Abstract- Electro – Fusion (EF) joint is a technique to join Polyethylene pipes (PE) pipes which carry gas or water medium. Generally it is assumed that the PE pipe has a 50 year life. But PE pipes get failed before its natural lifetime due to environmental load and conditions. PE joining is unavoidable in PE gas distribution pipe network. Failure of EF joint is a fundamental reason for the decrease in service life. This paper includes principles of Electro-fusion joint, temperature distribution, stress distribution due to thermal and structural loading. Due to this loading condition, inner cold region of EF joint has highly stress concentrated area. This paper analyzed using finite element analysis and found that the inner pressure causes to increase the gap between pipe and fitting while thermal load and external pressure tries to counteract the peeling effect. Due to this peeling effect, inner cold region acts as a crack initiation region. Weld joint strength depends upon the procedure adopted during EF joint which includes heating – cooling cycle, scrapping and contamination on joining surface are significant for the strength and life of the joint.

I. INTRODUCTION

Polyethylene (HDPE / MDPE) is commonly used to make gas pipes. Pipe system requires a long length pipe to transmit natural gas. It is difficult to manufacture long pipe, hence the require length of pipe is made by joining the short pipes. Also to form long pipe networks, it is necessary to use joining process like butt welding, electro fusion, mechanical joining etc. Generally electro-fusion joint is widely used because it is practically possible to conduct even in the limited space available. This joint must have higher functionality time. In past studies of failures, it is found that failure occurs due to initiation of crack in welding zone and brittle material failure takes place. Weld joint strength depends on factors like temperature, heating-cooling time, contamination, alignments etc.

Dr. Chris O’Connor et.al [3] has mentioned that fusion joint failure is the greatest threat to the integrity of polyethylene pipelines. Joint failure is due to poor quality material, inappropriate practice during joining.

According to Pedrom Tayefi et.al [4], decrease in EF joint performance is when components are subjected to contamination before welding process. When joining interface get contaminate, failures of joint occurs relatively short time. Jianfeng Shi et.al [5] has classified defects of Electro-Fusion joint in four categories i.e. i. Poor fusion interface, ii. Over welding, iii. Voids, iv. Structural Deformity. As per PPDC (Plastic Pipe Database Committee) 53% of failure happened due to failure in fitting.

II. PRINCIPLE OF EF JOINT

Electro-fusion welding is a common technique to weld PE-pipes. It involves a various fittings (coupler, elbow and tee) in which the two pipe ends can slide into. Most of fittings also have an internal stopper to prevent the pipe ends from meeting from both ends. Fittings has resistive heating copper coil for each pipe. The resistive heating coil is used to produce the heat to melt the surrounding polymer. Molten polymer that tries to escape from the fusion zone. But it cools down in the inner or outer cold zone, and restrict further molten material flow. Thus, cold zones maintain the molten polymer in the fusion zone where a melt pressure is build up. Weld indicators are given for visual indication of sufficient melt pressure has been generated. The fusion process can be divided into three stages: i. Initial heating and coupler expansion ii. Heat soaking to create joint iii. Joint
cooling the first two stages are commonly termed as the fusion time.

III. ELECTRO- FUSION JOINT PROCEDURE

In order to make a joint with good strength it is important to follow a certain cod of practice -

1) Pipe End Square cut – While starting the electro-fusion joint process, the pipe end should be cut square.
2) Marking – The marking is required to know which up to which length scrapping is required and to ensure that necessary pipe length is inside the fitting (insertion depth) or to ensure pipe is reaches to pipe stopper. [8]
3) Surface Preparation (Scraping) – Scrapping is small amount of outer material removing process, so as to fresh or free from oxidized layer is use for joining.[8]
4) Environmental Considerations- In case of adverse environment condition like high ambient temperature, rain etc., unsatisfactory joint take place. Proper protection is required to avoid surface contamination. Pipe and fittings can absorb heat and become hot so as it affects the fusion welding. To compensate high ambient temperature effect, thermal jackets must be used.
5) Heating and Cooling – Once the above stages are completed, the electric current is supplied to resistive coil to produce heat which causes heat progressive melting the surrounding polymer. To obtain good joint proper heating and cooling is very necessary. Hence, it is compulsory to maintain the heating and cooling time as per standard. [6]

IV. CLASSIFICATION OF EF JOINT DEFECT

Defects of electro-fusion joint can be classified into four categories: i. Poor fusion interface, ii. Voids, iii. Over welding, iv. Structural Deformity. Cold welding, un-scraped oxide layer, and contamination are reasons of the poor fusion interface. Good fusion joint highly dependent on heating time or welding power. Cold weld generally caused due to insufficient time of heating / welding power. Un-scraped oxide layer causes improper fusion joint causes poor joint interface. Presence of contamination on pipe and fittings causes reduction in effective fusion length. Voids are formed due to cooling of trapped air in joint or steam formed by water contained in PE material or due to contamination. Excessive welding temperature due to high energy input produces the over welding. Structural deformity means the failure of weld joint to maintain initial alignment, inadequate insertion, Cu wire displacement etc. [5]

V. FAILURE MODES OF EF JOINT

PE pipe and fittings get compressed by inner gas pressure and external load. It results in compression of the gap between pipe and fitting. Inner pressure tries to peel the middle fitting region from pipe surface. It creates three risks in EF joint under inner pressure: i. Fail at the fusion interface, ii. Crack propagation at fitting wall and iii. Failure at Cu wire (Displaced from original position). Failure through fitting wall by crack generation is due to stress concentration near Cu wire. Figure 6.4 shows failure of EF joint is due to crack generation at inner cold region and gets propagated through fusion length. [5]

VI. LOADS ACTING ON BURIED PIPE

The static structural analysis of Electro - Fusion Joints are carried out for total loads, which includes effects of the dead load exerted by surrounding soil and the live load caused by traffic or vehicle. Resultant of the dead and live load is vertical load which is a total static load on the pipeline. Along with this load one more load is acting which is nothing but internal pressure of gas on inner surface of pipe. The dead load is a weight of soil over pipe. The live load is due to external moving thing. The formula for pipe load is:

$$W = DL + LL$$
Where, \( W = \text{Pipe Load}, \)
\( DL = \text{Dead Load}, \)
\( LL = \text{Live Load}, \)

1) **Dead Load (DL)**

Marston Theory of Loads is used to find dead load acting on pipe. [9] The formula used to calculate the dead load is:

\[
DL = \frac{\gamma \cdot H}{144}
\]

Where, \( DL = \text{Dead Load, lb/in}^2 \)
\( \gamma = \text{Soil Unit Weight, lb/ft}^3 \)
\( H = \text{Height of Cover, ft} \)

Dead Load will be calculated for buried depth of 1 m from top ground surface.
\( H = \text{Height of Cover} = 1 \text{ m} = 3.28 \text{ ft} \)
\( \text{Soil Unit Weight} = 2150 \text{ kg/m}^3 \)
\( = 137.34 \text{ lb/ft}^3 \)

\[
DL = \frac{\gamma \cdot H}{144} = \frac{134.22 \cdot 3.28}{144} = 3.08 \text{ lb/in}^2 = 21.07 \text{ kPa}
\]

2) **Live Load (LL)**

The live load is due to external moving thing such as vehicles. Live load is very important in case of smaller buried depth.

For 1 m buried depth, the live load is 4.17 lb/in² = 28.75 kPa [9]
\( P = DL + LL \)
\( = 21.07 + 28.75 \)
\( = 49.82 \text{ kPa} \)
\( = 50 \text{ kPa} \)

VII. **FEA SIMULATION**

FEA simulations are carried out to find temperature distribution of Electro Fusion Joint subjected to thermal loading condition in case of PNG application and stress distribution of Electro Fusion Joint due static loading condition in case of PNG application.

1) **Geometry Of Electro – Fusion Joint**

The electro – fusion joint consist pipe and fitting which are the axisymmetric components. It will better to take advantage of axis symmetry the 2D model is developed as shown in Fig.3. The holes are the nothing but the resistive heating coil. The heating coils are made up of Cu. The stiffness of Cu material is much higher than PE material. Hence Cu wire is treated as a rigid body. EF joint has a gap of 0.5 mm between pipe and fitting. For this simulation CAX4R which is a 4 node bilinear axisymmetric quadrilateral element is used. The geometry has 3126 quadrilateral element. The pipe of SDR 11 has outer diameter 63 mm and corresponding fitting with SDR 11.

![Figure 3: Geometry of Electro - Fusion Joint](image1)

2) **Material Properties of PE Pipe**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s Modulus (MPa)</td>
<td>1115</td>
</tr>
<tr>
<td>Poisson Ratio</td>
<td>0.45</td>
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<tr>
<td>Yield Stress (MPa)</td>
<td>22</td>
</tr>
<tr>
<td>Thermal Conductivity (W/m°C)</td>
<td>0.38</td>
</tr>
<tr>
<td>Thermal expansion coefficient</td>
<td>0.00042</td>
</tr>
</tbody>
</table>

Table 1. Properties of PE Pipe [7]

3) **Boundary Conditions**

Symmetric boundary conditions are applied to model as shown in figure, where no \( y \) – direction displacement is permitted at the edges. Only \( x \) – direction displacement is permitted.

![Figure 4: Boundary condition](image2)

4) **Load**

- **Thermal load** – In this thermal analysis the load is applied in terms of temperatures i.e. inner temperature, outer temperature. Inside temperature will be set as constant because it is temperature of gas at 4 bar pressure. In this analysis the inside temperature is 15°C. The outside temperature will vary with respect to depth where pipes are buried. The outside temperature at same depth in various location is vary. Generally outside temperature varies from 3°C to 8°C.

![Figure 5: Thermal Loading Condition](image3)
After applying thermal boundary conditions, Fig. 7 shows the temperature distribution across pipe and fittings. The temperature at inner cold region is same as of gas temperature and goes decreasing outwards along fitting wall. Fig. 8 shows the effect of thermal load on Electro – Fusion Joint. The thermal load reduces the gap between PE pipe and fitting. Fig. 9 shows the deformation is maximum at inner cold zone. The deformation indicates that there peeling of fitting wall from the pipe surface. Fig. 10 shows the stress concentration occurs at inner cold region. This stress concentration will results in crack generation at inner cold region.

CONCLUSION

FEM analysis of PE Electro Fusion joint shows that peak stress occurs at inner cold region. Internal gas pressure is causes increase in gap between in pipe and fitting which results in stress concentration at inner cold zone. Crack initiation starts at this stress concentrated area. Internal gas pressure responsible for crack generation at inner cold region while outer pressure and thermal load tries to counteract the effect of internal pressure. This conclusion is based on linear finite element analysis of PE pipe. The future work contains the analysis of crack generated at this stress concentrated location using nonlinear finite element analysis i.e. XFem (Extended Finite Element Analysis). XFem analysis of EF joint with crack will give the crack propagation depending upon mechanical properties of pipe, fusion interface and fitting.

REFERENCES

[4] Dr. Chris O’Connor, “Polyethylene Pipeline Systems - Avoiding the Pitfalls of Fusion Welding”, GL Noble Denton (Oil & Gas), United Kingdom


