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Jointing Technology for PE pipes

Design features for increased processing safety of electrofusion fittings

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Jointing Technology for PE pipes:

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Pipelines are investment objects. The largest part of the capital of an utility or sewage company lies in the subterranean infrastructure of its pipe system. The safety, of course, is an essential aspect of the economy and the liability of the system.
This article deals with the aspects of product safety in application for the electrofusion procedure as jointing technology for PE pipes.

***Illustration 1:** burst test: The PE 100/SDR 11/PN16 pipe bursts at over 50 bar internal pressure, the electrofusion fitting joint will withstand considerably higher pressure.*

Modern plastic pipe systems made from polyethylene provide the utility company and its customers with durable, reliable and not least economic pipe systems. With today's experience and almost 50 years of operating experience, based on scientific tests, the life expectancy of top quality PE third generation pipe systems is forecast to be over 100 years [1].
Safety for pipe system operation starts early on with

- the planning, tenders and selection of suitable installation procedures
- the selection of materials – pipes – fittings – valves,
- the selection of suitable, certified contractors with specially trained staff as well as
- the construction site supervision to be scheduled to maintain quality requirements.

However, a pipe by itself – no matter how high the quality – makes no sense without the system being observed as a whole. A suitable, reliable and economic jointing technology is required to bring allround benefit and to optimise the fitness for use.

1. Jointing Technology

The fusability of polyethylene and the simple handling of fusion technology offer essential advantages over other materials. The homogeneous connection of the materials through fusion provides a level of stressability in line with the pipe material and even considerably superior to it through electrofusion fittings (illustration 1). It is good to know that the "weakest link" is the plastic pipe with its high stressability.
The system of the fused pipe after installation is therefore not made up of individual components – pipe/connection/pipe… - as opposed to the application of mechanical jointing techniques, but consists of a single, non-detachable, material-homogeneous connection due to the fuseability. The use of elastomeric sealing components can be limited here to a minimum, e.g. in valves.
Electrofusion and butt weld procedures are applied for underground pipe laying. Fittings are certified according to ISO/EN/DIN and DVGW requirements. The welder is trained according to German specifications, DVGW work sheet GW 330 [2], the welding supervisor according to DVGW work sheet GW 331 [3] for gas and water supply systems. The training content can be applied both in industrial pipe construction and in sewage technology. The guidelines of the DVS, German Association for Welding Technology, specifically apply.
Application emphasis for the butt welding procedure lies with the larger dimensions (> DN 200, d 225) due to the time consuming procedure of making the connection, and more specifically the installation of larger pipe lengths on open ground [4].
The electrofusion procedure has proved itself in a broad range of applications. Electrofusion fittings are used almost exclusively for house connections up to d 63 and in connection technology with saddle pieces for pipe branches.
For larger dimensions the simple and safe installation as well as fast processing due to short processing times and consequent reductions in personnel and civil engineering cost tip the balance in favour of the electrofusion technology. Electrofusion fittings are used in the large pipe range up to d 710mm as problem solvers where the butt weld procedure, e.g. for integration into existing pipes, changes in direction or repairs cannot be applied sensibly. The advantages of the electrofusion technology are specifically:

- simple installation and handling
- high reliability
- speed of processing
- economic value due to effective use
- universal applicability with regards to PE pipe material and wall thickness (SDR)
- suitability in practice for installation in restricted space in the trench.

2. Electrofusion fittings: Design effects on processing safety

National (e.g. DIN 16963) and international (e.g. EN 1555, EN 12201, EN13244) standards usually make a minimum of requirements of the technical and geometrical features of electrofusion fittings compromising at the smallest common denominator. This of course fulfills the requirements made of the pipe system – providing a very high standard of processing.
Tests in laboratory conditions may naturally not meet the exact conditions of processing in practice. Here the manufacturers need to take responsibility to provide the user with a reliable and practice orientated system. This requires

experience and know-how both in plastic technology and in construction site practices. In spite of the significant extent of the effect of product safety on pipe system as investment item – with an expected useful life of up to 100 years – this aspect is often underplayed in the face of short-term advantages with a mention of an existing product authorisation. Generally processing must of course take place in line with current guidelines and installation instructions by the manufacturers[5].

The most important developer is still the user. It is only through his or her input regarding shortfalls that practice-related improvements will be possible and problems solved.

2.1 Application spectrum

Basically the following aspects are taken into consideration for the development of electrofusion fittings [5] (observe manufacturers' indications!):

- Fusability of different pipe materials PE 80, PE 100 and PE-Xa
- Temperature range up to -15°C - +50°C
- Pipe series SDR 17,6 (17,0), SDR 11, SDR 7.4 (Standard dimensions in Germany)

Illustration 2: *Cross-section through electrofusion connection: comparison of insertion depth with different versions.*

  Dimensions deviating from standard SDR 41 - SDR 21 as well as SDR6 are possible with the application of suitable parameters.
- Fusability of tapping tees including the required tapping of the main pipe with all standard pipe dimensions pressure free and, depending on construction, even under maximum operating pressure.

2.2 Geometrical Features

The essential geometric aspect in the design of a electrofusion coupler is the insertion depth (illustration 2). This is subdivided into

- length of fusion zone, i.e. the effective area provided by the fitting for the homogeneous connection of construction parts. Simplified, the following applies: "The longer the fusion zone, the greater the achievable tightness and reliability of a fusion connection in the application".
- the length of internal and external cold zones with the task of
  - storing the melt occurring during fusion (build-up of melt pressure),
  - safely compensating for slight bending stress caused on the construction site and
  - balancing out or compensating for deviations from the ideal state caused on the construction site, e.g. ovality, conic dipping of pipe ends or pipe cuts not at right angles.

The cold zones not impacted by temperature act as a brake on the melt. The PE material liquidised during the fusion process cools down in the outer zones allowing a constant melt pressure to build up at the joining level. Alongside fusion time and temperature, the parameter "melt pressure" is a decisive factor for the fusion quality. Faulty chambering of the melt pressure can lead to escape of melt, reduce joining quality and is therefore not authorised.

The longer the cold zones, the better the resistance against bending stresses, e.g. as noted with the use of coiled pipes. The actual fusion zone will remain almost entirely unaffected by stress, as the pipe is guided through the cold zones and the increased coupler insertion depth.

This design feature was then consistently converted for the FRIALONG long coupler which provides user friendly problem-solving for the use of coiled pipes (illustration 3, illustration 4).

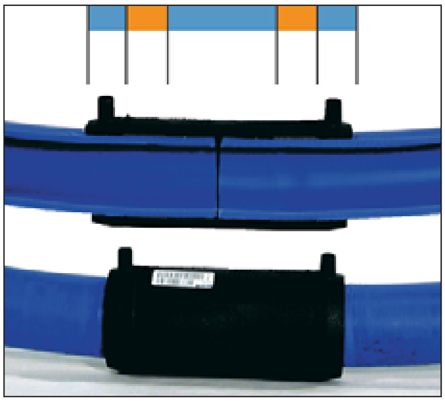

Illustration 3: *Section of installed FRIALONG long coupler with coiled pipes*

Illustration 4: *Detail connection zone: bending stresses due to coiled pipes are compensated by the supporting zone*

The inner cold zone deserves special attention. The typical dipping of cut PE pipe ends is usually compensated by this. Even an inexact right angle pipe cut on the construction site is balanced by the long design of this cold zone allowing the heating zone, including the remaining cold zone, to be unaffected and provide a safe fusion.

The design of the heating coil zone has a direct impact on the quality of the connection (table 1). The longer the fusion zone, i.e. the area actually available for the homogeneous material connection, the greater the processing safety in rough construction site conditions and by extension the long-term tightness of the pipe connection. The minimum lengths for fusion zones required by the European Standards allow little tolerance for processing on the construction site.

The wall thickness of the fitting must be designed to absorb safely the melt pres-

Table 1: Comparison of standard design requirements

Dimension	Min. fusion zone length [mm] according to EN12201-3, EN1555-3 [10,11]	Fusion zone length [mm] FRIALEN	Ratio
d 32	10	21	2.1
d 63	11	29	2.6
d 125	16	42	2.6
d 225	26	72	2.7
d 400	47	83	1.9
d 630	67	110	1.6

sure which builds up during the fusion. If wall thickness is insufficient the fitting can expand due to the reduced tightness while melt pressure brings in heat. Therefore, the parameter "fusion pressure" cannot be met sufficiently. Shrink stresses which may have frozen in the fitting and which are supposed to be used for creating melt pressure, are degraded immediately and have practically no longer any effect on this parameter. That is, if these still exist in the first place: it is well known that inherent polyethylene stresses are degraded in time, the material relaxes. If the radial shrink for the build-up of joining pressure during fusion is included in the design calculation, a "best before date" must be indicated for the application period of the fitting.

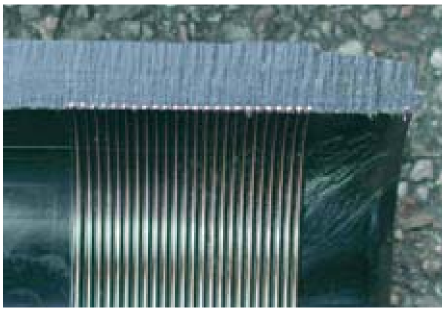

Illustration 5: *Cross-section: Exposed heating coil*

2.3 Exposed or covered heating coil: only a "philosophical" question?

For decades two fundamentally different design types (illustration 5, illustration 6) of the heating coil position in fittings have been available – and been discussed by users and manufacturers alike. Both systems – heating coil with a covering PE layer or exposed, visible in the moulded part – have been successfully tried and tested a million times over many years.
In spite of all this, strengths and weaknesses of the heating coil geometry become apparent in the application on the construction site. Starting the fusion process immediately sets off a heating process in the heating coil. Where the heating coils are coated and covered, the PE layer must first be melted down. Through the thermal expansion of the PE material of the fitting when molten this annular gap is closed. Only then is a considerable amount of fusion energy transferred to the pipe. Due to this process heat transfer in the fusion zone is obstructed, however at the same time more heat is injected into the body of fitting due to the heating coil being covered. The result is a melt ellipse asymmetrical to the fusion level (illustration 7) with its main proportion in the fitting and a reduced capacity for the bridging of the annular gap between pipe and fitting. The manufacturing related position of the heating coil and the thickness of the PE layer which naturally greatly affect heat penetration in the pipe cannot be recognised by the user other than through a destructive test or examination involving x-rays.
Exposed heating coils cause the heat to transfer to the pipe immediately once the fusion process is started following heat rays and air vortices caused by air flows due to different temperature levels in the fusion zone (convection). Although air – like PE – is a poor heat conductor, an instant heat bridge is in fact formed here with the given gaps between coupler and pipe of just 1/10mm.
It is possible to demonstrate this easily with an experiment using physics: If you point your finger at a source radiating heat, e.g. a cooker ring, at 1 mm distance – without actually touching it, you will quickly experience the relativity of the statement "air is a poor heat conductor". Of course it is correct to say that PE and air are poor heat conductors compared with steel and water. However, the relatively small difference between these materials, especially between liquid PE and air (table 2) will become clear only when comparing the values.
As over half of the wire is embedded in PE material, the energy during the fusion is continuously discharged to the ambient PE material. This ensures that the ensuing temperature of the wire remains at the level of the required fusion temperature.
Due to the direct melting of the pipe surface at the start of the fusion process, a thermal expansion of the pipe material occurs in the fusion area. The result is a very good bridging of the annular gap as the coupler "grows" inwards and the pipe outwards at the same time. The melting front does not run evenly but in waves, as opposed to the covered heating coil

Illustration 6: *Cross-section: Covered heating coil*

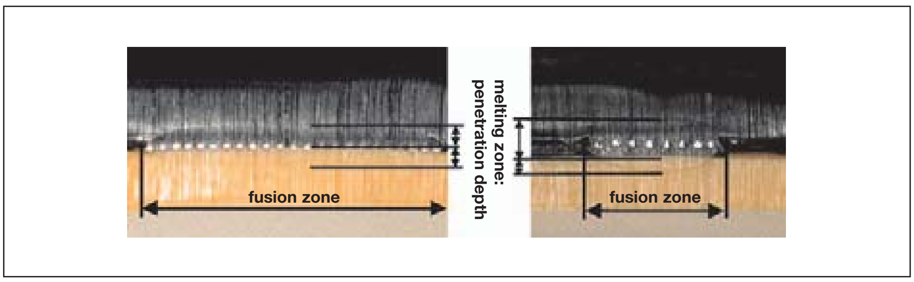

Illustration 7: *Approximate symmetrical presentation of the melt ellipse for fittings with exposed heating coil and asymmetrical presentation for fittings with covered heating coil*

version. Therefore the resulting fusion area is considerably larger.
If an oxidic layer forms in the coupling – in spite of the instruction to take the fitting out of the packaging only immediately prior to processing – this layer is broken up by the wave shape of the melt front and has virtually no impact on the fusion result. If the coupler was contaminated on the construction site, though this should really have been prevented by the packaging, the appropriate cleaning agent (DVGW VP 603) will remove it leaving no deposits.
Due to the form-fitting bedding of the heating coil in the material (illustration 5) it is not possible to release the windings without additional tools (e.g. screw driver) – in other words, by deliberate, appropriate manipulation. Therefore it is impossible to damage or remove the exposed heating coil by inserting the pipe. This has been tried in practice: After 30 years' experience in the rough conditions on the construction site we do not know of any complaints regarding damage to the heating coil by inserting the pipe.
In contrast, the position of the heating coil can be easily recognised – and controlled – by the user direct. This is a quality aspect which should not be underestimated with regards to the PE layer thickness of covered heating coils which may not be controlled.
Long term experiments were carried out and completed successfully on FRIALEN® safety fittings with exposed heating coils both in extremely acid and alkaline media. For decades the experiences in this field have been positive resulting in leading companies in the chemical industry using these moulded parts.

2.4 Labelling

Labelling of the moulded part is defined by the appropriate indications in the standards. Basic information such as manufacturer, nominal pipe diameter, material description, SDR series and manufacturing batch must be permanently legible. Indications relevant to the construction site may be done on separate labels (e.g. barcode label), for example fusion and traceability parameters, SDR processing range for pipes and the required cooling time after fusion.
All information should be available on the fitting in assembly condition (illustration 8).

2.5 Fusion Parameters

The fusion parameters are gathered in the barcode. This prevents basic faults such as the potential faulty manual programming of fusion time and current. This technology has been accepted worldwide as standard. To avoid mixups, the barcode has been sensibly applied as a label to each construction part and is therefore a proper part of the fitting which cannot get missed.
The design of the barcode is standardised and allows in addition to the automatic recognition of the fusion parameters the option of recording further data such as information on the manufacturer, processing dates etc. using fusion units with documenting facilities.
A second, subsidiary barcode contains data on construction part traceability which can be collected separately as an option and used electronically as a building block for the pipe book.
The barcode types are determined internationally preventing confusion (illustration 9).
The so-called temperature compensation is coded within the barcode. The fusion unit calculates individually for each fusion process a correction of the required energy depending on the ambient temperature.
This is measured by a sensor which is placed very close to the fusion process. The fusion time indicated by the barcode which relates to 20° C ambient temperature is extended automatically if temperatures are low and reduced if they are high. This creates roughly identical processing conditions in the connection zones covered and protected by the fitting. Almost all fitting manufacturers use the temperature compensation technology in order to exclude the negative impact of different ambient temperatures.
With the aid of barcode technology and the development of today's fusion units it has been possible to optimise the fusion parameters. Current indications by national and international standards allow us today to use the low voltage range up to 48 volt. This additional degree of freedom allows determination of optimum parameters with regards to fusion suitability, temperature range and pipe thickness, in order to achieve a top quality connection for the user. Other manufacturers abroad have carried out experiments to prove this effect[9].
A balanced definition of voltage and time parameters guarantees that the fusion process will lead to the best possible result bearing in mind varying tolerances regarding fusion gap, ambient temperature, PE material and of course the fitting.
As PE has relatively poor heat conductivity, and we need to avoid introducing excessively aggressive energy, a short fusion time has its problems for reasons of physics. It is possible that heat does not penetrate deep enough into pipe and fitting, which will reduce build-up of melt and affect the quality of the joint. In reality fusion times do not affect installation times on the construction site as they are usually a matter of mere seconds or minutes. There is only a superficial advantage here which is clearly contradicting the fundamental physics.

2.6 Jointing technology for large pipes

In order to safeguard the build-up of melt during the fusion, the fitting must be prevented from expanding. This can take place for example through reinforcement

Material	Heat conductivity	Comparison
PE, rigid	0.23 W/mK	-
PE, liquid	0.16 W/mK	-
Air, dry	0,02454 W/mK	with PE rigid: 9.4 with PE liquid: 6.5
Water	0.6 W/mK	with air: 25
Steel	47 - 58 W/mK	with air: ca. 2040

Table 2: *Comparison of heat conductivity of different materials[6]*

Illustration 8: *Labelling of electrofusion fittings*

Illustration 9: Barcode for fusion parameters and traceability data

Table 3: Comparison of external diameter tolerances on pipes

Dimension (pipe)	Nominal external diameter [mm] according to EN12201-3, EN1555-3 [10,11]	Central external diameter [mm] Min.	Max.	Tolerance [mm] Od
d 32	32	32.0	32.3	+ 0.3
d 63	63	63.0	63.4	+ 0.4
d 125	125	125.0	125.8	+ 0.8
d 225	225	225.0	226.4	+ 1.4
d 400	400	400.0	402.4	+ 2.4
d 630	630	630.0	633.8	+ 3.8

as for FRIALEN large couplers (illustration 10). This corset prevents the coupler from "expanding" and ensures a safe and sufficient build-up of melt.

In large pipe technology with diameters from d 280 mm to d 710 mm the so-called pre-heating procedure provides the user with additional safety. The authorised tolerances listed in the standards grow with the external diameter of the pipe (table 3). However, the fact that installation of the moulded part is user-friendly must be retained.

In addition, the storage of the pipes can lead to deviations from the ideal round shape, e.g. ovality and local flattening due to great inherent weight of large dimensions. The result is a circular or local gap between coupler and pipe which can have a negative effect on the fusion result. The problem can be solved by a special pre-heating parameter (illustration 11) which allows the gap between coupler and pipe to get smaller due to temperature-related increase of volume and reduction of inherent voltages. During this pre-heating process a temperature is created in the connection zone via the special parameter which lies below the melt temperature. This heat transfer affecting the pipe surface direct is made possible only by the open, exposed heating coils. The procedure may not be applied with covered heat conductors. The reduced gap will increase the joint quality considerably in these particular problem cases on the construction site due to the improved build-up of melt pressure.

3. Result

The electrofusion technology for the connection of gas and water supply pipes – and increasingly for sewage systems – has for decades been established as a reliable, economic and user-friendly procedure. Fundamental prerequisite for the reliability of the pipe system is to stay consistently with the safety aspect right through from planning to the approval and operating stage. Particular significance lies with quality demands regarding the choice of products to be used. Clear and obvious quality features can be found in the geometrical and design aspects of electrofusion fittings: large insertion depths, long fusion zones and exposed heating coils. The product is suitable for the rough conditions on the construction site due to its additional breadth of processing range.

Sources:

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[2] DVGW-Arbeitsblatt GW 330: PE-Schweißer, Lehr- und Prüfplan, 11/00
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[11] DIN EN 12201: Kunststoffrohrleitungssysteme für die Wasserversorgung - Polyethylen (PE)

Illustration 10: External fitting reinforcement prevents it from expanding during fusion

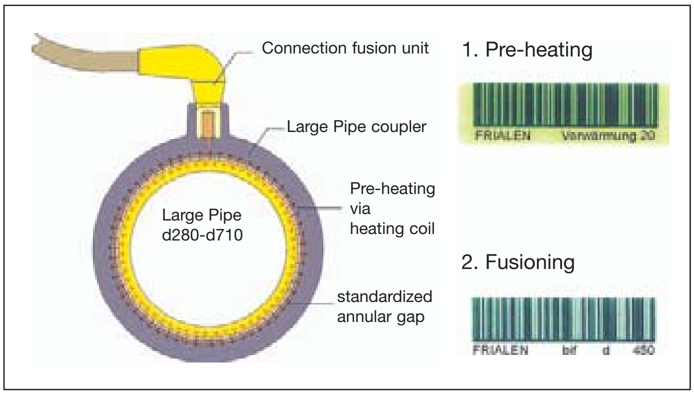

Illustration 11: Operating principle of pre-heating technique