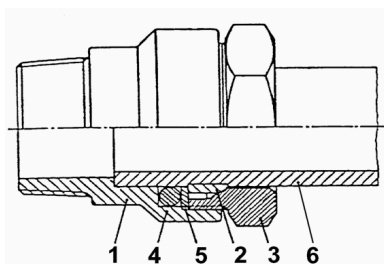


Fig. 6. Transition piece with an expandable sleeve. 1 - socket with expandable sleeve; 2 - connecting ring; 3 - screw cap; 4 - PE-HD pipe

The transition piece as a plug joint is shown in Fig. 7. The socket (1) shows a male thread for connection to the steel pipe. At the other end, the socket is conically shaped and has a seal (3) and

a conical connecting ring (2) inserted. In assembling a firm connection is formed by joint the socket cone, the conical connecting ring (2) and the seal (3).

Fig. 8 shows a transition piece with a flange. The steel socket (1) is conically shaped and mounted in the PE-HD pipe (4). The steel pipe has a flange (2). A seal (5) is mounted between the socket and the steel pipe. A screw collar ring (3) presses the PE-HD pipe to the socket (1) to form a firm connection. The joint between the steel pipe with the flange (2) and the screw collar ring (3) is made with screws (6) and nuts (7).

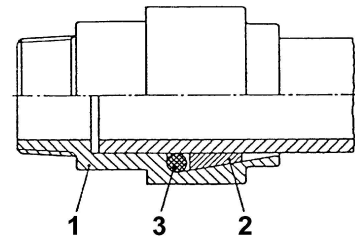


Fig. 7. Transition piece as a plug connection. 1 - socket; 2 - conical connecting ring; 3 - seal; 4 - PE-HD pipe

A short analysis of the four versions of the transition piece indicates that their production is complicated and the reliability of tightness dubious.

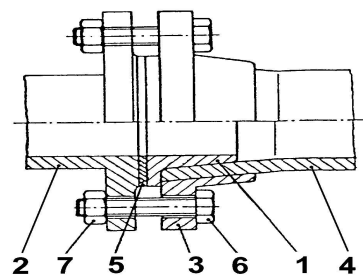


Fig. 8. Transition piece with a flange. 1 - socket; 2 - steel pipe with a flange; 3 - screw collar ring; 4 - PE-HD pipe; 5 - seal; 6 - screw; 7 - nut

In all the cases concerned the connection between the PE-HD pipe and the metal (pipe, socket, connecting ring) is based on the principle of friction. Because of eventual mechanical vibrations, temperature dilatations it may also fail.

These were the reasons for searching other solutions to the problem of connection of the steel and PE-HD pipes.

The first studies focused on finding a suitable adhesive and a suitable joint shape. Here the experiences of other researchers, i.e. authors, [4, 6-9, 15-22] were considered.

In all the cases a joint with an effective surface as large as possible was searched for. In spite of the fact that quite favourable results in terms of joint strength and tightness were obtained with several adhesives, we decided otherwise. No data, namely, could be obtained on how a particular adhesive ages with time, what the influence of environment on the adhesive-bonded joint may be, how the adhesive and the adhesive-bonded joint behave when attacked by various chemicals which might penetrate the ground.

4. A new design of the transition piece

On the basis of practical experience, theoretical studies, cost-effectiveness calculations, and long-time pressure tests under various conditions, it was decided to design a new transition piece as shown in Fig. 9. The correctness of the decision was confirmed by testing the transition piece in accordance with guidelines DVGW 600 VP.

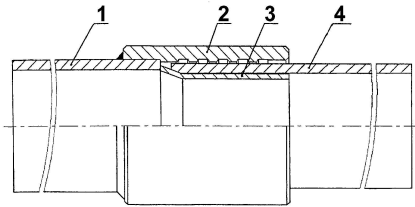


Fig. 9. Transition piece and its constituting parts. 1 - steel pipe; 2 - welded pipe connection; 3 - inside steel sleeve; 4 - PE-HD pipe

The steel part of the piece (1, 2 in Fig. 9) is made of a pipe having one end expanded. The pipe and the expanded part have been joined by MAG welding. The inside of the expanded part is not smooth, but has several grooves cut. The second part of the transition piece (4) is a PE-HD pipe.

The purpose of the grooves in part 2 (Fig. 1) is to increase the faying surface between steel and PE-HD and formation of a “mechanical” connection between the two elements. At the inside of the PE-HD pipe a stainless steel ring (3) is mounted which, due to its elasticity, considerably contributes to strength and tightness of the transition piece.

Transition pieces may be manufactured in various sizes. Some of the most frequently used combinations of steel and PE-HD pipes, including sizes, are given in Table 2.

The steel pipe and its expanded part welded to the pipe are made of low-carbon steel S 355 J0 (EN 10027-2). The inside sleeve is made of high-alloy steel X 5CrNi18-10 (EN 10027-2). The polyethylene pipe is designated SDR 11 PE80 in accordance with ISO 4437.

Table 2. Some of the most frequently used combinations of steel and PE-HD pipes

	STEEL PIPE	PE-HD PIPE
	D (mm) x s (mm)	d (mm) x s (mm)
20 - 3/4"	26.9 x 2.65	20 x 2.0
25 - 3/4"	26.9 x 2.65	25 x 2.3
32 - 1"	33.7 x 3.25	32 x 3.0
40 - 5/4"	42.4 x 3.25	40 x 3.7
50 - 6/4"	48.3 x 3.25	50 x 4.6
63 - 2"	60.3 x 3.65	63 x 5.8
75 - 2 1/2"	76.1 x 3.6	75 x 6.8
90 - 3"	88.9 x 3.6	90 x 8.2
110 - 4"	114.3 x 4.05	110 x 10

D (mm) – diameter of steel pipe
 D (mm) – diameter of PE-HD
 s (mm) – thickness of the wall of the pipe

For efficient assembly of the transition piece, all the elements concerned have to be produced in the tolerances specified. The PE-HD pipe shall be introduced into the expanded part of the steel pipe (part 2 in Fig. 1) by applying force. Then, using a special device the stainless ring is introduced into the polyethylene pipe also by applying force. The ring will expand so as to get stuck, at the inside of the transition piece, at the edge between the metal pipe and the expanded part of the pipe (parts 1 and 2 in Fig. 1).

5. Stress calculation

The stress calculation was made for the transition piece having the dimensions shown in Fig. 10.

In this connection, a few suppositions, e.g. deformation of the inner steel ring and of the wall of the PE-HD pipe (Fig. 10), were made.

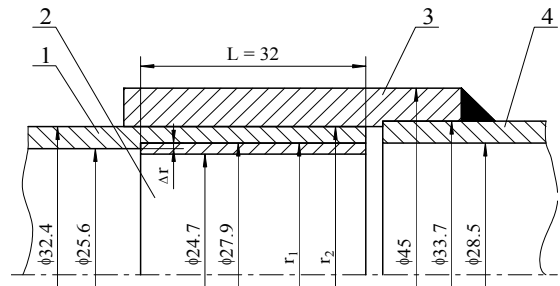


Fig. 10. Partial cross-section of the transition piece including data required for the stress calculation. 1 - PE-HD pipe; 2 - stainless-steel sleeve with a wall thickness of 1.5 mm; 3 - steel ring; 4 - seamless steel pipe

5.1. Mathematical model of the joint strength

The deformations with a (small enough) elastic deformation obey Lamé’s differential equation of equilibrium [17, 23]

$$2(1 - \sigma) \operatorname{div} \operatorname{grad} u + (1 - 2\sigma) \operatorname{rot} \operatorname{rot} u = 0 \tag{1}$$

If the longitudinal shifts are neglected, a pure radial deformation, $u = u(r)$, is obtained. Consequently $\operatorname{rot} u = 0$ and Eq. (1) turns into Laplace equation

$$\operatorname{div} \operatorname{grad} u = \Delta u = 0 \tag{2}$$

which gives in cylindrical coordinates

$$\frac{d}{dr} \left(\frac{1}{r} \frac{d}{dr} (ru) \right) = 0 \tag{3}$$

which has a double parametric family of solutions

$$u = Ar + \frac{B}{r} \tag{4}$$

$r_1 < r < r_2$ (see fig. 10)

The values A and B are selected in such a way that the shift at the inner pipe edge amounts to Δr and at the outer edge to 0, i.e., $u(r_1) = \Delta r$ and $u(r_2) = 0$. A linear system of equations is obtained for A and B :

$$r_1 A + \frac{B}{r_1} = \Delta r \quad (5)$$

$$r_2 A + \frac{B}{r_2} = 0 \quad (6)$$

which has the following solutions:

$$A = -\frac{r_1}{r_2^2 - r_1^2} \cdot \Delta r \quad \text{and} \quad B = \frac{r_1 r_2^2}{r_2^2 - r_1^2} \cdot \Delta r \quad (7) \quad (8)$$

which gives for u

$$u(r) = \Delta r \cdot \frac{r_1 r_2}{r_2^2 - r_1^2} \cdot \left(\frac{r_2}{r} - \frac{r}{r_2} \right) \quad (9)$$

where:

$r_1 = 13,85$ mm – inside diameter (see fig. 10)

$r_2 = 16,2$ mm – outside diameter of PE-HD (see fig. 10)

$\Delta r = 0,8$ mm – deformation of inside edge of PE-HD pipe

This function is almost linear in the interval $[r_1, r_2]$, i.e., practically it does not differ from the linear function

$$u_*(r) = \Delta r \cdot \frac{r_2 - r}{r_2 - r_1} \quad (10)$$

5.2. Stresses

A relationship between stresses and shifts is expressed by Hooke's law. In our case this is [15]:

$$\sigma_r = \frac{E}{1 + \sigma} \left(\varepsilon_r + \frac{\sigma}{1 - 2\sigma} \varepsilon_v \right) \quad (11)$$

where

$$\varepsilon_v = \frac{\partial u}{\partial r} + \frac{u}{r} \quad (12)$$

where:

σ_r (N/mm ²)	-stress
$E = 800$ N/mm ²	-Young's modulus of PE-HD
$\sigma = 0,45$	-Poisson number of PE-HD
$f = 0,101$	-coeff. of friction between steel and PEHD
ε_v	- volume dilatation
ε_r	-dilatation in the direction of radius

Here it has already been taken into account that the deformations in directions ϕ and z are negligible:

$$\sigma_r = \frac{E}{(1 + \sigma)(1 - 2\sigma)} \left((1 - \sigma) \frac{\partial u}{\partial r} + \sigma \frac{u}{r} \right) \quad (13)$$

Because of

$$\frac{\partial u}{\partial r} = -\frac{r_1 \Delta r}{r_2^2 - r_1^2} \left(\left(\frac{r_2}{r} \right)^2 + 1 \right) \quad (14)$$

and

$$\frac{u}{r} = -\frac{r_1 \Delta r}{r_2^2 - r_1^2} \left(\left(\frac{r_2}{r} \right)^2 - 1 \right) \quad (15)$$

we obtain

$$\sigma_r = -\frac{E}{(1 + \sigma)(1 - 2\sigma)} \cdot \frac{r_1 \Delta r}{r_2^2 - r_1^2} \left(1 + (1 - 2\sigma) \left(\frac{r_2}{r} \right)^2 \right) \quad (16)$$

5.3. Force of friction

The force required to achieve separation of the joint should be equal at least to the force of friction which is resisting it. The force of friction is obtained by the integration of the stress across the joint surface, i.e., in our case across the inside of the outer cylinder. All together is then multiplied with the (static) coefficient of friction f

$$F = 2\pi r_2 L \sigma_r(r_2) f \quad (17)$$

so that the force looked for amounts to

$$F = 4\pi f \cdot \frac{(1 - \sigma)E}{(1 + \sigma)(1 - 2\sigma)} \cdot \frac{r_1 r_2 \Delta r}{r_2^2 - r_1^2} \cdot L \quad (18)$$

where:

$L = 32$ mm - joint length

F (N) - force required to tear the PE-HD pipe out of the joint

$$F = 3.1 \cdot 10^5 \text{ N}$$

This force is most likely too high and undoubtedly exceeds the breaking force of the PE-HD pipe.

5.4. Relaxations

This is all true at the moment of joint establishment. With plastics, deformations and stresses are a function of time [18] and decrease with time; therefore, the force in Eq. (17) should be multiplied with the factor of relaxation

$$\left(1 + \frac{t}{b} \right)^{-k} \quad (19)$$

where there is $k \approx 0.5$ and $b \approx 10^{-5}$ hours for polyethylene. The expression for force F is thus the following:

$$F = 4\pi f \cdot \frac{(1-\sigma)E}{(1+\sigma)(1-2\sigma)} \cdot \frac{r_1 r_2 \Delta r}{r_2^2 - r_1^2} \cdot L \cdot \left(1 + \frac{t}{b}\right)^k \quad (20)$$

6. Study of mechanical and tightness properties of the steel/PE-HD transition piece

The idea of the new design of the transition piece was followed by theoretical stress calculations, determination of production technology, and dimensional, mechanical and pressure tests. At first stage, quite a general visual inspection tried to detect eventual defects, particularly cracks at the contact between steel and PE-HD. Numerous mechanical destructive tests were also intended to provide some information. In longitudinal static tensile tests almost in all cases a failure of the PE-HD pipe occurred while the steel/PE-HD joint could bear higher static shears loads.

6.1. Dimensional and visual inspections

The dimensional inspection of the transition piece was carried out after its production, during and after thermal testing. The thermal test consisted in exposing the transition piece for 50 hours to a temperature of 70 °C and for another 50 hours to a temperature of -10 °C. During the test the ovality of the PE-HD pipe in the transition piece, its outside diameter and wall thickness were measured. Maximum deviations at the elevated temperature, i.e. 70 °C, and at the lowered temperature, i.e. -10 °C, did not exceed 1.1 %. These values are much lower than those stated by various guidelines.

In visual inspection, eventual cracks or other imperfections in the transition piece as a whole were to be detected [23-25].

6.2. Longitudinal tensile test

The longitudinal tensile test was carried out on a special equipment. That is to say that only a force acting in the longitudinal direction and exerting no influence was present

A basic requirement was that during testing the steel/PE-HD joint remained intact and no cracks or damages occurred at individual constituent parts of the joint. The admissible load during the tensile test, Z , amounted to 7.5 N/mm², which is the admissible load of PE-HD.

During testing the calculated admissible tensile force was reached in 10 - 15 seconds, and was then maintained for one hour with an accuracy of ± 2.5 %. The testing temperature was 23 ± 2 °C. The joint withstood testing with the admissible stress without any permanent deformation.

It should be mentioned, however, that various guidelines and regulations specify a different course of testing and offer a

different explanation. DVGW 600 VP, for example, states that a relative movement of the PE-HD pipe from the socket immediately upon acting of the admissible tensile force is not considered as pulling-out of the pipe if the movement stops in a testing time of one hour. If there is another relative movement between the pipe and the socket at the end of the test, the test shall be repeated till the movement has stopped and the pipe gets pulled out of the expanded part of the steel part respectively [24 - 27].

6.3. Bend test

The bend test of the transition piece was performed in order to determine joint tightness and detect eventual cracks at the PE-HD pipe. The test was carried out on a special bending device shown in Fig 11.

The transition piece with the pipe end with a free length l_1 was mounted into the machine, namely between the socket to be tested and the shutoff device.

The pipe was bent over a bending template with a bending length l_2 and a bending radius r so that finally the pipe lay on the template and equally long pipe parts at the socket and at the shutoff device remained free.

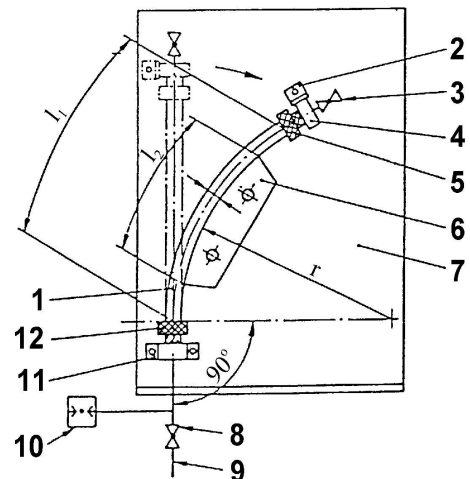


Fig. 11. Bending device. 1 - PE-HD pipe; 2 - stop; 3 - relief valve; 4 - holder; 5 - shutoff device; 6 - bending template; 7 - testing plate; 8 - shutoff valve; 9 - connecting pipe to pump; 10 - pressure gauge; 11 - connecting piece; 12 - limit stop

At a testing temperature of 20 ± 2 °C the tested pieces in a bent state were subjected to an internal pressure p which is calculated using a special equation:

$$P = (2 \cdot s_{min} \cdot \sigma_0) / (d - s_{min}) \quad (\text{bar}) \quad (21)$$

Where d (mm) is the mean external diameter at the bending length l_2 , s_{min} (mm) the minimum wall thickness in the bending length l_2 and σ_0 (N/mm²) the test stress for the PE-HD pipes, i.e. 1-15 N/mm².

In the test it was checked whether the socket was tight and whether any damages appeared at the PE-HD pipe inside the socket.

The testing time was one hour. All this time the pipe was bent along the total radius while in the pipe there was the calculated pressure. According to Eq. (21) this was 10 to 30 bar.

After the one hour test a thorough visual examination was performed to detect eventual cracks or the relative movement or pulling out of the PE-HD pipe from the expanded part of the steel pipe.

6.4. Pressure test

The pressure test was certainly most important since the basic function of the transition piece is to transmit a liquid or gas medium without any leaking. The pressure tests were carried out under different conditions (underpressure, overpressure, time duration, different media) and at different "stages", i.e. after production or after tensile and bend tests.

Long-time pressure test

The long-time pressure test took 168 hours at 23 ± 2 °C. All this time the transition piece was lying in a liquid made of 50% decane and 50% trimethylbenzol. During the test the pressure test in the transition piece amounted to 8.1 ± 0.2 bar.

During the test the behaviour of the transition piece, its eventual changes and eventual appearance of cracks were monitored. The pressure, which was to be constant, in the transition piece was monitored at the pressure gauge. After the test the transition piece was dried at 40 °C, cooled down to 23 °C, and then accurately weighed. A maximum allowable deviation from the mass before the test was 5%. The test results were very favourable for the pieces tested.

Pressure test with inner overpressure

The testing time was one hour and the inner overpressure was 15 bar. During the test the behaviour of the transition piece, eventual changes in its shape, eventual formation of cracks, and eventual reduction of pressure in the transition piece were monitored.

Pressure test with inner underpressure

In practice it often happens that a vessel may withstand high pressures but vacuum can not be established in it. Consequently, pressure tests of the transition pieces were carried out with an underpressure of $-0,8 \pm 0,05$ bar. The testing time was one hour. During the test the constancy of vacuum in the transition piece were monitored on a pressure gauge.

Pressure test after the tensile

Although no cracks or other damages were observed at the transition piece after the tensile test, the pressure test was made too. It showed that during the tensile test, in fact, no unacceptable defects occurred.

7. Conclusions

In the present paper the transition piece is described as a joint between the steel and PE-HD pipes. On the basis of a review of the literature, the theoretical studies, the design of the transition piece, the theoretical stress calculation, and the mechanical and pressure tests, the following conclusions can be drawn:

- On the basis of the present expertise, it is not possible to produce a conventional welded joint between steel and PE-HD.
- Between steel and PE-HD, an adhesive-bonded joint can be produced. Its strength and life depend on the type of adhesive used and the environment in which the joint operates.
- In practice, the transition piece is the most important application of joining steel to PE-HD.
- The paper presents a completely new design of the transition piece, which does not consist of any screw elements or seals made of materials susceptible to quick aging.
- For a concrete case, a stress calculation was made. It shows that the strength of the transition piece is higher, by a factor of 10, than the strength of the PE-HD pipe.
- The tensile test confirmed that the joint strength is much higher than the PE-HD pipe strength.
- The pressure tests of the transition piece manufactured carried out at an elevated pressure and in vacuum have shown that the design and production technology are excellently fit for the purpose.
- Also the special bend test has shown that the quality of manufacture of the transition piece is very high.

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