INTERNATIONAL JOURNAL OF ELECTRONICS; MECHANICAL and MECHATRONICS ENGINEERING Vol.3 Num 2 pp.(493-504)

AN ANALYSIS OF ELECTRO-MELTING AND HOT ELEMENT WELDING METHODS' SAFETY USED TO JOIN PE NATURAL GAS PIPES

Adnan AKKURT
Gazi University, Faculty of Technology, Industrial Design Engineering Dept, Ankara, Turkey

Abstract-
Use of natural gas as an eco-friendly and user-friendly fuel increases day by day, in parallel to developments in industry and need for comfort. The common use of natural gas arouses interest about gas transfer and joining of pipes in order to install gas pipe lines. In this study, two methods to join PE plastic pipes are compared: electro-melting welding and hot element (butt) welding methods. Tests are applied in order to measure the leaktightness and strength properties of the joined pipes in ambient conditions similar to actual working conditions. Results of the standardized tests are compared. Consequently, electro-melting welding is found to be the ideal method for pipes of certain diameters. However, for main transfer line pipes (of larger diameters), hot butt welding gave more successful results.

Key Words: *Plastic pipe welding, Electro-melting (Electrofusion), Hot butt welding, PE pipe welding, PE pipe welding safety*

I. INTRODUCTION

Developments in metallurgical technology increased the demand for easy-to-shape materials resistant to environmental working conditions and having high abrasion resistance. Usage of plastic and composite materials become widespread day by day and these materials replace timber, metal, ceramic etc. However, the widespread usage of plastic materials in industry and everyday life brings along several problems. The leading problem of plastic is its negative effects on human health. Therefore, production of plastic materials is subject to very tight standards, with respect to other types of materials. Products confirming to DIN, ISO, TSE, EN etc. standards and food legislations are long lived, environment friendly and human friendly, so they should be preferred [1, 3]. Various techniques are used to produce plastics materials. However, some parts can not be produced using the existing methods. Also, some other parts can be produced, but taking a longer time and with higher costs. Welding these parts, rather than directly producing, is much more effective and gives high quality results [4].

1.1 Welding Properties of Plastic Materials

In welding process, several parameters must be taken into account. These include material properties, working conditions, time-related changes in material properties, hardening tendency after welding, chemical and heat resistance of welded material, process and post-process security, and economy. Thermoplastic materials are acceptable with respect to each of these properties. Other types of plastic materials can not be welded effectively. To join these materials, bonding and mechanical joining are preferred, rather than welding [5, 6].

During welding of plastic materials, a heat-effected region is formed around the weld beam. As a result of the pressure and polymer flux, various types of crystal occur in the welding region. In semi-crystalline materials like polypropylene, condensed flux and rapid cooling also results in certain amounts of crystallized structure. Like metals, the heat-effected region of the workpiece becomes more fragile than the main body. Due to the excess welding strength in the heat-effective region and the aggressive liquids and dissolvers, corrosion in this region accelerates. Whilst melded metals easily flow into the welding bath and fill the welding bend, viscous fluid plastics needs to be compressed and forced to the welding region. In order to do filling, such an operation is required when working with plastics. However, such pressures make the chain replace in the flow direction, which results in anisotropy. As a result, notch strength, impact strength and tensile strength on joining line level become lower related to the vertical level [4, 6, 7].

1.2 Welding Methods Applied on Plastic Materials and the Effective Parameters

The leading methods applied to thermoplastic materials are the following ones:

- Hot Element (Butt) Welding
- Hot Gas Welding
- Extrusion Welding
- Electrofusion Welding
- Implant Induction Welding
- Infrared and Laser Welding
- Resistive Implant Welding
- Ultrasonic Welding
- Linear and Orbital Vibration Welding
- Spin (Friction) Welding
- Radio frequency Welding
- Microwave Welding

Each of these methods used to weld plastics has advantages and disadvantages. Hot Element (Butt) and Electrofusion (electro-melting) welding methods are widely used pipe melding methods to join polyethylene (PE) natural gas pipes. Reaching to a targeted quality in plastic welding requires an optimum combination of the following parameters:

Temperature: External surfaces of welding components are softened with heat (hot element, hot gas or friction). Direct flame is not preferred because of bad heat conductivity of plastics. If used, the materials would probably start burning before getting deeply hot. Similarly, if heated plastics are cooled suddenly with pressure air or water, sudden tensions occur in the welding region.

Pressure: As melted plastic is viscous, not fluid, the fibres slipping into each other should be supported with pressure.

Time: Because of poor heat conductivity of plastics materials, heating time and cooling time must be determined very carefully. If the melding heat source is not removed from the ambient for a long time, thermal damages emerge. Expansion and contraction degrees in plastic materials during the heating and cooling applications are higher than metals, which must be taken into account [4, 8, 9].

2. JOINING METHODS

2.1 Hot Element (Butt) Welding

Hot element butt welding is a commonly preferred method, because it is more simple, safe, secure and economical. Joining components are heated with a hot element in touch or radiation. When they are softened enough, components are joined under a certain pressure. An additional element can be used to press. The process can be named as direct heating or indirect heating hot element welding, depending on the preferred method. Graphic representation of welding steps is given in Figure 1. As can be seen in this graph, the process includes five steps [11].

Alignment: Joining parts are aligned to the heated tool in a parallel fashion to the tool. The parallelism should be controlled with the help of bead height. Alignment should be performed under P1 pressure for T1 time period. T1 is determined according to the bead height. The minimum bead height levels are given in Table 1.

Heating-Up: In this step, first the pressure applied for alignment is eliminated rapidly. So, the welding components are in touch with the heated tool under nearly no pressure (interface pressure). Meanwhile, heat moves on in the direction of pipe axis. Heating time T2 is given in Table 1. If this period is adjusted shorter than its optimum, the depth of melted plastic becomes shorter than the required depth. If this period is too long, the butt welding region will melt too much and degenerate.

Removal of Heated Tool: After heating-up, joining regions are detached from the heated tool. The joining regions should not be damaged or contaminated during this process. The removal time should be as short as possible. If joining process is not done quickly, cooling and oxidizing will occur in the joining regions and welding quality will deteriorate. The maximum time of removal (T3) is given in Table 1.

Joining: When the heated tool is removed, the joining regions are drawn closer to each other, but this must not be a beat. The desired P3 level of pressure (interface pressure) should be reached with linear increment. The required time T4 is given in Table 1.

Cooling: The joining (interface) pressure P3 must be kept constant while cooling. After joining process is completed, smooth dual bead forms up [13 – 15].

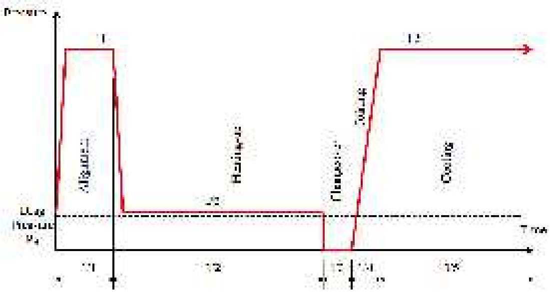

Figure 1. Graphical representation of process steps of hot element welding [10]

Table 1. Welding parameters suggested in hot element welding [10]

1	2	3	4	5	
	Alignment	Heating - Up		Joining	
Nominal Wall Thickness	Bead height on heated tool at the end of the alignment time (alignment with 0.15N/mm²)	Heating-up time 10 X wallthickness (heating-up with ≤ 0.02 N/mm²)	Changeover	Joining pressure build-up time	Cooling time under joining pressure (P=0.15 N/mm² ± 0.01)
mm	mm (min.)	s	s (max. time)	s	s (min. vaues)
4,5	0,5	45	5	5	6
4,5 – 7	1,0	45 – 70	5 – 6	5 – 6	6 – 10
7 – 12	1,5	70 – 120	6 – 8	6 – 8	10 – 16
12 – 19	2,0	120 – 190	8 – 10	8 – 11	16 – 24
19 – 26	2,5	190 – 260	10 – 12	11 – 14	24 – 32
26 – 37	3,0	260 – 370	12 – 16	14 – 19	32 – 45
37 – 50	3,5	370 – 500	16 – 20	19 – 25	45 – 60
50 – 70	4,0	500 – 700	20 – 25	25 – 35	60 – 80

Bead dimensions and form reveal the smoothness of the welding. Different types of bead forms can be formed in relation to the melt flow. The bead height must always be bigger than zero. Examples to bead formation defects due to inappropriate parameters and conditions can be seen in Figure 2.

The inappropriate conditions and their possible defects are summarized in Table 2. Figure 3.a shows an example of coin image. Figure 3.b and 6.c shows the results of an appropriate joining with appropriate parameters and application [14, 15].

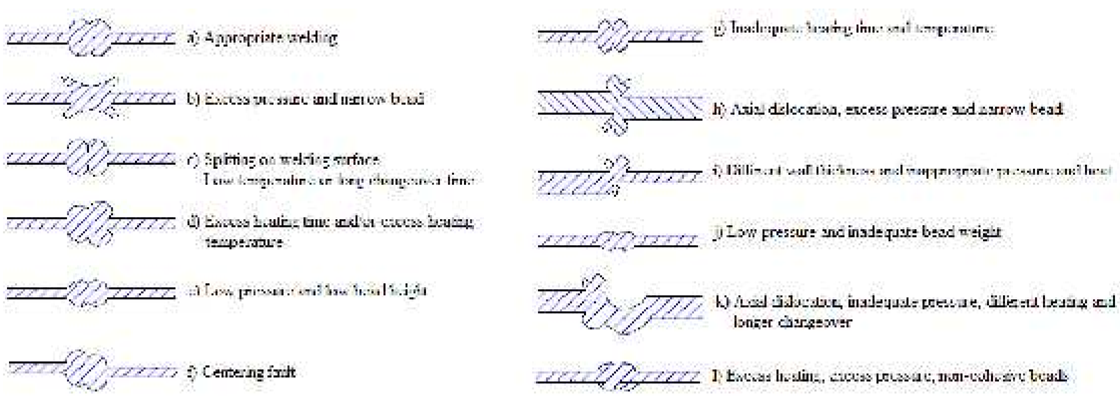

Figure 2. Bead formations [14, 16, 17]

Table 2. Hot element welding problems and their possible reasons [16]

Excess bead width	Excess heating or excess joining pressure
Excess space height in the middle of the bead	Excess joining pressure; inadequate heating; Pressure during heating
Flat bead top	Excess joining pressure; excess heating
Non-uniform bead around pipe	Incorrect position (centring); defective heating tool; inadequate treatment

Smaller beads	Inadequate heating; inadequate joining pressure
Not rotating bead to pipe exterior surface	Little space in the middle of bead: Inadequate heating and inadequate joining pressure Large space in the middle of bead: Inadequate heating and excess joining pressure
Bigger beads	Excess heating time
Square external surface of bead	Pressure applied during heating
Rough bead surface	Hydrocarbon spread to butt welding region during welding process

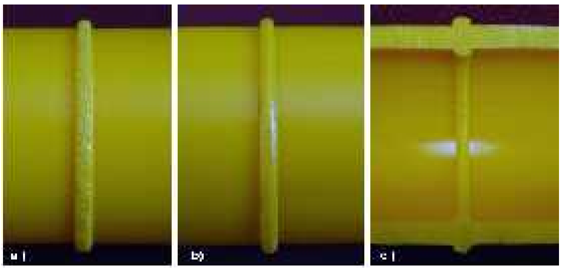

Figure 3. a) Inappropriate welding parameters b) Appropriate welding parameters c) Appropriate welding parameters and pipe internal surface appearance [18]

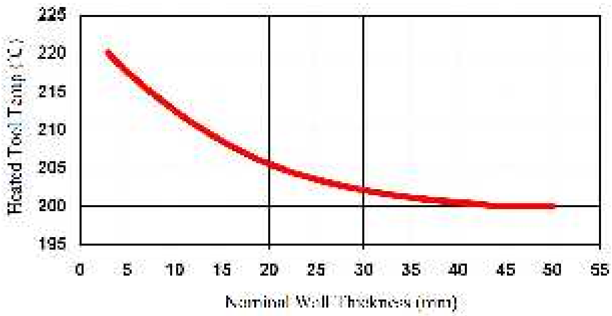

Figure 4. Temperatures with respect to wall thicknesses [19]

Temperature, heating time, cooling time, removal time of heated tool and pressure are among effective parameters of hot element welding. Change in temperatures according to the nominal pipe wall thickness values are given in Figure 4. As seen in the graph, while high temperatures are needed for thin walls, thick walls require low temperatures.

2.1.1 Important Points about Hot Element Welding Quality

In order to obtain a successful butt weld;

- Welding components should match each other in form. The working area should be protected against moisture, wind and low temperature, which affect the butt welding parameters negatively.
- The butt welding region should be protected against direct sunlight etc. to be sure that faces of welding components are at the same temperature at the end of the heating time.
- Dust, shavings etc. on the faces of welding components should be removed before butt welding process.
- Pipes should be properly bound to heads before starting butt welding process.
- It is necessary for both properly centring the pipes and preventing them from leaving the heads and giving harm to operator during treatment.
- During butt welding process (including cooling time) welding components should not be exposed to any kind of mechanical force or coercion. Other end of the pipe should be on a sliding ground, so it can move easily. It is necessary for easy feed forward and feedback without applying any force to butt welding region.
- Treatment tool should be sufficiently sharp. The blade must be sharpened or changed at certain intervals.
- There should not be any deep scratches or notches on teflon coat of the heated tool. Surface of the tool must be checked at certain intervals [11, 20].

2.2 Electrofusion (Electro-Melting) Welding

Resistive implant welding is a simple technique applicable to any kind of thermoplastics and thermoplastic composites. In this method, a direct or low frequency alternating current is drawn into electric conductor implant materials (resistance wire) placed between the welding components; so thermoplastic around this implant melts down. Resistive implant welding is widely used for welding pipes with electro-melting. A specially designed socket with electric resistive cables is used for joining. In our country and in the world, custom-engineered sockets are used in butt welding of polyethylene natural gas and water pipes, for T-branching of pipes and valve assembling to pipes. The common name of the method is electro-melting. Even though the principle of electro-melting method is new, the use of resistance wires for heating dates back to 1900s. In 1956, Mannesman AG improved electro-melting method for the first time to join PE pressure pipes [21]. Electro-melting method is widely used nowadays to join pipes of 20 – 200 mm diameter. Each joining element (fitting, sleeve or socket) in this system is equipped with an integrated heating wire (electric resistance cable), embedded and close to the melting surface (Figure 5, Figure 6). Wire wounds can be single or double wound. Main advantage of single wound to double wound is elimination of a possible short circuit during melting process. When a current generator equipped with a voltage regulator and a timer system is switched on, inner side of the joining element is melted by means of heating elements. Internal diameter of the joining elements should be 1.1% larger than the external diameter of joining pipe. When the joining element is heated, this space between pipe and the element decreases due to thermal expansion (Figure 7).

Melting material creates pressure, which is necessary for adhesion of the joining element and the pipe. Interfacial heat is provided by a current generator. This energy depends on the wound resistance, voltage applied and heating time. Melting time can be controlled automatically via a control box, depending on these parameters. The voltage is about 35 – 40 V; a regulator is needed to optimize this energy and to maintain a decisive voltage. The welding system is shown schematic in figures.

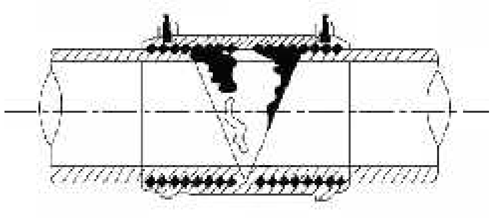

Figure 5. Schematic demonstration of joining [4]

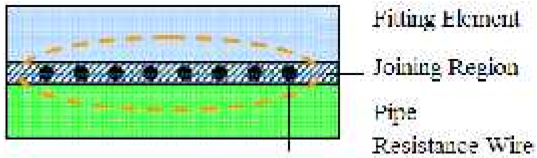

Figure 6. Electro-melting process regions [22]

It is determined that performance of an electro-melted welding is much better than the performance of pipes, as long as the joining process is well done. Wire wounds contribute to this performance. Also, slow cooling of the joining region affects positively. Main negative effect on performance is dirty surfaces [23].

In order to eliminate the risk, the pipe is generally shaved before welding process. Various apparatus are developed to mechanically remove chips of certain height and thickness from external diameter of the pipe.

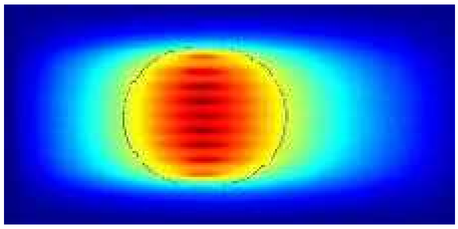

Figure 7. Resistance wire [23]

Some space between the joining element and the pipe (Table 3) is crucial for an ideal joining process [24].

Table 3. Maximum Allowed Space Width [21]

Pipe External Diameter ØD (mm)	Space Width t (mm)
≤355	0.5
400 < 630	1.0
630 < 800	1.3
800 ≤ 1000	1.5
> 1000	2.0

2.2.1 Conditions and Parameters of Electro-Melting Welding

- Plastic pipes of same raw material can be welded with electro-melting welding.
- Flow rate of melted material for electro-melting welding of YYPE pipes is between 0.3 – 1.7 g/min. Solution flow rate of welding pipes and sleeve should be within these values. Pipes with same solution flow rate can be welded.
- The welding region must be kept safe from adverse weather conditions (snow, rain, wind, effective sun light etc.).
- Ambient temperature should be between 5°C and 50°C.
- Generally there are barcode readers on electro-melting welding machines; and barcodes are on electro-melting additional materials (sockets), indicating necessary welding parameters. The welding parameters can be uploaded to the machine via barcodes but welding parameters written on the additional materials can also be saved to the welding machine manually [25].

3. EXPERIMENTAL STUDIES

3.1 Material

In this study, polyethylene (PE 100) plastic material used in natural gas pipe production is analysed. Polyethylene is one of the most commonly used materials in industry; because this material is elastic, resistant to earthquakes and landslides; it reserves its elasticity at -40°C temperature; it is also resistant to chemicals, abrasion and corrosion. As there is not any molecule changeover between polyethylene pipe and the fluid inside, there is not any carcinogenic effect. Polyethylene is 8 times lighter than metals, because of its lower density. Polyethylene pipes can work properly for minimum 50 years under working pressure. They are 100% leak-proof, without any assemblage leakage. They do not affect properties (taste etc.) of transferred materials, including water, gas, petrol or chemical substances. The pipes have higher impact resistance at lower temperatures. They are resistant to environmental conditions, UV rays, fractures and distortions. They can be joined with several welding methods without any need to cathodic protection [4, 26, 27]. Their chemical composition is:

Ethylene Polyethylene

$CH_2 = CH_2 \rightarrow$ Polymerization $\rightarrow (-CH_2 - CH_2)\ n$

3.2 Method

In this study, polyethylene natural gas pipes of 20 – 315 mm nominal diameters are joined with butt welding methods. These pipes can be used under 4 bar pressure and 60°C temperature at maximum. Some samples are joined with hot butt welding using Taurus Welding Machine, in accordance to the parameters given in Table 4. Then, other samples are joined with MSA 300 electrofusion welding machine. Parameters of this welding process are given in Table 5.

Table 4. Hot butt welding parameters and properties of welding equipment [28]

Process Parameters	
Heating up temperature	120 °C
Heating element temperature	280 °C
Heating up temperature	60 psi
Joining temperature	30 psi
Changeover time	10 sec
Joining and cooling time	36 sec
Working pressure	130 bar
Fluid Flow Rate	30 ml / min
Taurus Welding Equipment Properties	
Conforming TS ISO 12176-1 norms 380V-2200 Watt Treatment Tool 5000 Watt Mono Block Heater Iron Three-faze Hydraulic System 380V-2,2 kW (16 lt/min -150 Bar)	Maximum nominal wall thickness 32 mm 220 V - 2800 W heated tool Maximum welding tolerance 0.3 mm Heating plate temperature difference ± 5 220 V -0.55 kW hydraulic system engine

Welded samples conforming to standardized dimensions are tested in appropriate conditions for each test. Some tests gave numerical values; whereas in some tests, the changes and negativities in joining regions are evaluated and formation of any damage is questioned. Each test is applied to 4 – 8 samples, depending on nature of test; and the arithmetical means are calculated. In the tests about damage formations, samples are evaluated individually. If none of the samples are damaged, the result is indicated as DAMAGE FREE. In pressure tests, ALC BTC Pressure Test Devices are used. Also, other examinations are carried by hand, tensile strength test device and bending test devices. Outcomes are given in Table 6.

Table 5. Electrofusion welding parameters [21]

MSA 300 Process Parameters	
Working temperature	-10°C + 45°C
Mains Voltage	180V – 264V AC
Input Voltage	380 Volt
Mains Frequency	45 Hz – 65 Hz
Fusion Welding Voltage	8 – 42 (48) V AC
Fusion Welding Power	Max. 80A
Use of Power	Max. 3780 W
Protection	1 / IP65
Power Capacity	3.5 KW
Welding Time Interval	Min.20 min. Max. 30 min.

The most important point to remember when carrying a test is that butt welding can only be applied to pipes with same polymer structure. So, polyethylene (PE 100) plastic material is used in the study. Polyethylene is among widely used plastic materials. High density polyethylene (HDPE) pipes are subject to least abrasion in nature. As seen in a small abrasion of 0.09 mm is observed in the internal surface of HDPE pipes after first 100000 test cycles [27]. Methane permeability of samples prepared with natural gas pipes is maximum 0.075m2/bar a day, for at least 2 mm-thick samples. For butt welding, new material should be used because new materials are resistant to crack formation and propagation. If old materials are welded, crack formation is generally seen near the welding region. For this reason, developed countries occasionally withdrew their old materials from markets [28].

4. EXPERIMENTAL DATA AND DEBATE

The most delicate issue in welding in relation to the welding quality and post-process safety of pipes is positioning the pipes in line. Nominal wall thickness difference should not exceed %10. When cooling process is completed, the pipe is removed from machine. Adequacy of welding, bead width, bead height, presence of any dirt on the joining region, space on heat-effected region and presence of cracks, fractures etc. in adhesion region must be controlled visually. If the visual control is satisfactory, tests should be applied according to international standards. If visual control is not satisfactory, joining process should be repeated after the required pre-treatment process is completed (treatment and cleaning of both pipes after removal of beads). Tests are applied to production and quality control of PE pipes, according to the following standards. Pipes can be conveyed after these tests and controls are completed [29, 30].

Determination of Density (ISO 1183)
This test aims to determine material's weight in unit volume. The material is first weighed in air then in a fluid of a known density with analytical balance. The density of material is calculated using the standardized calculation method.
Determination of MFI (ISO 1133)
This process is carried on in order to evaluate behaviour of materials in relation to temperature changes, before processing the material. Samples are weighed with analytical balance after being tested by MFI device. The weight values are uploaded to the device and results are obtained in g/10 min.
Tensile Strength (ISO 527)
In this test, material's strength to forces is analysed. The tensile strength and elastic module is determined.
Tensile Elongation (ISO 527)
In this test, elongation amount of the material at break is determined as percentage (%).
Hydrostatic Pres. Test (ISO 9080 EN 921)
In this test, behaviour of pipes under pressure in time is determined under abbreviated ambient conditions. High pressure is applied on the pipes

and changes in the pipes in a time equivalent to 50 years are observed.

Homogeneity Test (ISO 13949)

This test is carried on to analyse homogenous pigment dispersion and possible spaces in material structure. A microtome cross section of 10-15µm is examined with microscope.

Carbon Black Amount Analysis (ISO 6964)

This test aims to determine the carbon amount in percentage (%) added to the material homogenously in order to strengthen it against UV rays. Sample is burned with nitrogen in high temperature ovens. Unburned parts are carbon; the percentage of this part is calculated [22, 31 – 34]. According to the Deutscher Verband für Schweißtechnik DVS (German Society of Welding Technologies) this product pressure has to be multiplied by 0.8 for butt fusion.

Table 6. Tests applied and results of measurements

HYDROSTATIC INTERNAL PRESSURE TEST REPORT (F50)	**PE 100**
Hydrostatic Strength (80°C,165 h)	Damage Free
Hydrostatic Strength (80°C,1000 h)	Damage Free
Hydrostatic Strength (20°C,100 h)	Damage Free
Determination of Gas Flow Rate/Pressure Decrease Relation UGETAM Test Reprt	At 0.5 mbar ≥ 0.25 m/sec
Leaktightness Under Bending and Temperature Conversion Conditions Experiment	Damage Free
Tensile Test Under Constant Speed and Constant Load at 23°C Test Report (F61)	Damage Free
Leaktightness After Tensile Test at 80°C Test Report (F60)	Damage Free
Leaktightness in Temperature Conversion Experiment Report (F62)	Damage Free
Hydrostatic Strength 80°C, 165 h Hydrostatic Pressure Test Report (F50)	Damage Free
Density Raw Material Quality Control Report (F39)	959 kg/m^3 PE 100 944 kg/m^3 for PE 80
Hydrostatic Strength 80°C, 1000 h Hydrostatic Pressure Test Report (F50)	Damage Free
Hydrostatic Strength 20°C, 100 h Hydrostatic Pressure Test Report (F50)	Damage Free
MFR Raw Material Quality Control Report (F39)	0.40(190°C/5 kg) PE 100 0.88 (190°C/5 kg) PE 80
Splice Strength Report (F 96)	%100 Fusion.
Impact Resistance UGETAM Report	Damage Free
Pressure Drop UGETAM Report	At 0.5m bar ≥0.33 m/sec.
Oxidation Induction Time	33 min.
Electrical Properties Process Control Form (F-12)	4.01 Ω
The statement DAMAGE FREE indicates that no leakage or deformation is observed.	

4.1. Comparision of Butt – Fusion and Electrofusion Welding

When PE pipes are heated up the material properties become weaker at a factor of 0.8. This situation is true only for butt-fusion. For electrofusion welding, it doesn't occur considerable amount of weakening since wall thickness increases (pipe + fitting) at the same time. For butt fusion, obtaining high quality welding is not possible all the time due to necessity of very high man skill, the use of complicated welding machines for welding process, low resist to the pressure at the welding place and also high possibility of leaking [21, 35]. For electrofusion however, at a minimum level of operator knowledge is necessary and it is easier. Also, the welding process can be done with easily usable welding machines giving high quality all the time (Table 7). If one wants to use SDR 17 pipes, they should at least take away the welding bead. As by the bead the pipe is weakened additionally, especially at the outside by the tensile stresses. This is particularity true for PE 100, where the stress concentration factor (another factor to multiply the original strength with) of the notch will weaken the pipe again and very severely [36]. When it is compared in the aspect of both safety and economical respects using of electrofusion welding technique instead of butt – welding is much more proper. Using of electrofusion welding techniques have been increasing rapidly in many countries even for large diameters [21]. But it can be said in general, that there is a much higher risk of failures because of bad workmanship during welding while applying butt fusion compared to electrofusion. A higher possibility of bad workmanship of the welder can create massive problems in the long-term behavior of pipes.

Calculation of operating pressure;

$$P = \frac{20 \times MRS}{} \text{ bar} \quad (1)$$

C x (SDR -1)

P : Operating pressure (bar)
MRS : Minimum circumferential strength (10Mpa for PE 100)
C : Safety factor (C_{min} = 1.25)
SDR : Standard dimension ratio

Operating pressure for PE 100 SDR 17 pipe:

$$P = \frac{20 \times 10}{1.25 \times (17 - 1)} = 10 \text{ bar} \quad (2)$$

Operating pressure for PE 100 SDR 11:

$$P = \frac{20 \times 10}{1.25 \times (11 - 1)} = 16 \text{ bar} \quad (3)$$

For butt-fusion welding;

PE 100 SDR 17 pipe " 10 x 0.8 = 8 Bar
PE 100 SDR 17 pipe " 16 x 0.8 = 12.8 Bar

Conclusion;

1 – For the piping system where the pressure is 10 bar, if butt-fusion is used the PE 100 SDR 11 should be used. However, this increases the cost of pipe at a percentage rate of %50.

2 – For the piping system where the pressure is 10 bar, with using PE 100 SDR 17 and electrofusion welding technique it is possible to obtain the strength of 10 bar [21].

Table 7. Comparision of Butt – Fusion and Electrofusion Welding [21, 34]

General Criteria	***Electrofusion***	***Butt-fusion***
Operating pressure for straight piping system	Same with operating pressure of selected pipe.	Decreases 20 % of operating pressure of selected piping system. (The piping system which is designed for 10 bar can only be operated at 8 bar).
The effects of components like elbow and tee to the operating pressure of piping system	Same with operating pressure of selected pipe.	Operating pressure of selected piping system: decreases at a rate of; *At tee components = % 80 + % 50* *At elbows = % 80 + % 80* Example: For the fittings which is manufactured by using 10 bar pipe: Working pressure at tee : *10x0.8x0.5 = 4 bar* Working pressure at elbow : *10x0.8x0.8 = 6.4 bar*
Reduction in the inner diameter of the pipe	Reduction doesn't occur in the inner diameter of the pipe.	Reduction occurs in the inner diameter of the pipe.
The cost of machine equipment	The cost of standard electrofusion welding machine is 2500€	The cost of standard butt-fusion welding machine is between 5000€ and 30000€
The usable flexibility of machine equipment	An electrofusion welding machine can be used for all diameters of the pipe	A butt-fusion welding machine cannot be used for all diameters. The machine must be changed for some intervals according to diameters of the pipe.
The weight of the machine equipment	20 kg	150 – 300 kg
Welding speed	For d 125 pipe 50 welding operation can done in one day	For d 125 pipe 15 welding operation can done in one day
Neccesity of the fitting material	Additional coupler is necessary for straight piping system	Nothing is necessary for the piping system

	Electrofusion			Butt-fusion		
The automation of welding process	█	█	█	█		
Needed skill for the operator	█			█	█	█
	Little	Middle	High	Little	Middle	High

Taking all these comparisons into account, it is found out that the ideal welding method for PE pipes up to 250 mm diameter is electrofusion welding method

The long term tensile test, which the relevant test to show the long term behaviour of plastics in known conditions, will show a long term welding factor of 0.8, which means a reduction of 20% of the strength, compared to unwelded material. Therefore I would like to confirm to you, that altogether form a safety and economic point of view, it is certainly better to use electrofusion rather than butt fusion [36].

If butt welding method is applied with optimum welding parameters, welding quality is generally high and excellent leaktightness is achieved. However, material hardness increases and elasticity declines in and around the joining region.
PE plastic pipes of 250 mm and bigger diameters should be joined with hot butt welding. Methods other than butt welding do not give good results for such big diameters. Also, components welded by hot butt welding gave best results in folding tests, compared to other welding methods. The welding temperature and change in size of weld had negative effects under pressure in both of the different processes. Expansion of welding region narrows the cross section. These shrinkages result in a decrease of natural gas transfer pressure.

5. CONCLUSIONS

Welding of PE pipes used for natural gas transfer is important in relation to its effects on human life, industry and environment. Hot butt welding method is widely preferred as a cheap and easy method. But, internal beam formed during joining process reduces gas flow in small quantities. On the other hand, electrofusion method gives better results in pipes of certain diameters. However, penetration and space formation are its main disadvantages.

In this study, tests are carried in accordance with international standards. It is found out that the most preferable method for joining PE pipes is hot butt welding method, in terms of easiness, safety, durability and economy.

7. REFERENCE

[1] Anık, S., Dikicioğlu, A., and Vural, M. 1994. "Termoplastik Malzemelerin Kaynağı", Kaynak Tekniği Derneği, Yayın No. 2, İstanbul.
[2] Jim Craig, P. E. 2005. "QA Technology for Polyethylene Butt Fusion Joints", North American Society for Trenchless Technology, McElroy Manufacturing, Inc. Florida.
[3] Ogorkiewicz RM., 1970. "Engineering Properties of Thermoplastics", Willey-Interscience, London. p .249 – 317.

[4] GEV–ATB–2009. "Plastik Malzemeleri Birleştirme Yöntemleri", Gedik Eğitim Vakfı.

[5] ASTM D2657-97. 2002. "Standard Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings", Volume 8.04. American Society of Testing and Materials. Baltimore.

[6] Jun, H. Y, Grimm RA. 1998, "Infrared welding of thermoplastics: Practical characterization of transmission behavior of eleven thermoplastics", Proceedings of ANTEC 1998, Conference Proceedings, Society of Plastics Engineers. p. 1030–1035.

[7] Ziegler, D, 2004. "Welding of termoplastics", Welding Journal, Vol. 83, No. 10, p. 45- 47. October.

[8] Steven A., Kocheny, S. A., and Miller, B., 2009. "Laser Welding: It's Not Just for Metals Anymore", Welding Journal, Vol. 88, No. 3, p. 28 - 30.

[9] Hawkeye Industries Inc. 2008. "Fabricated Fitting Butt Fusion Procedure", Technical Bulletin: TB-0308-FF, FPR IDC and NIDC Fittings.

[10] http:// www.akatherm.com/files/ Pressure/ Weld ing %20polyolefins.pdf.

[11] ASTM F1056-97. 2002. "Standard Specification for Socket Fusion Tools for Use in Socket Fusion Joining Polyethylene Pipe or Tubing and Fittings", Volume 8.04. American Society of Testing and Materials. Baltimore.

[12] Plastics Pipe Institute Inc. 2009. "Recommended Minimum Training Guidelines for PE Pipe Butt Fusion Joining Operators for Municipal and Industrial Projects", TN-42/September 2009.

[13] Runcev, D., Trpkovski. Lj., 2008. " Heated Tool Butt Welding Of PE Pipes", 8 International Conference Advanced Manufacturing Operations, p. 21- 25.

[14] Crawford S. L., Cumblidge S. E., Hall T. E., Anderson M. T., 2008. "Preliminary Assessment of NDE Methods on Inspection of HDPE Butt Fusion Piping Joints for Lack of Fusion", Prepared for the U.S. Nuclear Regulatory Commission under U.S. Department of Energy.

[15] General Guidelines for the Heat Fusion of Unlike Polyethylene Pipes and Fittings, Report TN-13, Plastics Pipe Institute, Washington, DC.

[16] Arthur. E., 2006. **"**Inspection of Fusion Joints in Plastic Pipe", National Energy Technology Laboratory, February 23.

[17] The Plastics Pipe Institute, Inc. 105 Decker Court, Suite 825, Irving, TX 75062 P: 469-499-1044 F: 469-499-1063 www.plasticpipe.org

[18] TR-45/2008, Butt Fusion Joining Procedure For Field Joining of Polyamide-11, January 2008

[19] Starostin N. P., Ammosova O. A., 2009. "Thermal Processes in Butt-Welding Polyethylene Pipe at Low Ambient Temperatures", Russian Engineering Research, Vol. 29, No. 1, p. 12–16.

[20] Arkema Inc. , 2004. "Optimization of Parameters Influencing Butt Fusion Integrity in Polyamide 11 Pipe", King of Prussia, 900 First Avenue, PA 19406-0936

[21] PE Jointing Technics, www.tega .com.tr

[22] Messer, B., Yarmuch, M., Boer, P., 2003. "Novel High Resolution Defect Detection For Thermoplastic Butt-Welds", Pipeline & Gas Journal, RTD Quality Services Inc. Vol. 230, p. 46, March, 2003

[23] Dong. H. N., 2005, "A Study of The Combined Socket anda Butt Welding of Plastic Pipes Using Through Transmission İnfrared Welding", Presented in Partial Fulfillment of the Requirement for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

[24] Fujikake. M., Fukumura. M., Kitao. K., 1997. **"**Analysis of the electrofusion joining process in polyethylene gas piping systems", Proceedings of the 11th ADINA Conference, Volume 64, Issues 5-6, September 1997, Pages 939-948

[25] Jack. Q. Z., Lyne. D., Denis. B., 2002. **"**Effect of joint contamination on the quality of butt-fused high-density polyethylene (HDPE) pipe joints", Canadian Journal Civil Engineering 29(5): 787–798

[26] Kaluç, E., Taban, E., 2005. "Doğalgaz Boru Hatlarında Kullanılan Polietilen Boruların Kaynağı", MakinaTek, Bileşim Yayıncılık, s. 118 - 124, İstanbul.

[27] http://www.pilsa.com.tr/eng/katalog .html

[28] http://www.ceka-ltd.com/GFdocs/ Alet_Listesi/MSA300.pdf

[29] Donoghue, P. E., Kanninen, M. F., Green, S. T. and Grigory, S. C. 1991, "Results of a thermomechanical analysis model for EF joining of PE gas pipes", In Proceedings of Twelfth Plastic Fuel Gas Pipe Symposium, p. 331–342, Boston.

[30] Polytubes Technical Note, 2007. "Butt Fusio Technique", POLYETHYLENE, Technical Note**.** Polytubes Technical Bulletin. July 2007**.**

[31] Takasu, N,. 2003. "Friction welding of plastics", Selected from journal of the

Japan Welding Society Welding International" , 17(11), p.856, 2003**.**

[32] Barber P, Atkinson JR. 1994. "The use of tensile tests to determine the optimum conditions for butt fusion welding certain grades of polyethylene", polybutene-1 and polypropylene pipes. J. of Materials science, p.1456.

[33] M.G. Murch, M.J. Troughton, 1993. "A Study of the Applicability of the Tensile Weld Test for Thick Walled Polyethylene Pipe", TWI, p. 757.

[34] Murch, M.G., Troughton, M.J., 1993. "A Study of the Applicability of the Tensile Weld Test for Thick Walled Polyethylene Pipe", TWI, p. 757

[35] Saint Royre, D., Gueugnaut, D. and Reveret, D. 1989. "Test meth - 1995. odology for the determination of optimum fusion welding ABAQUS Theory Manual", Version 5.3, Hibbit, Karlsson conditions of PE. J. Appl. Polym. Sci., p.147–162

[36] Fischer. W., 1999. "Experts for Pipes and Plastics Engineering", Fischer Engineering, Regensburg, Germany.