Analysis of Induced Stresses during Welding of Mild Steel Pipe

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***Abstract* - The influence of welding is of great importance in fatigue behavior and fracture in the heat-affected zone of welding pipes.It is essential to simulate the welding process to better understand and predict the mechanical and thermal behavior of welded components.There are two major methods of determining residual stresses, experimental methods and computerized simulations methods. With modern computing facilities, the finite element (FE) technique has become an effective method for prediction and assessment of welding residual stress and distortions.**

In this analysis, determination of residual stresses is done by advance simulation software ANSYS 16 by thermo mechanical coupling for the mild steel pipe joint of thick thickness. Also the results for induced stresses are calculated using X-ray diffraction machine and results are validated which are obtained from simulation software. For experimental analysis pipe sample is welded by SMAW (Shielded Metal Arc Welding) process. It is always necessary to predict accurate stress induced in component for the prediction and prevention of life and failure of that component. In this analysis validated method is established for the calculation of residual stresses using simulation software.

***Index Terms*-welding, welding joint, plate, residual stresses, stress analysis, finite element method.**

I. INTRODUCTION

Welding is widely used in various industries to assemble various products. It is well known that the welding process relies on an intensely localized heat input, which tends to generate undesired residual stresses and deformations in welded structures, especially in the case of pipes/thin plates Due to rapid cooling and solidification of the weld metal during welding, alloying and impurity elements segregate extensively in fusion zone and heat affected zone resulting in inhomogeneous chemical and metallurgical distribution. Residual stresses may lead to loss of performance in corrosion, fatigue and fracture. Therefore, estimating the magnitude of induced residual stresses and characterizing the effects of the welding conditions are deemed necessary. [1]

With modern computing facilities, the finite element (FE) technique has become an effective method for prediction and assessment of welding residual stress and distortions. However, the welding deformations are various with production variations such as dimension, welding materials and welding process parameters. Therefore, rapidly and accurately predicting welding induced distortion and induced residual for real engineering applications is more challenging. [2]

Many techniques have been used for measuring residual stresses in metals including stress relaxation techniques, diffraction techniques, cracking techniques and techniques by use of stress sensitive properties. These techniques cannot obtain complete stress distribution and most of them are costly and time consuming and some of them are destructive. Nowadays, numerical analyses are established to solve the complex engineering problems and among them evaluation weld-induced residual stresses. The finite element method is the conventional means of calculating residual stresses. [12].

In this analysis the residual stress analysis of mild steel pipe of grade A-106 which is commonly used in oil and gas , chemical industry for carrying high pressure, high temperature fluid is carried out. Such analysis for mentioned grade pipe is necessary because the application where this pipe is being used is very critical.

II. WELDING PROCESS

Welding of mild steel pipe is done using commonly used welding procedure SMAW (Shielded metal arc welding) process. Many times it is also termed as MMAW (Manual metal arc welding).

A.SMAW Process:

An electric current is used to strike an arc between the base material and a consumable electrode rod. The electrode rod is made of a material that is compatible with the base material being welded and is covered with a flux that protects the weld area from oxidation and contamination by producing CO_2 gas during the welding process. The electrode core itself acts as filler material, making the separate filler unnecessary. The process is very versatile, requiring little operator training and inexpensive equipment.

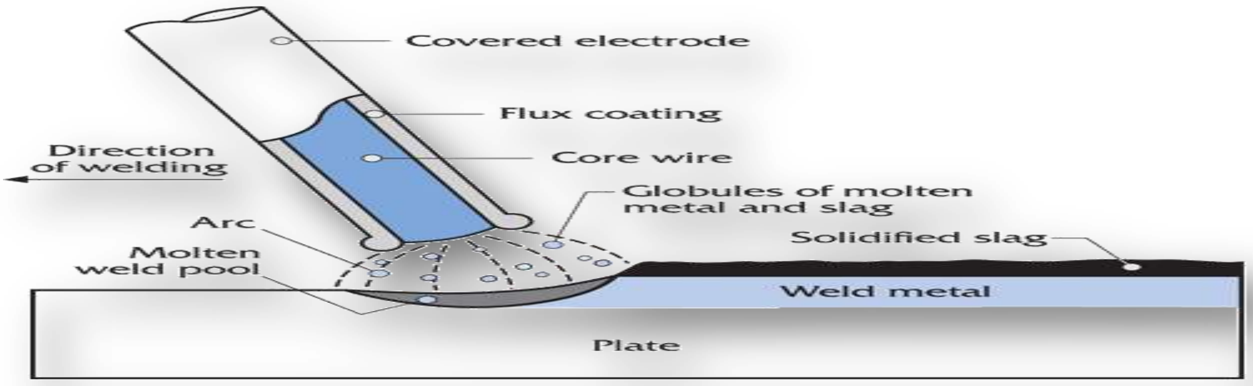

Fig. 1 Shielded metal arc welding [21]

The versatility of the method makes it popular in a number of applications including repair work and construction [21].These are the mainly used welding process in industry. In this analysis we used most commonly used method of welding in industry which is SMAW process.

B. Material selection:

For this analysis we have selected the mostly used carbon steel pipe (A106Gr.B) for line fabrication of highly corrosive/toxic material in chemical and oil and gas industry.

Usually this type of pipe is used in oil and gas industry, high pressure system, critical systems and for other chemical process fluid transfer.

Welding pipe Dimension:

Size- 1 ½"N.B. (48MM O.D. and 33.6MM I.D.)

Length: 150MM each piece (2 piece of pipe)

M.O.C.: C.S. (Grade: ASTM A106 Gr.B).

Chemical properties:

For the accurate analysis material was tested from testing laboratory. The result obtained from chemical analysis are meets the requirements of ASTM A-106(2011) gr. B specification.

Pipe geometry is as shown in below figure,

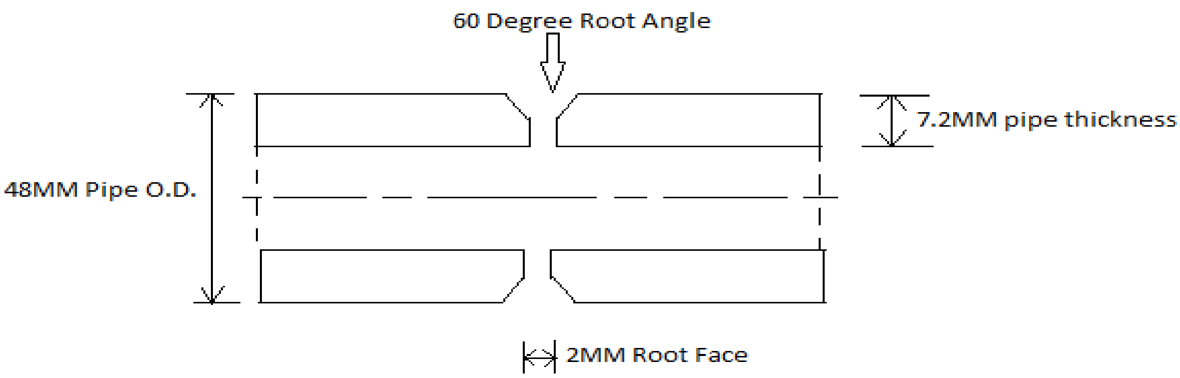

Fig.2

Pipe Geometry

The welding is done on selected pipe the parameter responsible for heat input like voltage, current and speed are taken by calibrated instrument. The values obtained are,

Table No.1 Parameter Obtained During Welding

	Voltage	current	Speed
Welding Pass	26	80	0.96MM/Sec

Welding is done by single pass and the welded sample is then tested by X-ray diffraction method for stress calculation.

III. SIMULATION

A. Theoretical Considerations:

This work includes FE models for the thermal and mechanical welding simulation. To develop suitable welding numerical models it necessary to consider the process parameter (welding speed, number and sequence of passes, filling material supplying, etc.), the geometrical constraints, the material nonlinearities and all physical phenomena involved in welding. Therefore it is a great challenge to consider all factors at the same time; so generally the models include some approximations: in the works we can find some attempts to reduce modeling efforts and computer time. This work deals with the following main assumptions and features about the thermal model:

(I)The displacements of the parts, during the welding, do not affect the thermal distribution of the parts themselves;
(ii)All the material properties are described till to the liquid phase of metal and are temperature dependent.
(iii)Convection and radiation effects are considered;
(iv)Coupled field analysis (thermal + structural) procedure is used.

B. Material Properties:

Density at room temperature: 0.2833 lb/in.3 (7.85 x 103 kg/m3)
Specific gravity at room temperature: 7.85
Shear modulus at room temperature: 10.88–11.61 psi X 103 (75.0–80.0 GPa)
Melting point: 2597ºF (1425ºC)
Poisson's ratio at room temperature: 0.29.
Tensile Strength: 415 MPa (min)
Yield Strength: 240MPa (min)
Elongation in 50MM (%) min – Longitudinal=30/Transverse=16.5.

Table 2 Thermal Properties of Material

Temperature ºF	Thermal Conductivity British thermal units (Btu)/hr.ft°F	Mean Coefficient of Thermal Expansion $\alpha x10^{6}$: in/in/F	Modulus of Elasticity Pounds per square inch ($Ex10^{-6}$: psi)
70	35.1	6.07	29.5
200	33.6	6.38	29.8
300	32.3	6.6	28.3
400	30.9	6.82	27.7
500	29.5	7.02	27.3
600	28	7.23	26.7
700	26.6	7.44	25.5
800	25.2	7.65	24.2
900	23.8	7.84	22.4
1000	22.4	7.97	20.4
1100	20.9	8.12	18
1200	19.3	8.3	16

We used the above data to enter the material properties in ANSYS simulation. Given properties are of Mild steel pipe ASTM 106 Grade B pipe.
Heat input for the analysis is calculated by below formula,

$$Q=n\frac{UI}{V}$$

Where, U is the welding voltage, I is the current and v the welding speed and $n$is efficiency.
The element type in thermal analysis is SOLID70 (linear 8-node brick element with one degree of freedom, i.e., temperature at each node) and in structural analysis is SOLID45. (linear 8-node brick element with three degrees of freedom at each node: translations in the nodal x, y, and z directions.)
The total number of element exceed than 30672.Mesh refinement is give in welded zone area for increasing the accuracy of result. In the simulation of girth welded pipe computation of the temperature history during welding and subsequent cooling is completed and this temperature field is applied to the mechanical model as a body force to perform the residual stress analysis. The heat input during welding is modeled in commercially available software by the equivalent heat input which includes body heat flux.

IV. RESULTS

For circumferentially welded cylinders, stress normal to the direction of the weld bead is the axial stress. Compressive and tensile axial stress fields are observed in and near the weld region on the outer and inner surfaces of the cylinders, respectively. This is attributed to different temperature profiles on the inner and outer surfaces of the cylinders. Varying shrinkage patterns through the wall thickness on the inner and outer surfaces due to different temperature gradients; results in tensile and compressive residual stress fields on inner and outer surfaces, respectively, near the weld line (WL).
The graph for above result can be shown as below,
Graph in above figure shows the stress distribution along axis at the surface of the pipe. These readings are taken on at the start position of the welding. The compressive residual axial stresses near the WL diminish to zero after 7.5 mm on both sides of the WL.

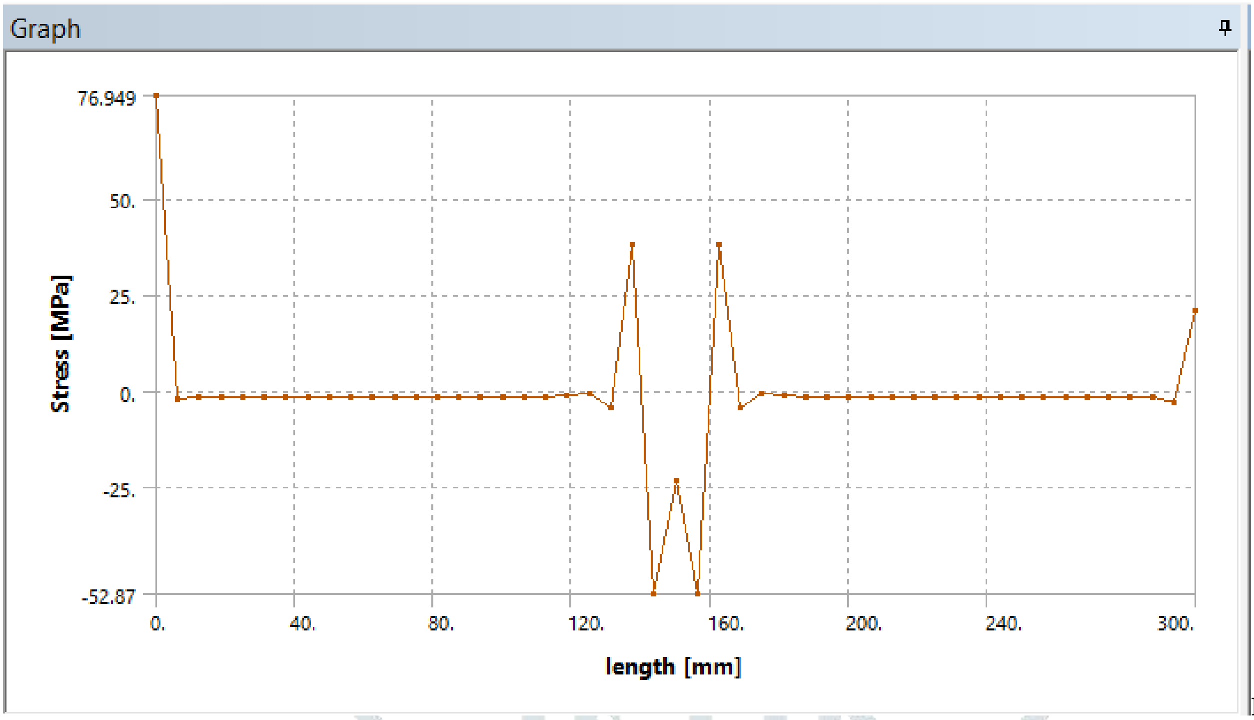

Fig. 3 Stress Graph along weld line

Beyond this, a stress reversal from compressive to tensile is observed. These low magnitude tensile stresses again approach a zero value almost 20 mm away from the WL. After 20 mm from the WL a constant axial stress value near to zero is obvious from Fig. 3.

The welded sample is then tested for stress measurement by X-Ray diffraction. The stress is measured at 2 mm from the welding bed.

The result obtained is as below,

Table 3 Stress Result-Xray diffraction

Sample no	Stress(MPa)
1	-61.9

Comparing the results obtained from X-ray diffraction and by computer simulation shows the almost similarity.

V. CONCLUSION

To study the residual stresses due to circumferential girth welding of Mild steel pipe three-dimensional model simulations is performed using ANSYS 16.

Within the range of experiments performed on the work avowed in this thesis, the following can be concluded,

1. Computational methodology and techniques based on finite element analysis for the prediction of temperature profiles and subsequent weld induced residual stress fields and distortion patterns in welded thick-walled pipe of low carbon steel are developed and analyzed successfully.
2. Due to symmetry across the weld line, the residual stresses (axial) are symmetric.
3. Along the weld line near weld bed a high compressive residual stress occurs and it reversed to tensile stresses at just vicinity of the weld bed.
4. The result obtained from experimental approach by X-ray diffraction and by FEA simulation is closely matches.
5. Cost required for Residual stress measurement by X-ray diffraction is very high which is not bearable for many industries many times. Instead of in simulation in ANSYS is economical with its some limitations.

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