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Numerical Prediction of Inner Pipe Temperature in Pipeline Hot Work Repair by In-Service Buttering Layers Welding of Pipeline Sleeves

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Abstract

In-service welding is a type of hot work repair process using pipeline sleeves. It is hazardous and necessitates thorough planning and procedures. The inside pipe surface and fluid temperature are all unknown and unpredictable. Therefore, the risk resulting from burn-through where the welding arc causes pipe wall breaching, hydrogen cracking, and the likelihood of occupational health risks are high. Hence, this work aimed to predict the pipe's inner surface temperature and fluid temperature in contact with the pipe's inner surface during the buttering layers welding of the pipeline sleeve to determine if it is safe to carry out welding of the buttering layers in a no-flow condition. This analysis was achieved through 2-dimensional Steady-State Thermal Analysis in Ansys APDL (Ansys Parametric Design Language). The Ansys simulation results showed that the fluid temperature was high, almost getting to the fluid autoignition temperature, and in some instances, even higher than the fluid autoignition temperature. The implication is that, in-service buttering layers welding of pipeline sleeves must not be performed in a no-flow condition during pipeline repair. Also, hot work repair welding for pipeline sleeves by the in-service method could be safely done following all necessary precautions and preventive measures where in-service welding for pipeline sleeves during the buttering layers might cause a severe hazard and dangerous incidents such as explosion. The temperature prediction helps to assure safety in in-service welding for pipeline sleeves to avoid pipeline explosion due to extremely high temperature or decrease in the toughness of the Heat-affected-zone (HAZ) in the welded joint because of the high cooling rate of the weldment, which reduces the pipe mechanical strength.

Keywords: In-Service Welding, Buttering Layer, Burn-Through, Heat-Affected-Zone (HAZ), Pipeline Sleeve, Steady State Thermal Analysis.

1.0 INTRODUCTION

In-service welding of pipeline during pipeline repair by the sleeving process in the repair of either a corroded pipeline or repair of an illegal connection on the pipeline without having to shut it down is advantageous in timesaving, labour, and expenses. Preserving product flow get rid of the revenue lost through the shutdown of pipeline operations. It also gets rid of the concerns of draining pipeline liquid contents into the environment and releasing gas into the atmosphere. It will cause significant economic losses and environmental pollution once the pipeline fails. In order to ensure the strength of a defected pipeline, type-B sleeves weld are used to reinforce defected or damaged pipelines [1, 2]. However, this sleeving process is a high-risk activity. The need for strict precautions and engineering concept during performance of this activity is inevitable. Three welding beads deposition types are involved during pipeline repair by the sleeving process. First is longitudinal butt welding, in this type, welding beads do not make contact with the live carrier pipe. Backing-strip is inserted in-between both sides, on the upper and lower sleeve, which prevents the longitudinal butt-welding beads from contact with live carrier pipe. The second weld bead deposition is the buttering layers, where the welding beads are deposited directly on the live carrier pipes. This is the riskiest, and the internal heat generated by this buttering layer is this research focused. The third weld beads deposition is the fillet weld along the pipe circumference. The risk encountered during in-service pipeline repair by the sleeving process during the buttering layers welding are burn-through and breaching pipe wall which can cause explosion. Also, explosion can occur because of high heat in the internal fluid and hydrogen-induced cracking resulting in loss of the structural strength. There have been different studies on in-service welding, for example [3], investigated the welding stress of in-service welding on the X80 steel pipeline using 3D finite element method. The parameters of heat source and axial and hoop welding stress were verified in their experiment and they observed that the heat-affected-zone (HAZ) location of the pipeline and sleeve, the outer wall was predominantly under compressive stress, while the inner wall was mainly subjected to tensile stress and the hoop stress was greater than the axial stress. Furthermore, their results showed that maintaining the natural gas pressure at 1 MPa, keeping the flow rate below 12 m/s, and controlling the preheating temperature at approximately 50 °C can enhance the performance of the fillet weld during the in-service welding of X80 steel pipelines. It has been reported that welding stress during in-service welding could be complex for increasing the wall thickness of pipelines, and a greater risk must be faced [4-7]. Relatedly, burn-through is a serious challenge in in-service welding which needs to be avoided to minimize failure. Research conducted on burn-through during in-service welding of pipelines with corrosion defects shows that the maximum radial deformation, von Mises stress, and hoop stress in the defect region increased when the medium pressure rises and the depth of the defect has a pronounced influence on the radial deformation and the stresses [8-11]. There are studies too, on hot tapping which involves the attachment of branch connections and cutting holes into the operating pipeline without interrupting fluid flow and with no release or loss of product to the atmosphere [12]. Hence, it is essential to ascertain the risk in pipeline repair by the sleeving process by predicting temperature of pipe internal surface and fluid in contact with the pipe interior surface during in-service buttering layer welding. There were also studies involving the stress and heat generated during the fillet welds along pipe circumference and it associated temperature during in-service welding [13-16]. From literature, to the best of the authors, no work has been done on predicting the fluid temperature in contact with the pipe inner surface during welding of buttering layers in the repair of the pipelines by the sleeving method. Hence, this work intends to predict pipe inner wall surface and fluid temperature in contact with the pipe internal surface during in-service buttering layer welding to determine how safe is buttering layer welding when the fluid is static condition.

1.1 Type-A Sleeves

The ends of Type-A sleeves are not welded directly to the live pipe circumferentially (Figure 2.). The Type-A sleeve isn't very good at keeping internal pressure in check, but it does serve as reinforcement for a weak faulty spot. It's employed for non-leaking defects and defects that will not increase in size during service or defects that the damage mechanism is fully understood [17].

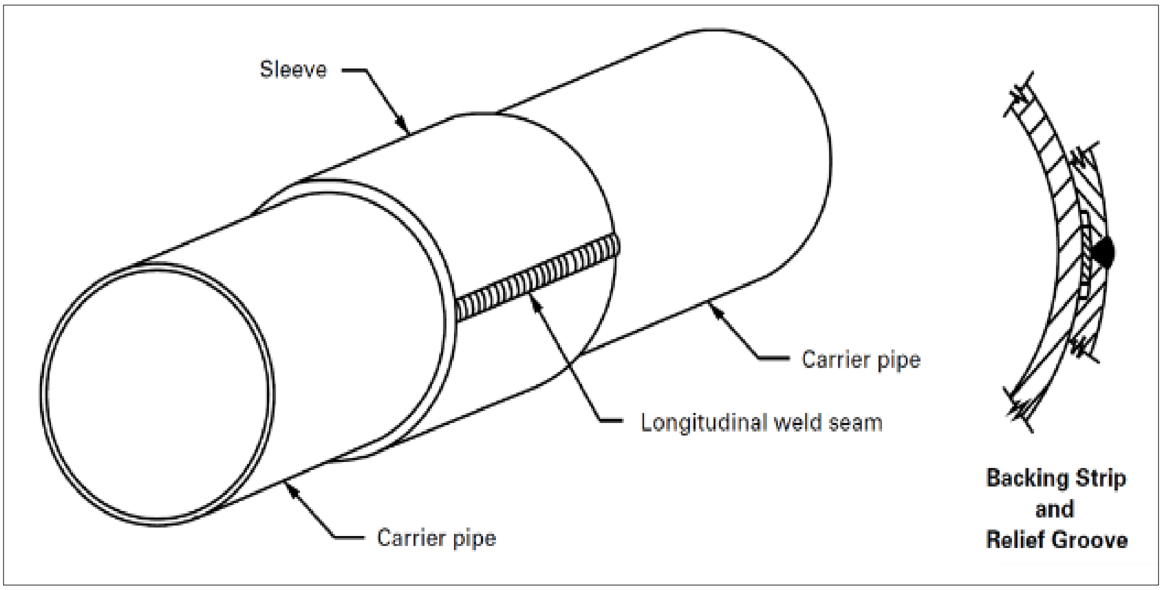

Figure 1: Type a Sleeve

1.2 Type-B Sleeve

The carrier pipe circumference is welded to the Type-B ends (Figure 2). Because the ends are welded (fillet weld) to the live pipe, a Type-B sleeve can withstand the pipe's internal pressure. It is used during repairs of pipe leaks, defects in pipe that may leak, and reinforce pipe having flaws that lower the axial load-carrying capability of pipe [17, 18].

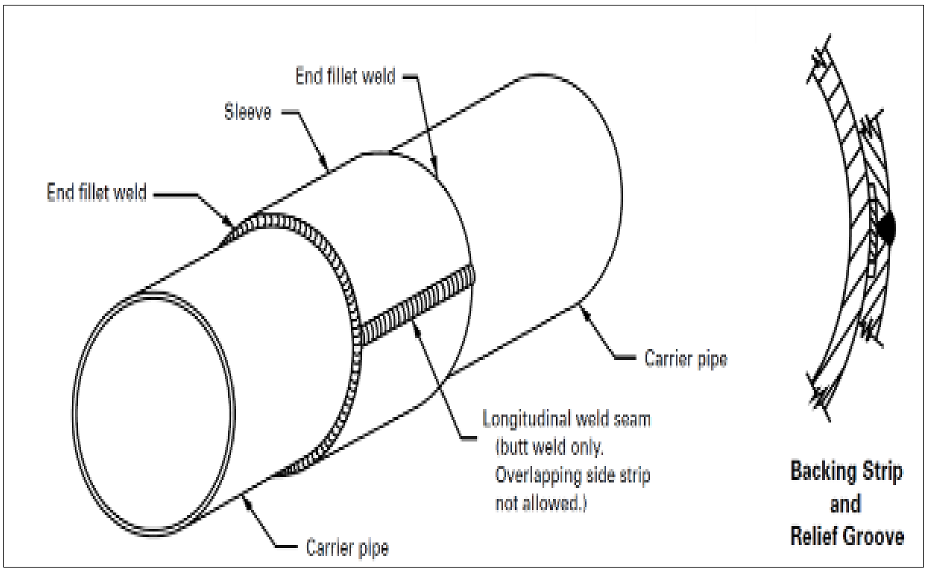

Figure 2: Type-B Sleeve

1.3 Type-B Sleeve Buttering Layers

The pipe inner surface temperature prediction is founded from the buttering layer of type-B Sleeve. The buttering-layer is the molten Weld deposited on outer surface of the primary material to give build-up as shown in figure 3.

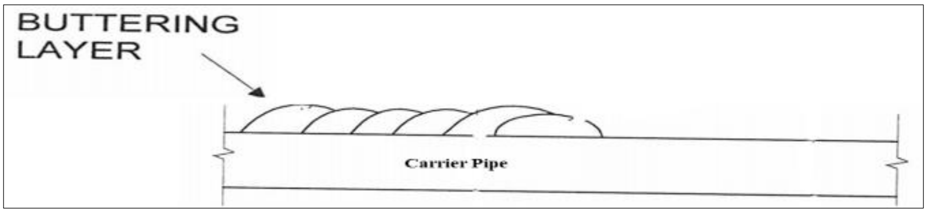

Figure 3: Buttering Layer

1.4 Welding Sequence of the Full Encirclement Sleeve

When full encirclement sleeve is installed on a pipeline, chain clamps are employed to hold the two sleeve sections together. Tack welds are then made between middle of the clamps. The chain clamps are taken out after completing tack welding to hold the sleeves together. Thereafter, the root-pass will be finished upon adding welds. The welder manually adds weld passes layer by Layer till it gets to the expected weld size. The sequence of welding includes Longitudinal Weld, Buttering Layers, and Circumferential Fillet-Weld.

1.5 Longitudinal Butt-Weld

The longitudinal-weld attaches the upper and lower halves sleeve fitting with a supporting strip in between to stop weldment from coming into contact with live pipe (Figure 4 and 5).

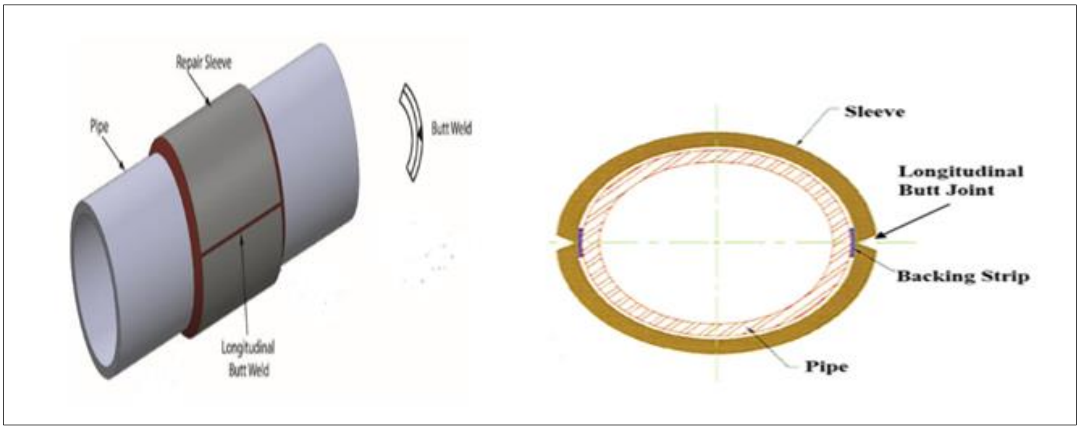

Figure 4: Longitudinal weld schematic

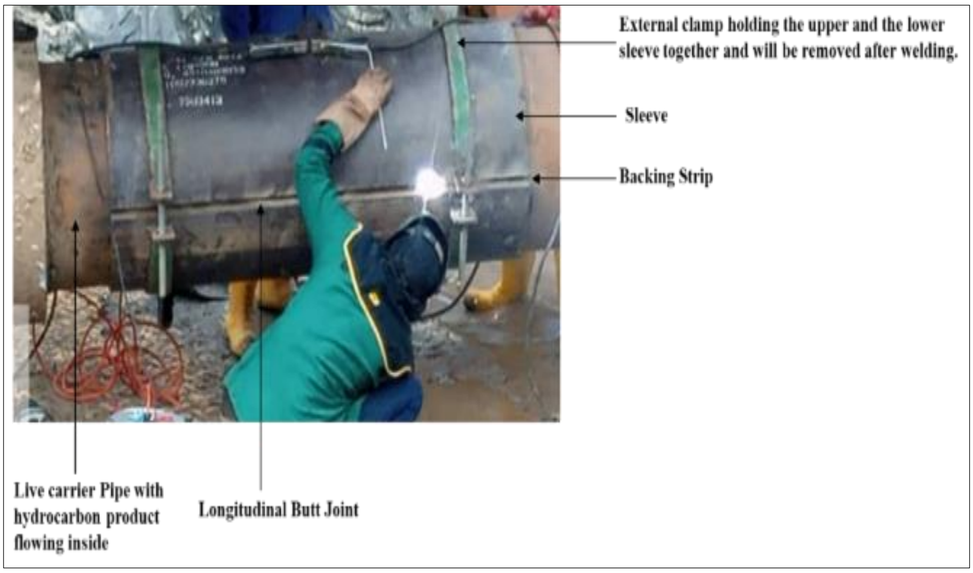

Figure 5: Longitudinal Welding Operations

1.6 Buttering Layer

This is the weldment deposited on live pipe to provide build-up. The buttering layers helps to prevent a rooting problem with pipe circumference as shown in figure 6.

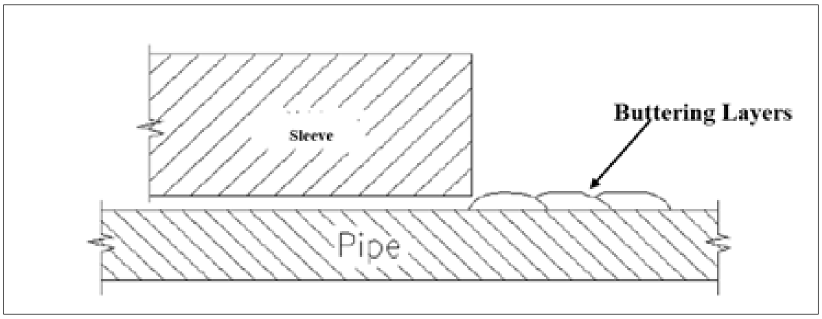

Figure 6: Schematic of the Buttering Layers

1.7: Fillet Weld

The fillet welds on pipe circumference are made for the assurance of the pressure-containing maintenance capability. The pipe sleeve preparation, buttering layer welding process and completed circumferential fillet-weld are shown in figures 7 to 9, respectively.

Figure 7: Pipe Sleeve Preparation

Figure 8: Buttering Layer Welding

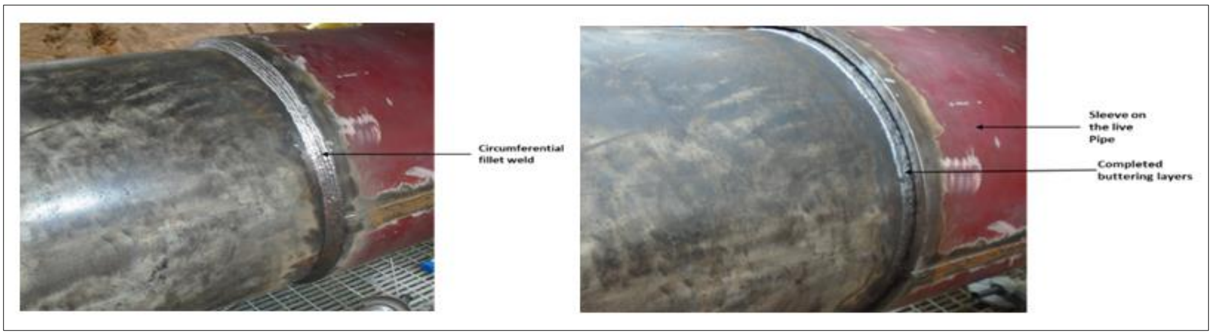

Figure 9: Completed Buttering Layers

2.0 RESEARCH METHODOLOGY

The pipe specification chosen is from actual production facilities in Nigeria's Niger Delta. API 5L X60 Carbon-Steel (CS) Pipe is the pipe specification. A 24-inch pipe with a 12.7mm pipe wall thickness. However, due to the nature of the activity (pipeline repair), the minimum field measurement of the wall thickness is used.

3.1 Welding Heat Calculation

The buttering layer welding heat formula according to [18], could be expressed as;

$$HI = K \cdot \frac{V \cdot A}{S} \quad (1)$$

where:
HI = heat input (J/mm)
K = net factor
V = voltage (volts)
A = current (amperes)
S = travel speed (mm/s)
For this analysis, the welding parameters was extracted from a qualified approved Welding Procedure as described in table 1.

Table 1: Welding Parameters Data

Weld Layers	Weld Pass	Process	Consumable	Size (mm)	Polarity	Voltage Range (v)	Amperage Range (A)	Travel Speed (mm/min)	Heat Input (J/mm)
1	Buttering	SMAW	E8045-P2	2.4	DC+	23 - 26	63-118	109	0.80-1.69

The SMAW process was selected using a low hydrogen electrode as this will make burn-through unlikely. Among the three weld passes, Longitudinal Butt Weld, Circumferential Fillet-Weld, and the Buttering Layers, only the buttering layers was considered. This is because the Buttering Layer imposes the highest welding danger pass, as is the only weld that is in contact with the live crude oil pipe. It involved depositing weld beads directly on the live pipe. The first buttering layer heat was considered.

2.2 Pipe Surface Temperature

The welding data values in figure 10, which is from an approved Welding Procedure is first used to identify the buttering layer heat in estimating pipe internal surface temperature. The Heat in the first buttering layer were considered due to chances of risk of burn through. The welding data used in estimating inside pipe surface temperature using DEP 31.38.60. (2016) chart, was initially for the first buttering pass. The pipe thickness of 9.5 mm and, welding Heat of 800 J/mm were used to estimate the pipe inside surface temperature. Figure 10 under beads on plate and the red intersecting lines point, the internal pipe temperature was estimated to be 275 ºC, while the penetration depth was estimated to be 2.01mm.

Figure 10 Welding Temperature of Pipewall-Initial wall Temperature of 25^0C.

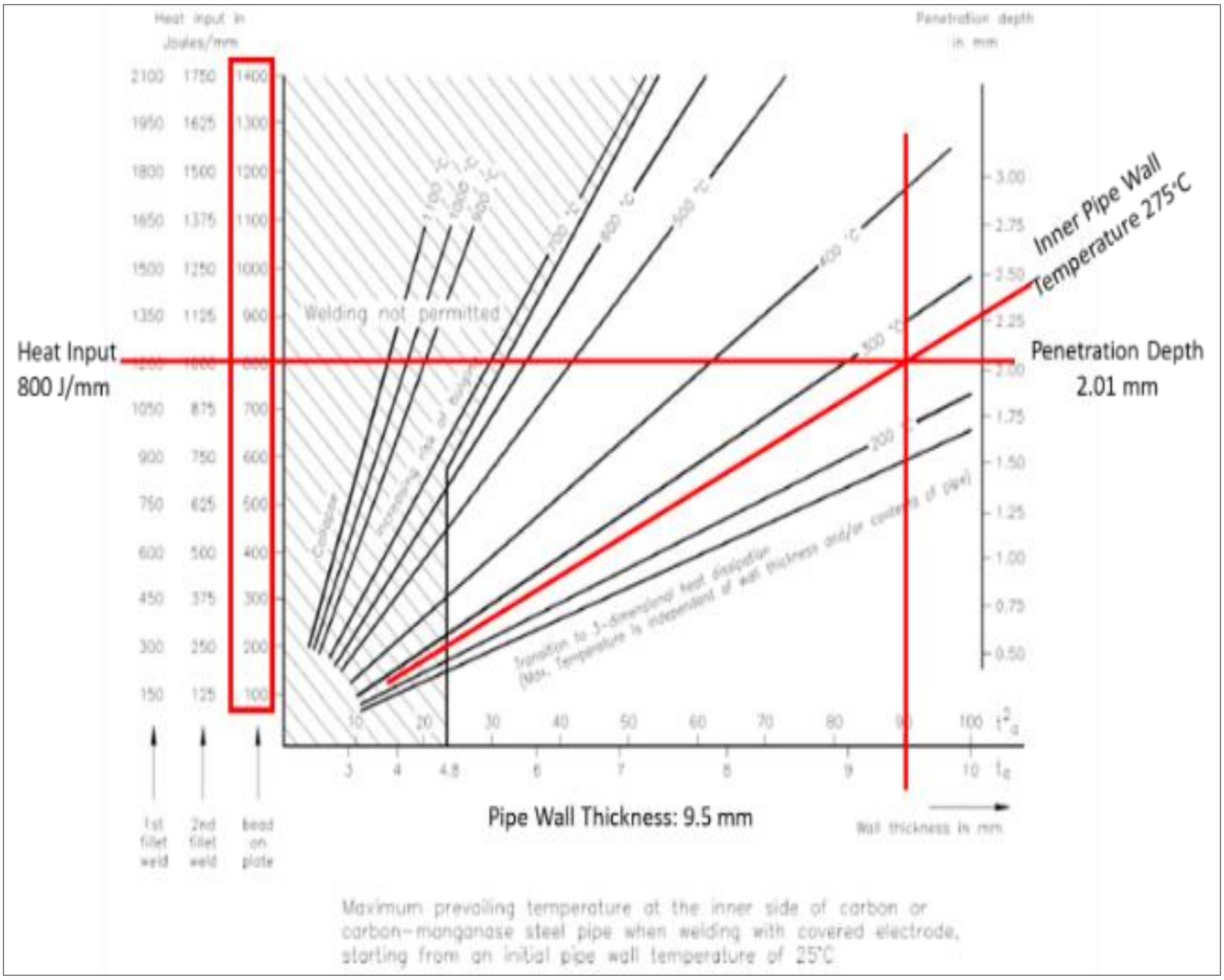

Figure 10: Chart prediction of internal pipe temperature

2.3 The Finite Element Model

The Ansys APDL model was simulated under certain boundary conditions during the buttering layer welding operations to compute temperature of interior pipe surface and the fluid. The Ansys thermal analysis is splited into two sections. First, the chart predicted internal pipe temperature was compared to the Ansys simulation output predicted internal pipe temperature. This comparison validates the accuracy of predicting the inside pipe wall temperature using ANSYS simulation. This validation contributes to achieving correct findings for the second stage simulations in forecasting interior fluid temperature within the pipeline during buttering layer welding when process fluid is introduced into the pipeline. The pipe's 2D cross-sectional plane was used to create the 2D model. Heat exchange to the ambient atmosphere is thought to occur via free convection in fluid motion, with heat transmission through the pipe wall material is approximated to be pure conduction.

2.3.1 Ansys Simulation Boundary Conditions

The simulated boundary conditions and the 2D model geometries were defined. The crude oil attributes utilized in the ANSYS simulations are shown below, and they were based on a crude oil pipeline infrastructure in the Niger Delta.

Table 2: Crude oil Physical Properties

CRUDE OIL PROPERTIES	
Specific Gravity, γ	0.85
Density, ρ	835 kg/m^3
Convection Coefficient, h	1470 W/m^{2}K
Temperature	25°C

In this scenario, the crude oil level is assumed to occupy half of the pipe's internal diameter. The fluid is not moving, and heat transfer is supposed to take place within it via free convection and conduction. The physical properties of API 5L X60 CS are listed in Table 3.

Table 3: API 5L X60 Pipe, Carbon Steel

Pipe Properties	
Material type	CS (API 5L X60)
Thermal Conductivity (k)	54 W/m.°C
Specific Heat Capacity (cp)	502.4 J/kg. °C
Density, ρ	7850 kg/m3
Pipe size	609.6 mm or 24.00 inches
Outer Diameter	609.6 mm or 24.00 inches
Pipe Wall Thickness, t (from field measurement)	9.5 mm or 0.374 inches
Initial Pipe Wall Temperature, $T_{initial}$	25°C

The air within the pipe, the outside surface of the pipe, and the half section of the inside diameter of the pipe that was not filled with fluid were also taken into account, and air is assumed to be static.

Table 3.4: Air Properties

Pipe Properties	
Material type	CS (API 5L X60)
Thermal Conductivity (k)	54 W/m.°C
Specific Heat Capacity (cp)	502.4 J/kg. °C
Density, ρ	7850 kg/m3
Pipe size	609.6 mm or 24.00 inches
Outer Diameter	609.6 mm or 24.00 inches
Pipe Wall Thickness, t (from field measurement)	9.5 mm or 0.374 inches
Initial Pipe Wall Temperature, $T_{initial}$	25°C

Following the establishment of the boundary conditions in the ANSYS APDL preprocessing phase, the model was constructed, meshed, and the heat transfer directions (conduction and convection) were determined. In real-world situations, welding heat travels in the same direction as shown. The fluid entry is not taken into account in the first model. Temperature output data from the first model run were compared to temperature forecast data from internal pipe wall temperature prediction without liquid (figure 11). The second model was simulated with fluid in the pipe after the first was validated (figure 12).

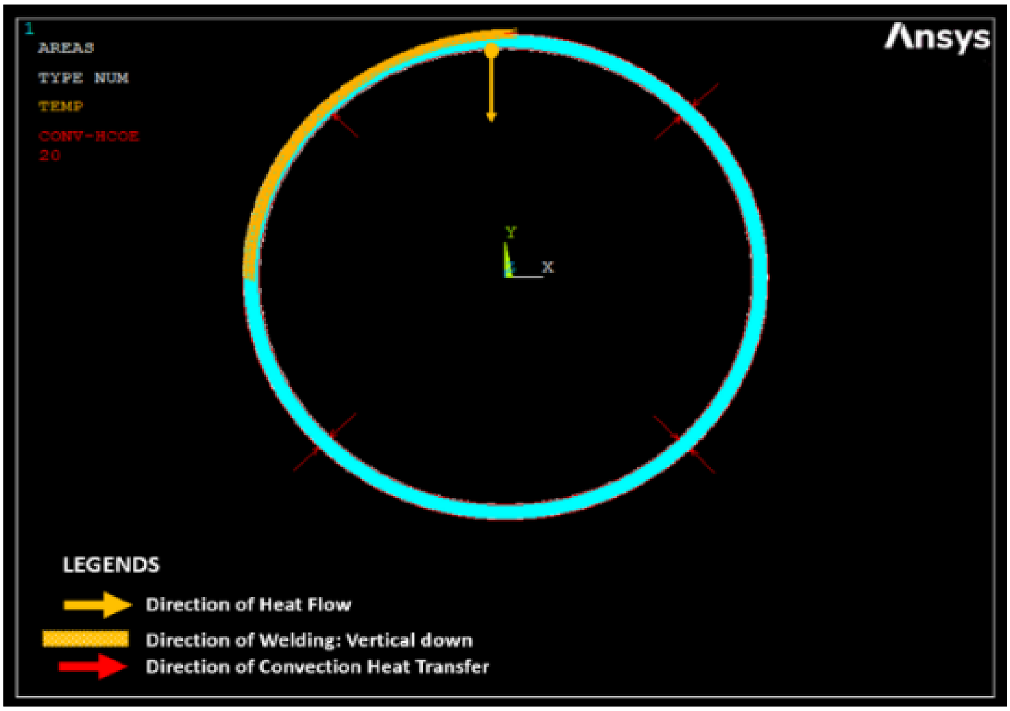

Figure 11: ANSYS Model without Liquid

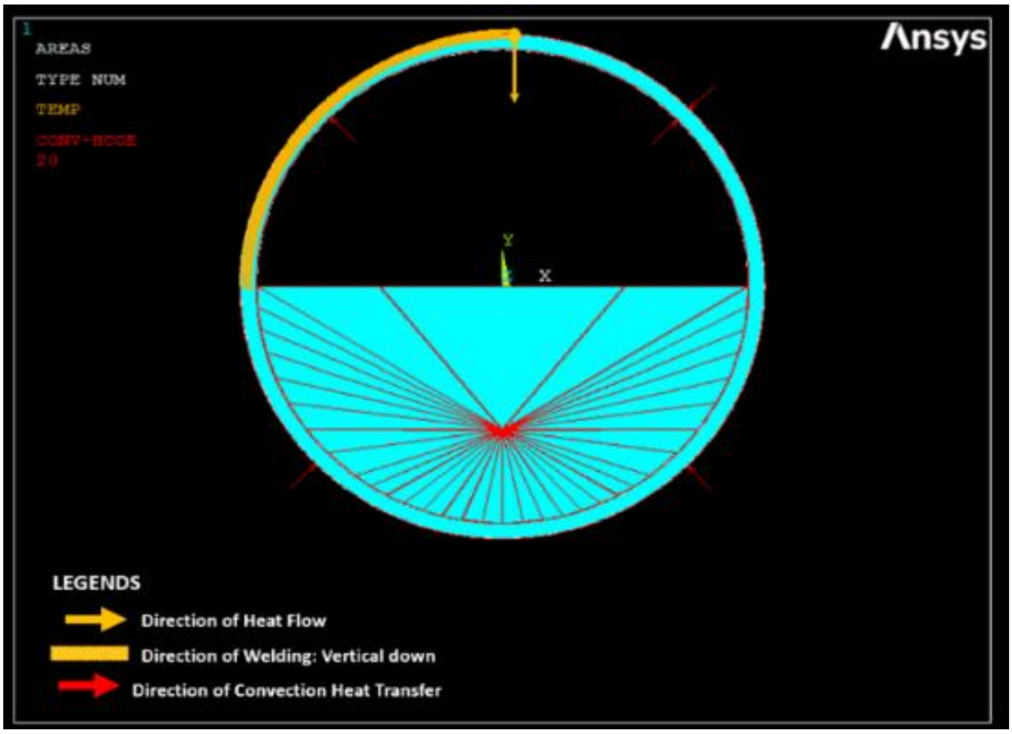

Figure 12: ANSYS Model with Liquid

3.0 RESULTS AND DISCUSSIONS

3.1 First Ansys Simulation

Figure 13 is the Ansys temperature profile for the prediction of pipe inner surface without fluid. The pipe inside surface temperature was assessed to be 275.2°C and the value calculated from the chart in figure 10 was around 275°C. There was no discernible difference between the two numerical numbers. This validates the heat modeling in Ansys. In this simulation, the welding heat was 800 J/mm, with a 24-inch pipe thickness of 9.50 mm.

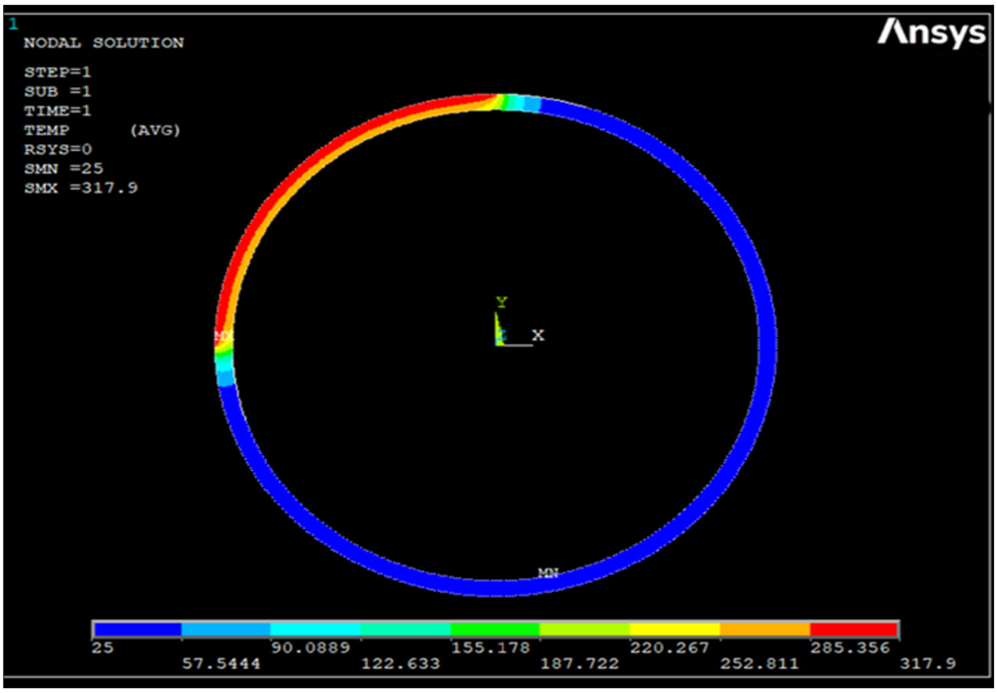

Figure 13: Ansys simulation temperature

3.2 Second ANSYS Simulation

Ansys predicted temperature characteristics of the internal pipe surface with fluid in the pipe are shown below—welding direction from 12 o'clock to 9 o'clock.

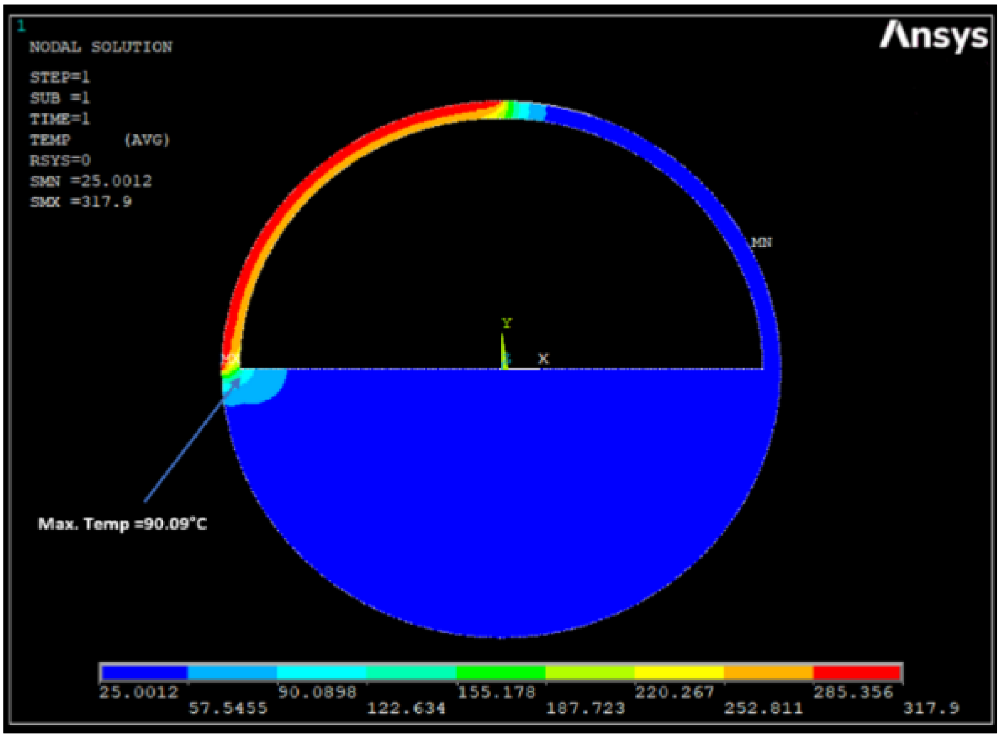

Figure 14: Ansys simulated temperature with fluid

Figure 14 depicts the temperature profile inside the pipe when the fluid level is 50%. (half-filled). The pipe's nominal diameter was 24 inches, and its thickness was 9.5 millimeters. The maximum fluid temperature ($T_{max-oil}$ = 90.09°C) is found at the point where the fluid meets the interior surface of the pipe, as shown in Figure 14. As the welding heat is transferred to the fluid, the temperature drops even further. This is an entirely risk-free welding procedure. Because the buttering layer travels around the pipe, the following ANSYS Simulation represents welding heat application in various positions.

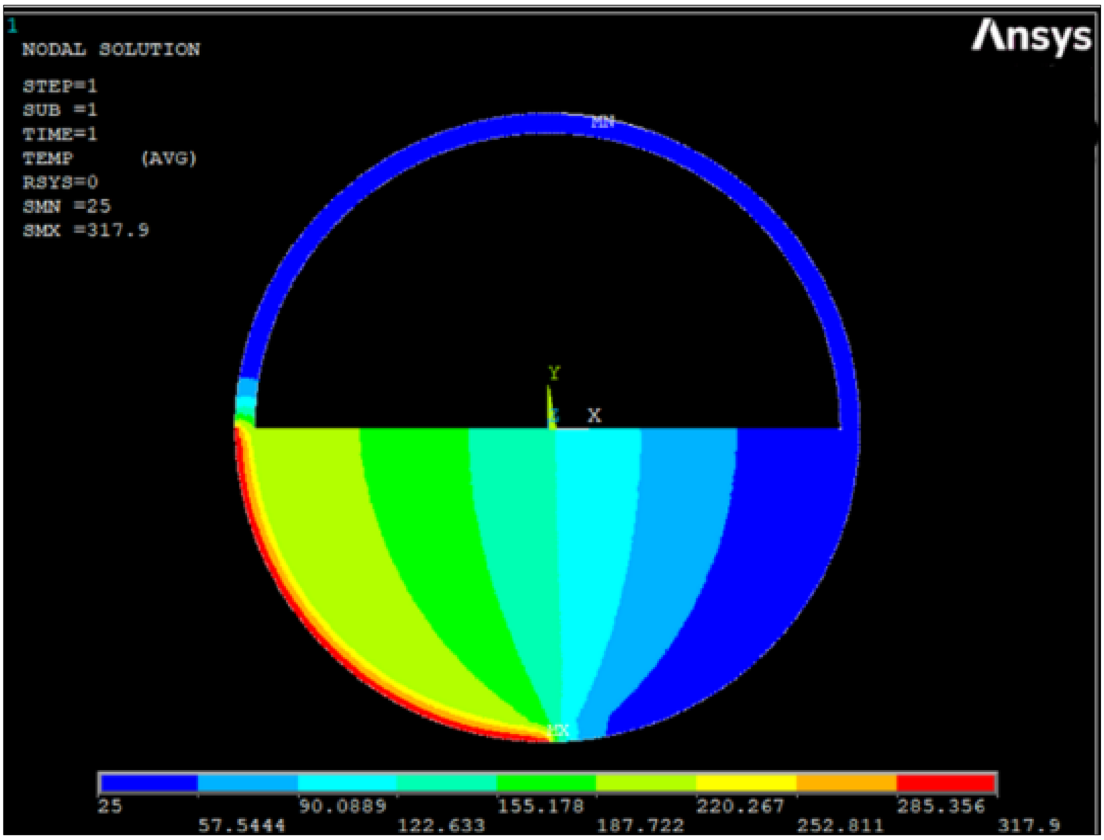

Figure 15: Welding in the direction from 9 o'clock to 6 o'clock with fluid introduction

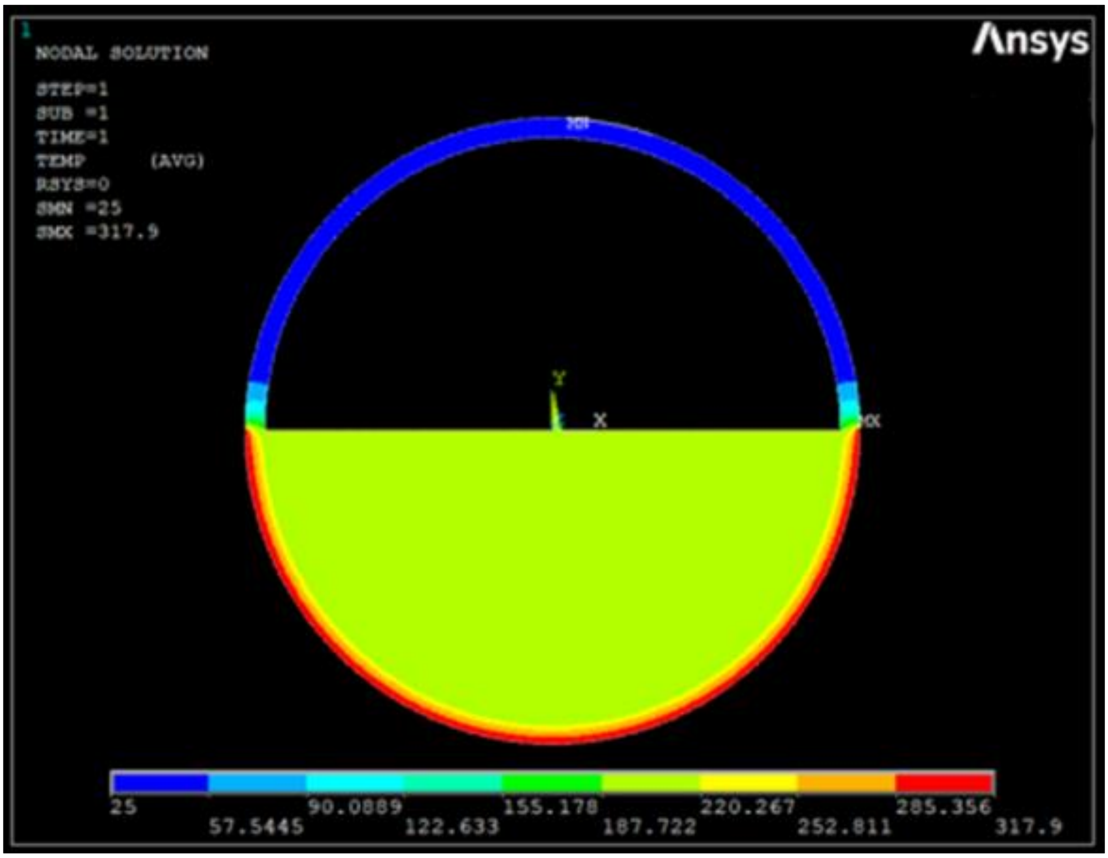

Figure 16: Welding from 3 o'clock to 6 o'clock and from 9 o'clock to 6 o'clock with fluid

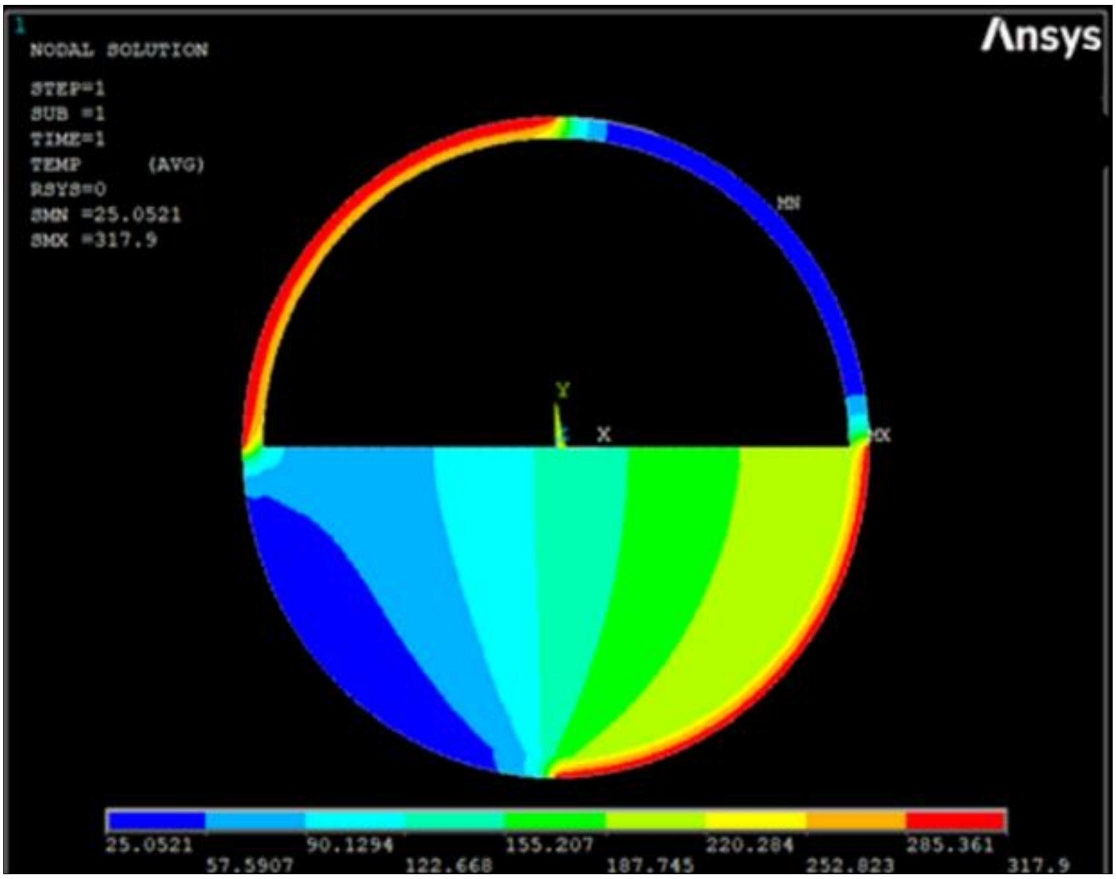

Figure 17: Welding from 12 o'clock to 3 o'clock and from 9 o'clock to 6 o'clock

From figures 14 to 17, the difference in temperature profile is seen in terms of the colour changes within the process fluid.

3.3 DISCUSSION

According to the ANSYS simulation, when fluid was introduced into the system, the welding heat input makes the fluid temperature to rise as can be seen in the fluid colour changes. Comparing the temperature profile for each of the colour as shown in the colour scale with the autoignition temperature of the process fluid, we can see that it is almost and, in some cases, even higher than the autoignition temperature of the process fluid. As a result, when there is no flow in the system, pipeline repair by sleeving using the in-service buttering layer welding method should never be attempted. In all field applications, the fluid estimated temperature must always be kept below the fluid autoignition temperature to avoid the risk of explosion due to spontaneous fluid ignition even in the absence of a source of ignition such as a spark or flame. Also, the oxygen concentration in the pipe should be considered because the fluid auto-ignition temperature increases as the oxygen concentration increases, even though the fluid is static in this simulation. Pipeline repair by in-service welding for the pipeline sleeve must not be done in real-world practice if there is no flow within the pipeline. The flow will ensure that there is no oxygen trap within the pipe.

CONCLUSION

During pipeline repair employing in-service welding for pipe sleeves' buttering layers, the simulations' output data can be utilized in approximating the temperature of pipe inside surface and the fluid interacting with the pipe's inner surface. The first segment of the ANSYS simulation confirmed the correctness of heat dispersion and the modelling. The simulation findings were validated alongside the temperature readings obtained using the Chart method. The second phase of the ANSYS simulation, the fluid temperature was verified with the fluid's autoignition temperature to determine a safe temperature margin during buttering layer welding. Temperature of fluid in pipe should never exceed its autoignition point to prevent spontaneous combustion. In-service buttering layer welding of pipelines sleeve should not be attempted under no flow condition. The simulation shows spontaneous increase in temperature both in the inner surface of the pipe and the fluid in contact with the inner pipe surface. Buttering layer welding under this condition can be catastrophic and should be avoided. But under a flow condition, the simulation data could serve as guide but not taken as final decision for in-service buttering layer welding of pipeline repair by the sleeving method. Projects differ, and atmospheric conditions can change at any time during welding operations; hence, it is vital to qualify welding procedure for each specific project. But in every condition, the temperature should be checked, so is not beyond the auto-Ignition temperature. From this work, it is certain that pipeline repair by in-service buttering layer welding of pipeline sleeves is not practicable under no flow condition.

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