

# MINIMUM THICKNESS FOR REPAIR GIRTH WELDS IN CORRODED PIPE

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The minimum weldable thickness is numerically assessed in this work, as a function of pressure during the welding operations of a corroded gas pipeline, according to the approach by Battelle. The minimum weldable thickness is found to increase when the flow rate of the transported gas in the section being repaired increases. Integrity of the repairs is assessed, and alternative measures to momentarily increase the flow in the area of the repair are evaluated. .

## 1.- INTRODUCTION

Companies transporting natural gas have thousands of miles of buried pipes, which date back to the 40's and 50's. At that time, protection techniques against corrosion (e.g. protective coatings and cathodic protection) were not well developed, and the companies commonly face defects due to corrosion degradation. Worldwide the most common way to repair gas leakage is to change the defective portion of the pipe. To do this, however, it is necessary to stop pumping gas and vent the affected portion of the line. Where there are no loops to deviate the gas flow, doing this means stopping provision of gas to some areas, with the consequent losses to the users and the transporting company. One of the alternatives available to minimize service losses and restore serviceability of corroded lines is the use of full encirclement sleeve repairs.

Full encirclement welded sleeves are used to repair defects in underground gas pipelines, see **Figure 1**. The reinforcements consist of two half sleeves welded lengthwise, which are also welded circumferentially to the pipe if there is a gas leakage or other severe defects. Standard designs are found in API RP 1107 [1]. These reinforcements habitually are carried out in areas where local loss of thickness or gas leakage are detected, generally due to corrosion. When a through-the-thickness defect is detected, reinforcements with O-ring and venting valve are used to prevent gas from reaching the welding operations. This kind of repair requires a circumferential (girth) fillet weld to the pipe, to prevent gas leakage during subsequent service. The possibility of repairing gas leaks is probably the most important advantage of welded sleeve repairs over competing techniques, such as clock springs [2].

In-field welding of these sleeves is normally a difficult task. Usually, short times and poor soil or weather conditions make cutting, handling and welding the sleeves to the buried pipes require especially trained personnel and equipment. It is no surprise, therefore, that several weld repairs fail in different ways. These failures have in many cases been the driving force for changes and improvements

in the fabrication of the sleeves, field welding procedures and non destructive testing of the repairs.

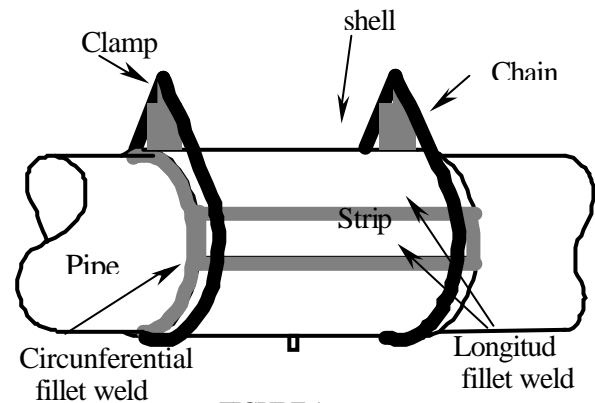


FIGURE 1

If not properly trained, due to the fear to burn through the pipe, welders tend to minimise the welding time and use high deposition rates, which are obtained with cellulosic electrodes. The use of cellulosic-coated electrodes is a common practice in the construction of pipelines but for welds made onto in-service pipelines there is a serious risk of reduction in ductility and toughness by Hydrogen Cracking [3] the specification of low-hygroscopic basic electrodes is now recommended, along with specified preheats and heat inputs to avoid high cooling rates and burn through [4].

The occurrence of burn through during the circumferential reinforcement-to-pipe weld is governed by the thickness of the pipe being welded and the penetration of the molten pool during welding. Weld penetration depends on weld heat input, heat dissipation along the pipe and the reinforcement, and the dissipation through the gases inside (natural gas) and around (air) the pipe. This last dissipation depends upon temperature and flow parameters, pressure and flow rate. The controlling parameter is the gas flow rate.

The gas transporting company TGN has carried out several steps to transform this procedure into a Remaining Life Management tool for the gas pipeline. Previously, this type of repairs was sometimes considered an “emergency” fix.. A new welding procedure was put in practice.. Experimental determinations of stress states in sleeve repairs were done to define the effects of reduction of pressure during welding, load and place of positioning clamps, length of the repair sleeve, and use of O’ring – based devices to prevent gas leakage [5]. Large stresses, up to 270 MPa, were found on tests with artificial gas leaks. Several operative aspects were optimised, to minimise the stresses in the reinforcements and to reduce the risk of failures.

Previous work in the field includes evaluations of the strength and integrity of the sleeves by pressurizing them to failure, with no attempt to measure the stresses developed during the process. [6,7]. Strain gages have been used extensively to monitor stress states in full scale pipeline tests [5,8]. Analytical or numerical estimation of stress distributions in the area of the girth reinforcement-to-pipe welds involves a parametric analysis of the influence of each of the geometric and loading variables (thickness of pipe and reinforcement, reinforcement length, reinforcement-pipe gap, pressurization of the gap, etc.). Analyses of the stresses associated to full encirclement reinforcements carried out by Smith and Wilson [9] derived in analytic elastic solutions. Their main conclusions are:

- Increasing the thickness of the reinforcement above the thickness of the pipe decreases the stresses in the root area of the girth weld.
- Reducing the size of the fillet weld increases radial and hoop stresses, but longitudinal stresses remain almost constant.

More recently, Gordon and collaborators [10] carried out an extensive programme of numerical modelling to analyse the influence of the different geometric variables involved in the full encirclement weld repairs and to develop a procedure to determine their fitness for service. Analysed geometric variables are thickness of the pipe ( $t_1$ ), thickness ( $t_2$ ) and length ( $d$ ) of the reinforcement, and reinforcement to pipe gap ( $g$ ).

Until the moment, when detecting a reduction of thickness in the pipe in the area of the circumferencial weld, one or more additional reinforcements are placed, until sound material. This procedure involves additional risks. The placement of tandem reinforcements increases the stresses, especially in the longitudinal sense in the reinforcement material. [5], and the risk of inner collapse increases in the event of abrupt depressurizations of the line [11]. The purpose of this study is the numerical evaluation of the conditions that control the minimum remaining thickness needed on the pipe, in order to avoid burn-through during girth welding the reinforcement to the pipe, to define the conditions of acceptability of corrosion thickness losses in the areas of the pipe to be welded, and to ensure the integrity of the reinforcement under conditions of

maximum pressure. This numerical evaluation, along with previous experimental measurements of the stresses generated during the repair, has as final objective to optimise the assembly and welding conditions of the reinforcements.

## 2. EXPERIMENTAL & NUMERICAL CONDITIONS

The occurrence of tube perforation during the circumferencial reinforcement to pipe weld is governed by the thickness of the pipe being welded and the penetration of the molten pool during welding. Weld penetration depends on weld heat input, heat dissipation along the pipe and the reinforcement, and the dissipation through the gases inside (natural gas) and around (air) the pipe. This last dissipation depends upon temperature and flow parameters, pressure and flow rate. The controlling parameter is the gas flow rate. This flow is approximately constant between pump stations, while gas pressure falls due to friction losses. The most unfavorable combinations in pressure and flow rates are found immediately downstream the stations. In this study, the flow conditions are evaluated in a representative tract of the North gas pipeline operated by TGN. Flow and pressure conditions studied in this paper are 370.000 m<sup>3</sup>/hour at 60 kg/cm<sup>2</sup>, which roughly corresponds to the normal gas Operating Pressure OP of the pipeline, 260.000 m<sup>3</sup>/hour at 48 kg/cm<sup>2</sup> (80% OP), and 50,000 m<sup>3</sup>/hour at 36 kg/cm<sup>2</sup> (60% OP). Flow rates are defined at normal conditions, 15 C and 1 atm.

The pipe evaluated is an API 5LX52, 24” diameter, 7.1 mm nominal thickness, subjected to an operating pressure OP = 61.7 kg/cm<sup>2</sup>. Gas temperature is 50C. The transported natural gas is 90% methane, 6% ethane, with the remaining 4% propane, CO<sub>2</sub> and N<sub>2</sub>, and other gases. Welding parameters (current, voltage and speed) used in this work are: 120 Amp., 22 V and 10 cm/mm, giving a heat input of 1.58 KJ/mm. Results of previous works carried out by Battelle [12] and other investigators show that the perforation of the pipe does not happen if the temperature in the inner surface does not exceed 982 C. Other works by the Edison Welding Institute [13] show that for electrodes of 3.2 mm diameter at 110 Amp, with a heat input of 0.87 KJ/mm, the minimum weldable thickness is 4 mm. To determine the distribution of temperatures in the wall of the gas pipeline, for different combinations of gas flow rate and pipe thickness, they developed a series of three-dimensional models using the finite element method. For each condition of flow rate, the minimum thickness below which the temperature in the inner surface of the pipe is below 982 C was considered.

Welding parameters and thermal properties of the circulating gas have been defined. The variables to analyze now are the parameters of flow (pressure and rate), the mechanical loads on the repair weld area, and especially the pressure to which the repair is carried out. The definition of Battelle's 982C temperature limit is based on the experimental observation that perforation takes place when the temperature in the inner surface of the pipe reaches 1260 C. The 278C difference was introduced as a safety margin [13]. Although Battelle's criterion has been validated experimentally, it could still be over conservative. The criterion is based in an axisymmetric heat flow model, neglecting heat flow in the welding direction [14].

An intuitive concept among field welders is that to reduce the danger of arc burn through the gas pressure should be reduced. However, little difference in the temperature of the inner surface of the tube has been observed between conditions of no gas flow and low flow [12]. Although the reduction of pressure is mandatory as a safety measure, in order to prevent a pipe blow out during the repair, gas pressure has little effect on the occurrence of burn through. Because the heated surface is small, the stresses in the pipe wall are redistributed around the heated area, in the same way as it occurs around a small pit of corrosion. Previous works indicate that the reduction of the pressure could lead to higher temperatures in the inner surface of the pipe, and consequently to a higher risk of burn through [12,15].

### 3.- MODEL OF TEMPERATURE DISTRIBUTION

A modeling of the through the thickness distribution of temperatures was carried out, for the different gas flow conditions. The heat contributed by the welding process under the surface, Q, is important when high energy sources are used. In processes that involve low energy densities, the energy source is applied directly to the surface of the material [16], and characterized by a distribution of heat flow q(x,y) applied on a small area. The heat spreads by a combination of radiation and convection, in the material to weld and the surroundings. Applied heat input is governed by the weld heat input (incorporating voltage, current and weld speed), the heat distribution, and the heat transfer efficiency of the welding process, which is typically between 0.66 and 0.85 for SMAW [16]. Two of the three beads of the circumferencial repair fillet involve dilution with pipe base material. In order to simplify the model, the weld of a bead on the pipe was modeled without the sleeve reinforcement, that is, a bead-on-plate weld. The presence of the 7.1 mm thick reinforcement provides additional heat dissipation, and is partly incorporated through the weld efficiency, which is used as calibration variable of the temperature model.

The gas flow in insulated long pipes is isothermic for high pressures [14]. The conditions and characteristic of gas flow were determined based on the following hypotheses [18]: Isothermic flow; no mechanical work is done on the system; flow rate remains constant in time, flow rate is represented by the mean velocity in the section; the perfect

gas laws apply, the friction factor is constant along the pipe; the pipe is strait and horizontal; and accelerations can be rejected pipes long enough. Gas flow is given in cubic meters per hour under normal conditions of pressure and temperature The Reynolds number is given by:

$$Re = E 432 \frac{q'_h Sg}{d m}$$

Where q'\_h is the gas flow, Sg is the relative density, d is the pipe diameter in mm, and μ is the absolute dynamic viscosity in centipoises. The flow efficiency factor Y is defined by experience, and is usually supposed 0.92 for mean operating conditions [14]. The coefficient of thermal transfer h was determined from the number of Nusselt, using the numbers of Reynolds and Prandtl and the coefficients of friction for the gas flow conditions that correspond to 100%, 80% and 60% of the operating pressure OP [13]. Values of h are summarized in **Table 1**. All coefficients were defined for conservative conditions. The coefficient of thermal transfer of the air was defined for conditions of 1 atm and 27 C, for still air. This way a number of Nusselt of 15.2 and a coefficient of thermal transfer in free convection of 13.32 W/m<sup>2</sup> C were defined..

**Table 1:** h values for the three flow conditions

P [kg/cm <sup>2</sup> ] (% of operative)	q'_h [m <sup>3</sup> /h]	Re	H [w/m <sup>2</sup> °K]
61 (100)	370.000	1.65 10 <sup>7</sup>	757
48 (80)	260.000	1.16 10 <sup>7</sup>	560
36 (60)	40.000	1.25 10 <sup>6</sup>	86

To determine the distribution of temperatures in the pipe wall for the different combinations of gas flow and pipe thickness, three dimensional finite elements numerical models of the welding process were carried out [19,20]. The heat model of the welding process is a source of heat that moves along the weld bead, on the outer surface side of a long pipe that dissipates heat by convection toward the outer (air) and inner (natural gas) atmospheres. Symmetry is defined along the weld bead, and the dimensions of the model were chosen so that the weld heat does not reach the borders of the model.

Meshing was carried out using three-dimensional linear eight node and six node elements, totalling around 6100 elements and 5400 nodes. Elements were concentrated around the weld area, to accurately model the high thermal gradients that are developed. The weld process was modeled using an incremental technique, by discrete displacements along the weld bead of a point source of heat. The central area area of the model is swept by the advance of the source, with finer meshing and far from the borders. The speed weldadvance was

considered as 10 cm/min. As a result, an advance of 0.665 mm in each time step of 0.4 seconds was modeled.

#### 4.- DETERMINATION OF MINIMUM WELDABLE THICKNESS

To calibrate the model, the depth of the molten pool was experimentally during actual pipe welding. For different inner gas pressures, but without gas flow, the depths of the molten pool were around 2 mm, with a the maximum depth of 2.3 mm. A conservative calibration of the model was done by correcting the weld efficiency, in order to obtain a depth of the molten pool of 2.5 mm, for a pipe thickness of 7 mm. Since the welding process was modeled by an incremental technique, it is necessary to define the necessary increments to achieve the stabilization of the thermal process. The number of steps depends on pipe thickness, so convergence studies were carried out for different thicknesses.

The time of continuous welding is defined by the and the burn rate length of the electrode, and was experimentally set at an average of 30 seconds. Since convergence is asymptotic, the number of steps of the model was defined so that the change rate of the depth of the molten pool becomes smaller than 0.01 mm/sec.. Then, the change rate in the last step is extrapolated until the calculation time of 30 seconds.

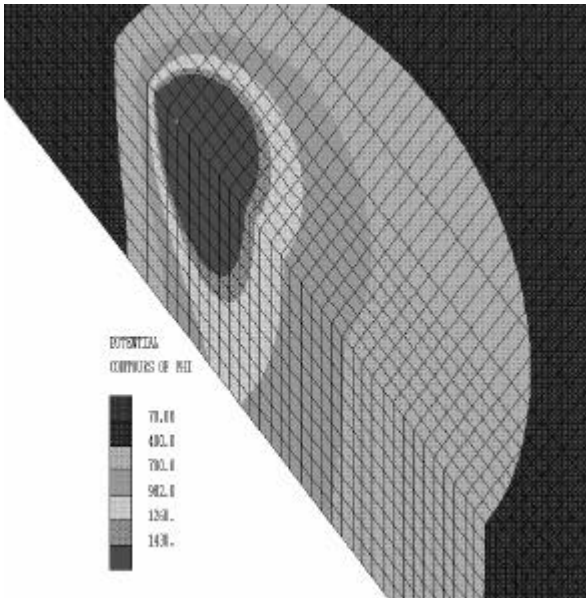


FIGURE 2

**Figure 2** shows a typical map of isotherms. **Figure 3** shows the through the thickness temperature distributions for each step, for an example thickness of 5 mm. Zero depth is the outer surface, where the heat source is located.. The asymptotic convergence of the model toward a stable condition is observed. For thickness 7 mm, 20 steps (8 seconds) were necessary to achieve an adapted increment rate, while for thickness 5, 4 and 3 mm, 40 steps (16 seconds) were necessary.

FIGURE 3

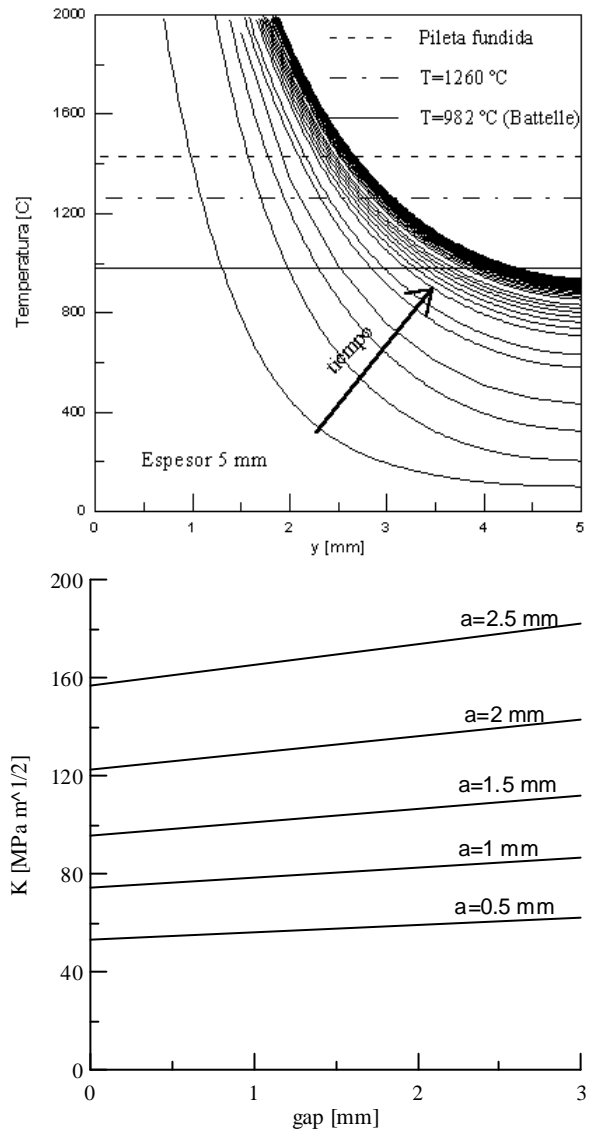


FIGURE 4

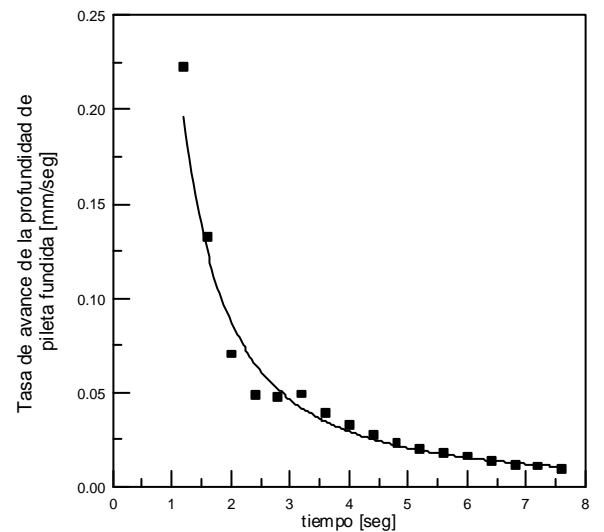


FIGURE 5

**Figure 4** shows the rate of depth change of the molten pool as a function of time for thickness 7 mm. Its final rate was used to extrapolate and calibrate the model. This procedure was used in all the models, to assess the depth of the molten pool and the depth at which Battelle's temperature is obtained. **Figure 5** shows the isotherms of 1430 C (limit of molten pool), 1200 C (experimental critical temperature), 982 C (limit defined by Battelle), 700 C, 400 C, and 70 C (initial pipe temperature), for thickness 5 mm, with maximum gas flow ( $p = 100\%$  OP). For each condition of gas flow, the minimum thickness below which the temperature in the inner part of the pipe is lower than 982 C was considered. For this condition, pipe burn through would not take place during welding.

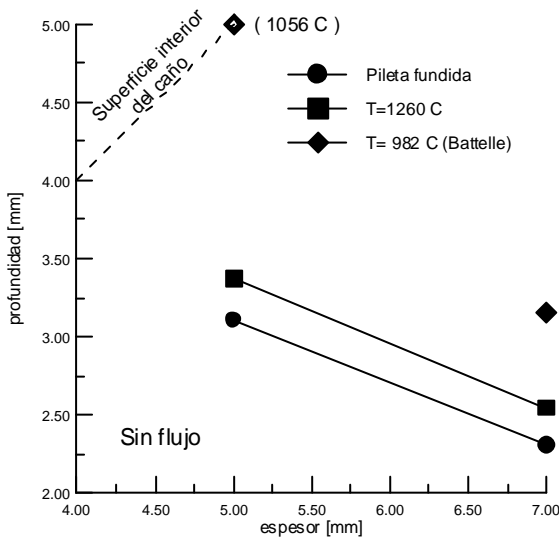


FIGURE 6.A

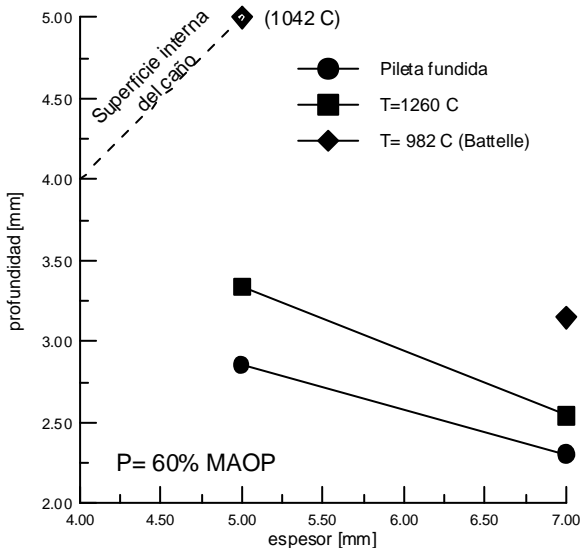


FIGURE 6.B

**Figure 6** (a,b,c,d) shows the depths to which the characteristic temperatures are reached, as a function of pipe thickness, for each of the gas flow conditions: (a) without gas flow, and with gas flow corresponding to pressures (b) 60% OP (c) 80% OP and (d) 100% OP. Shown temperatures are the limit of the molten pool (1430 C), the experimental limit for burn through (1260

C), and Battelle's temperature (982 C). Dotted lines correspond to the inner surface of the pipe.

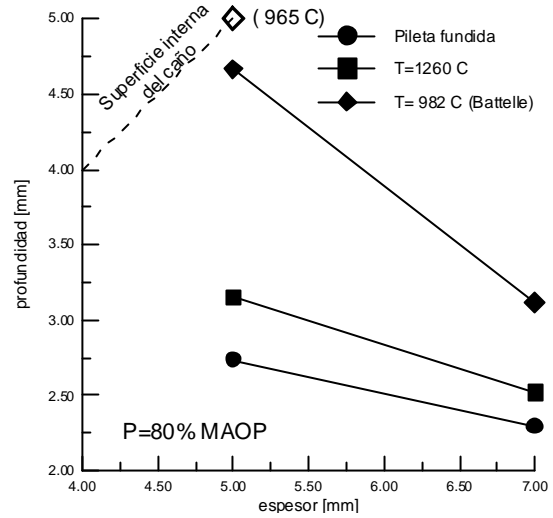


FIGURE 6.C

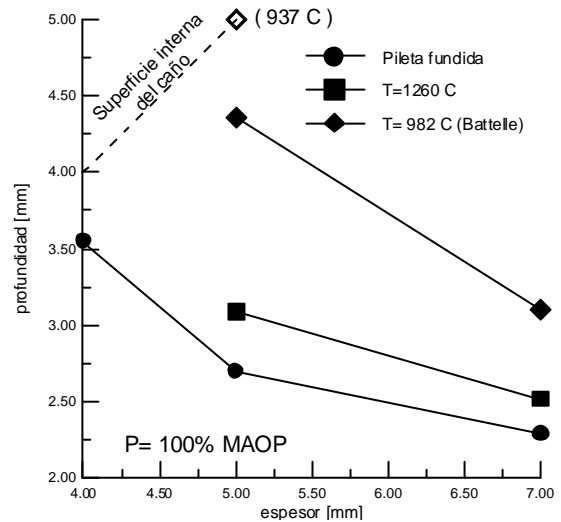


FIGURE 6.D

For a 7 mm pipe thickness the depth of Battelle's isotherm is about half of the thickness in all the cases, and the temperature in the inner surface is in the range between 300 C and 320 C. As the thickness diminishes, the depth of Battelle's isotherm increases, and this increase is larger for lower gas pressures. The same trend is observed with the temperature of the inner surface. If a thickness of 5 mm is welded, the maximum temperatures in the inner surface are of 935C, 965C, 1042C and 1056 C, corresponding to pressures of 100%, 80%, 60%, and 0% OP, respectively. Maximum temperatures in the inner surface are less than 100 C over Battelle's temperature and 200 C below the experimental burn through temperature.

For a thickness of 5 mm, the depth of the molten pool is between 2.7 mm (100% OP) and 3.1 mm (without gas flow). When the repair pressure is 60%

OP the depth of the molten pool is 2.85 mm. Comparing both the cases of 60% OP and of 100% OP, The differences in the depth of the molten pool are small, but the temperature of the inner surface of the pipe varies in 119 C (compare figures 5.a and 5.d), which shows the effectiveness of gas flow in increasing the dissipation under the molten pool.

From the results in Figure 6 the depths at which Battelle's temperature is obtained were assessed as a function of thickness, for each case of gas flow. Numerical interpolation of these results allowed to determine the minimum weldable thickness  $t_{min}$  for each flow condition (defined by the pressure P). The regression curve is represented by the equation:

$$t_{min} = 9.2355 - 0.1513 P + 0.00124 P^2$$

The minimum weldable thickness  $t_{min}$  for each condition analyzed were in this way estimated. For P = 100% OP,  $t_{min} = 4.65$  mm For P = 0.80 OP,  $t_{min} = 4.80$  mm, and for P = 0.60 OP,  $t_{min} = 5.30$  mm. Note that  $t_{min}$ , according to Battelle's condition, increases when the gas flow in the section being repaired increases. This implies that it would be desirable to repair when large gas flows are transported. This happens in winter, when lower room temperatures represent an additional advantage, since increased heat dissipation through the pipe metal decreases weld penetration. However, regulations based on safety aspects require to reduce gas pressure during the repair, and this in turn makes gas flow to be also reduced. It could be possible to evaluate alternative measures, among them maneuvers with the valves in the ends of the damaged sector, that would allow to momentarily increase the transported flow reducing at the same time the pressure in the area of the repair.

### 5.- INTEGRITY OF THE REPAIRED REGION WITH REDUCED THICKNESS

To assess the fitness for service of the full encirclement repair on pipe with thicknesses below 7 mm, and in particular with the minimum weldable thickness (5 mm), the distribution of stresses in the area of the pipe to reinforcement weld was modeled following results by Gordon and other researchers. The following load conditions are evaluated: longitudinal stresses, inner gas pressure in pipe, pressure in reinforcement to pipe gap due to perforation being repaired, and constant bending loads. The dependence of the stress field in different areas with geometric factors are summarized in the **Table 2**. It can be seen that the most critical area is the weld toe [10] (point A, see **Figure 7**). The Stress Concentration Factor (SCF) in this area is typically between 3 and 4. Only if the reinforcement-to-pipe gap is pressurized, the stresses in the root region of the fillet weld (point C in figure 8), but these stresses are mainly compressive. Consequently, cracks in this area would not experience large tensile stresses under normal operation conditions, and they would not represent a significant risk for the integrity of the repair. Increasing the length of the reinforcement from 1.5 to 4 times the pipe diameter does not seem to affect the

stress field in the area of the weld, even when the gap is pressurized.

**Table 2.:**

X: strong dependence / I: weak dependence

	axial stress				inner pressure			
	d/t	t <sub>1</sub> /t <sub>2</sub>	l/d	g/t <sub>1</sub>	d/t	t <sub>1</sub> /t <sub>2</sub>	l/d	g/t <sub>1</sub>
A-B						X		
A-C								X
E-C		X		X				X
D-C								

	inner pressure with perforation				constant bending			
	d/t	t <sub>1</sub> /t <sub>2</sub>	l/d	g/t <sub>1</sub>	d/t	t <sub>1</sub> /t <sub>2</sub>	l/d	g/t <sub>1</sub>
A-B					I	I	I	I
A-C		X		X		X		X
E-C		X		X		X		X
D-C						X		X

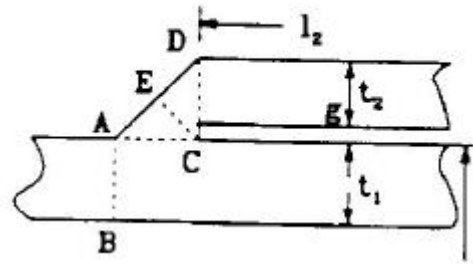


FIGURE 7

The growth of preexisting defects often lead to premature failure of buried pipes. Fracture Mechanics uses an appropriate field parameter to relate the three key elements of the analysis [21]. These are: the stresses applied to the defect area, material toughness, and morphology and size of the defect. Failure can occur as plastic collapse or fast fracture, typically starting in the highly stressed region of the weld toe, usually referred to as hot spot [22]. There are three main factors that control the susceptibility of a component to fracture: (i) Fracture toughness of the material, (ii) Stress level, (iii) defect characteristics, and (iii) fracture toughness of the material. Linear Elastic Fracture Mechanics (LEFM) uses the concept of the stress intensity factor, K. Fast fracture occurs when the applied K reaches a critical value, K<sub>Ic</sub>. This way, K<sub>Ic</sub> represents the fracture toughness of the material. Applied K is given by:

$K = Y \sigma \sqrt{\pi a}$ , where  $\sigma$  is the applied stress,  $a$  is the crack depth and  $Y$  is a factor that depends on the geometry. The equations presented by Newman and Raju establish the value of  $K$  in each point in the tip of a semielliptic crack, for given values of applied nominal tensile and bending stresses.

Fast fracture and plastic collapse are simultaneously assessed by the Failure Assessment Diagram (FAD). In a FAD, the ordinate axis,  $K_r$ , represents the relationship between the applied  $K$  and the fracture toughness of the material, while the abscissa  $S_r$  represents the relationship between the applied stress and the yield strength of the material. The external points to the curve in the FAD indicate failure situations, while the interior points represent situations of safety. The conditions of failure with higher risk are related to fast fracture [23]. The assessment points are defined when the weld toe is subjected to different loads. Material toughness  $K_{Ic}$  was chosen as  $120 \text{ MPa m}^{1/2}$ , an average of experimental results on different tracts of the pipeline, which was built in 1951. For these conditions, the failure conditions at the weld toe are reached when  $K_r = 0.90$ . This means that the failure occurs due to fast fracture, and that plasticity effects can be neglected.

Gordon et al [10] propose a methodology for the determination of  $K$  in cracks at the toe of the reinforcement-to-pipe circumferential fillet welds (point A in Figure 8). According to the results shown in the Table 2 and the objectives of this work, analysis variables are remaining pipe thickness and reinforcement-to-pipe gap “a”. Figure 8 shows as an example the values of  $K$  applied to different crack depths, as a function of the reinforcement-to-pipe gap. These data were calculated for the maximum operating pressure. The stresses in the defect plane was obtained overlapping the stress fields due to each applied load (longitudinal stress due to inner gas pressure, pressurization of the gap and welding residual stresses) The residual stress was considered as base metal yield stress, since the repair procedure does not include a post weld heat treatment [10]. To consider mechanical stress relief, the residual stress is reduced when the sum of longitudinal stresses exceeds 1.4 times the yield strength, in such a way that the total stress never surpasses 1.4 yield strength.

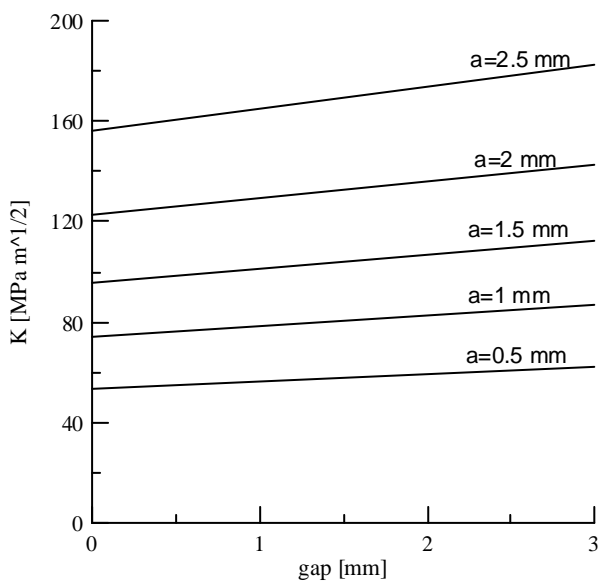


FIGURE 8

Previous studies by the authors indicate that when reinforcements with O-rings are used to repair gas leaks gaps “a” (figure 8) between tube and reinforcement are close to 3 mm [4]. Figure 9 shows that for a value of  $K_{Ic} = 120 \text{ MPa m}^{1/2}$ , the critical crack depth for a thickness of 5 mm is  $a_c = 1.5 \text{ mm}$ . Very small gaps increase the value of  $a_c$  up to about 2 mm. This value is not strongly dependent on the thickness of the pipe in the welded area.

## 6.- DISCUSSION OF RESULTS

It is concluded that the minimum weldable thickness is 5 mm, for a nominal pipe thickness of 7.1 mm. Therefore, it is important to ensure that NDT inspection of the area to be welded would detect thickness losses of less than 2 mm with precision, especially in the presence of corrosion pits and other defects of difficult access with the normal ultrasonic transducers. Once minimum thickness is verified, abrupt thickness changes should be eliminated by grinding to clean metal. In the event of repairs shortly downstream compressor plants and in other sectors with high risk of stress corrosion (SCC) or fatigue cracking, penetrant dies should also be used to ensure a crack free surface to be welded.

The minimum weldable thickness strongly depends on weld penetration. Therefore, deviations from the qualified weld procedure should be minimized. For the weld procedure with 3 mm basic electrodes assessed in this work, maintaining welding current in the range around 120 A, straight beads and a weld speed of at least 10 cm./min is mandatory. A 1.5 mm deep surface defect in the circumferential weld would be roughly semielliptic, with a surface length of at least 3 mm. This value defines the defect size that could be left undetected by after weld NDT.

Previous work by the authors show that stresses in sleeve material increase when repair is done at low pressure [4]. The lower gas flow rates also generate lower weld heat dissipation, and both the depth of the molten pool and the temperature in the inner wall surface increase slightly. Therefore, repair procedures that allow to weld smaller thicknesses could be developed. For doing this, high gas flow rates at the maximum gas pressure compatible with safety regulations [1] should be attained. and small diameter electrodes with currents up to 80 A should be used. In this way, welding of wall thickness as small as 4 mm could be proved to be safe, although these alternative repair procedures may present numerous operative shortcomings.

## 8.- CONCLUSIONS

When the pressure during the welding operations is 100% of the operative pressure, the minimum weldable thickness is 4.65 mm, according to the approach by Battelle. For gas pressures during

welding of 80% and 60% of the operative pressure, the minimum thickness is 4.80 mm and 5.30 mm, respectively. The minimum weldable thickness increases when the flow rate of the transported gas in the section being repaired increases. It would be desirable to repair in winter, when large gas flows are transported at lower environmental temperatures. It is possible in principle to evaluate alternative measures, among them maneuvers with the blocking and venting valves at the ends of the sector being repaired, that would allow to momentarily increase the transported flow reducing at the same time the pressure in the area of the repair.

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### REFERENCES

1. American Petroleum Institute, Recommended pipeline maintenance welding practices, API RP 1107, USA.
2. J.F. Kiefner, Defect repair procedures, 6<sup>th</sup> Symposium of lime pipe research, p I 1, Houston, USA (1979).
3. "AWS Welding Handbook – Volume 4, Part 2: Materials and Applications". 8<sup>th</sup> ed., American Welding Association, Miami, USA, 1998.
4. J L Otegui, A. Rivas, C. Manfredi: Weld failures in sleeve reinforcements of pipelines., C. Martins. Engineering Failure Analysis, vol. 4 – 3/v3, pp. 1-17 (1999).
5. M.D. Chapetti, J.L. Otegui, C. Manfredi, C.F. Martins.: Full scale experimental analysis of stress states in sleeve repairs of gas pipelines. Accepted, Int'l Journal of Pressure Vessels & Piping, 2000.
6. J.F. Kiefner, Defect repair procedures, 6<sup>th</sup> Symposium of lime pipe research, p I 1, Houston, USA (1979).
7. J.F. Kiefner, Corroded pipe: strength and repair methods, 5<sup>th</sup>Sym. lime pipe res., p L1, USA (1971).
8. F. Valenta et al, Int. J. Pres. Ves. & Piping, vol. 66, p187-198 (1996)
9. K. Smith and M. Wilson. "Stress Analysis of a Fillet Weld Between a Pipe and Sleeve Reinforcement". Gas Council Engineering Research Station, File No.. 2633/5 and 2597, July, 1972.
10. J.R. Gordon, P. Dong, Y.Y. Wang and T. Jutla. "Fitness-For-Purpose Assessment Procedures for Sleeve in Pipelines: Summary Report". EWI project No. J7185, J7193 & J7215 to the American Gas Association, Dec. 1994.
11. J.L. Otegui, S. Urquiza, A. Rivas, A. Trunzo: Local collapse of gas pipelines under sleeve repairs Accepted, Int'l Journal of Pressure Vessels & Piping (2000)
12. Guidelines for weld deposition repair on pipelines. EWI project No. 40545CAP,1997.
13. W.A. Bruce, R.L. Holdren, W.C. Mohr, Edison Welding Institute, and J.F. Kiefner, Kiefner and Associates. Repair of Pipelines by Direct Deposition of Weld Metal – Further Studies. PRC/International. Project PR-185-9515, November 1996.
14. M.J. Cola, J.F. Kiefner, R.D. Fischer, T.A. Bubenik, D.J. Jones and W.A. Bruce. "Development of Simplified Weld Cooling Rate Models for In-Service Gas Pipelines". AGA Project Report No. J7134. July, 1992.
15. J.F. Kiefner and R.D. Fischer. "Repair and Hot Tap Welding on Pressurized Pipeline", Symposium during 11<sup>th</sup> Annual Energy Sources Technology Conference and Exhibition, New Orleans, LA, January 10-13, 1988, New York, ASME PD -Vol. 14, pp.1-10 (1987).
16. "AWS Welding Handbook – Volume 1: Weld Processes". 8<sup>th</sup> ed., American Welding Association, Miami, USA, 1989.
17. R.A.Dodge and M.J. Thompson. Fluid Mechanics. McGraw-Hill, 1937.
18. B.S. Petukhov. Heat transfer and friction in turbulent pipe flow with variable physical properties. Advance in Heat Transfer, Vol.6, pp.503, 1970.
19. E.C. Guyer. Handbook of Applied Thermal Design. McGraw-Hill, 1989.
20. ALGOR Finite Element Design Software. Algor Inc., USA, 1998
21. D. Broek: Practical use of Fracture Mechanics. 1990
22. J. Barsom, S. Rolfe: Fracture and Fatigue Control in Structures, Prentice Hall, 2nd. Ed.
23. BSI PD6493/91 "Guidance on some methods for assessing the acceptability of flaws in fusion welded structures". British Standards Institution, London, 1991.