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Thermal Stress Analysis in Butt Welded Thick Wall Cylinder

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ABSTRACT: - Welding is a reliable and efficient joining process in which the coalescence of metals is achieved by fusion. Welding is carried out with a very complex thermal cycle which results in irreversible elastic-plastic deformation and residual stresses in and around fusion zone and heat affected zone (HAZ). A residual stress due to welding arises from the differential heating of the plates due to the weld heat source. Residual stresses may be an advantage or disadvantage in structural components depending on their nature and magnitude. The beneficial effect of these compressive stresses have been widely used in industry as these are believed to increase fatigue strength of the component and reduce stress corrosion cracking and brittle fracture. But due to the presence of residual stresses in and around the weld zone the strength and life of the component is also reduced. To understand the behavior of residual stresses, two 90 mm thick ASTM A516 Grade 70 rolled thick plate cylinder are butt welded using the Shield Metal Arc welding (SMAW) and Submerged Arc welded (SAW) process. Numerical analysis (finite element analysis) was then carried out to calculate the residual stress values in the welded plates. Three types of V-butt weld joint – two-pass, three-pass and four-pass were considered in this study. In multi-pass welding operation the residual stress pattern developed in the material changes with each weld pass. Finite element method based, ANSYS software was used to develop coupled thermal-mechanical three dimension finite element model. The finite element model was evaluated for the transient temperatures and residual stresses during welding. Also variations of the physical and mechanical properties of material with the temperature were taken into account.

Keywords: **Residual Stress, Butt joint, Finite Element Analysis.**

NOMENCLATURE

C	specific heat capacity (kJ/kg K)
E	elastic modulus (Pa)
h	heat transfer coefficient (W/m2 K)
HAZ	heat-affected zone
I	current (A)
ID	Inside Diameter
OD	outside Diameter
PM	parent metal
Q	net line energy (J/m)
Ri	pipe inside radius (mm)
T	pipe wall thickness (mm) or temperature (1C)
TSOFT	softening temperature (1C)
U	voltage (V)
v	weld electrode speed (m/s)
V	weld pass volume (m3)
WCL	weld centre line
WM	weld metal
cr	coefficient of linear thermal expansion (1/K)
Dt	duration of the triangular time function (s)
Z	arc efficiency
L	thermal conductivity (W/mK)
n	Poisson’s ratio
sy	yield stress (Pa)

I. INTRODUCTION

Circumferentially and butt welded thick walled cylinders have a key role in nuclear, aerospace .marine engineering and high pressure vessels applications. SMAW and SAW are the common joining techniques used for high strength welding parts. The efficiency of this welding process is very high as compared to other processes and forms a strong joint. Residual stresses and distortions are two of the major concerns in welded parts. Residual stress are the stresses which remain within in the welded part when all external load or reactions are removed hence they must be self –balanced within the weld par itself. Residual stresses exits in welded parts the plastic deformation must have occurred which are associated with a temperature cycle involving temperature up to the melting point of the metrial. Welding residual stresses not only cause of distortion but also significant affect the performance of welded parts. Especially for the failures occurring under low applied stresses such as brittle fracture, fatigue and stress corrosion cracking. Residual stresses are the major constitute of a stress field around a crack which may lead to cracking. Tensile residual stress reduces fatigue strength and corrosion resistance while compressive residual stresses diminish the stability limit. Tensile residual stresses may initiate the failure due to fracture while the compressive residual stresses near a weld can reduce the capacity of the weld parting bulking and collapsing. The residual stress in some region may be as high as the yield strength of the material. Behavior and residual stresses in butt-welded pipes are measured in weld parts by using finite element method and experimentally. The results of the finite element analysis are compared with experimentally measured data to evaluate the accuracy of the finite element modeling. The developed FE modeling was used to study the effects of weld groove shape and weld pass number on welding residual stresses in butt-welded pipes. The hoop and axial residual are also studied in welding joint.

II. LITERATURE REVIEW

There are many techniques for measurement of residual stress in welding parts. In literature various type of finite element analysis and experiment method are used to residual stress in welding parts .Generally numerical methods are mostly used to measure residual stress as compared to experimental methods due to highly expensive rate. Some time results of finite element analysis compared with experimental method to evaluate the accuracy of the finite element method. Sattari-Far [1] employed the finite element method to determine (estimate) residual stress in butt welded pipe joint. They developed FE modeling was to used to study the effect of weld groove shape and weld pass number on welding residual stress in butt welded joint. The hoop and axial residual stress in welded joint of different grove shape and pass number were studied. By comparisons the result of finite element method with the experimental measurement. It has been shown that the used computational procedure is very Effective method for predicting the welding residual stresses. A.K.Yaghi [2] developed finite element method has been applied to simulate residual stress and hoop stresses generated in the weld region and heat –affected zone of an axis symmetric 50 –bead circumferentially butt welded p91 steel pipe with an outer diameter of 145 mm and wall thickness of 50 mm. the FE simulation consists of a thermal analysis and a sequentially coupled structural analysis. Residual axial and hoop stresses have been depicted through the pipe wall thickness as well as along the outer surface of the pipe. Deng Dean [3] investigate the influence of solid state phase transformation on the residual stress distribution in butt welded modified 9cr -1MO steal pipe. In this study the residual stress distribution was simulated by an uncoupled thermo mechanical finite element formulation using ABAQUS. The finite element model for welding residual stress analysis which taken into account. The volumetric change and yield strength change due to marten site transformation was developed according to the result it is clear that the volume change due to marten site transformation has a significant influence on welding residual stress. It is not only change the magnitude of residual stresses but also alters the sign of residual stress in welded zone.W. A Ellingson [4] presents measurement of the bulk residual stress in 100 mm and 250 mm diameter schedule piping weld ments using strain relief techniques. Both laboratory welded specimen and field welded specimen from reactor in service were studied.(4) Deng Dean [5] develop an effective and efficient thermal elastic finite element analysis (FEA) producer based on ABAQUS code to predict welding residual stresses for 2.25 Cr-1 MO steel pipe. In the influence of solid state phase transformation on welding residual stress was taken into account. Effect of volumetric change and yield straight change to solid state phase transformation on welding residual stress was investigates using numerical analysis. The simulate result show that both volumetric change and yield strength change have significant effect on welding residual stress in 2.25 Cr-1 Mo steel pipe. The simulated results were conformed to experiment measurement and the effectiveness of the developed FEM producer was confirmed. H. Parmohamd [6] investigates residual stress developed during the circumferential Butt Gas Tungsten Arc Welding (GTAW) process of Incoloy 800 H pipes were simulated using the finite element method. The element birth and death technique was used for the addition of the filler material in the weld pool. The goldac double ellipsoidal model was used to simulate the distribution of arc heat during welding. To validate the thermo structural model both temperature and residual stress distribution within the pipes were measured using thermo couple and strain gauge. E. M. Qureshi [7] used computational methodology based on finite element simulation and Parametric studied are conducted to analysis the effect of varying tack weld orientation on residual stress field. From the result presented, it is conducted that identical axial residual stress field are observed on cylinder outer and inner orientation under study with some exception on tack welds and starts / stops location. On the outer surface the effect of both start and end are pronounced whereas on the inner surface only the effect of weld start are pronounced.

III. MODELING, SIMULATION AND ANALYSIS OF BUTT WELDED JOINT

MODELING

In this study ASTM A516 Grade 70 material is used. This is special material which is used for high pressure vessel. A516-70N carbon steel plates can withstand 70,000 pounds per square inch (psi) to 90,000 psi. Its yield strength is 38,000 psi. Grade 70 represents the strongest carbon steel plates specified by the ASTM (formerly the American Society for Testing and Materials) ASTM A516 Grade70 can be tested for resistance to hydrogen induced cracking (HIC), a common problem in the oil, gas and chemical industry. Shield metal arc welding and submerged arc welding is carried on butt joint. Thick plate rolled cylinder has been modeled using ANSYS finite element software. Different properties and chemical composition of material given in table.

Table .1 Properties of ASTM A516 Grade 70 material

Description	Grade 70
Tensile strength (ksi)	70-90
Tensile strength (MPa	485-620
Yield strength (ksi)	38
Yield strength (MPa)	260
Elongation in 200mm (min)(%)	17
Elongation in 50mm (min) (%)	21
Thickness (max)(mm)	205

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Table .2.Chemical composition of ASTM A516 Grade 70 material

Carbon (C)	%	Manganese (Mn)	%	Phosp h-orus (P)	%
12.5mm or less 12.5 - 50mm 50 - 100mm 100 - 200mm > 200mm	0. 27 0.28 0.30 0.31 0.31	12.5mm or less • Heat Analysis : • Product Analysis :Over 12.5mm • Heat Analysis : • Product Analysis :	0.8-1.2 0.79 1.30 0.85 1.20 0.79 1.30	(max)	35
Sulphur (S)	%	Silicon (Si)	%		
(max)	0.035	• Heat Analysis : • Product Analysis :	0.15 - 0.40 0.13 -0.4		

The diameter of the cylinder is 1375 mm and wall thickness is 90mm.thye weld groove angle is 60°. The various dimensions of the butt weld joint are shown in figure1.

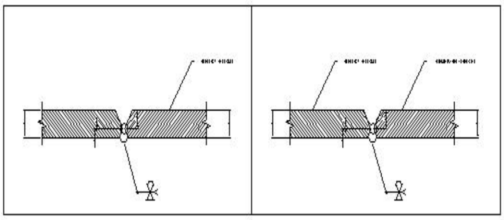

Fig. 1: Detail of the geometry

IV. SIMULATION

ASTM A516 Grade 70 material is welded by SMAW which have high efficiency then other welding processe.The heat input during welding is modeled in the finite element software Ansys by the equivalent heat input which includes body heat flux. The amount of heat input, Q has been calculated by using empirical relation shown in equation (1). Arc efficiency is denoted by Z, arc voltage by U, arc current by I and travel speed by V.

$$Q=UIZ/V$$

The efficiency of SMAW is 80%and efficiency of SAW process is 100%

Table 3: Typical parameters of various welding techniques used for determining heat input

S NO.	PROCESS	FILLER METAL	CURRENT	VOLT AGE
First layer	SMAW	E-7018-1	160-190	25-35
Second layer	SMAW	E-7018-1	210-240	25-35
Third & remaining layers	SAW	Eh-14	550-700	25-40

By using this value of heat input first of all by thermal analysis the temperature at different points are noted and after that the values of residual stresses are calculated by means of stress analysis.. This simulated temperature field is then used in analysis step for calculating the residual stresses.

Fig 2. Finite element mesh of the single butt welded thick cylinder

V. ANALYSIS

ANSYS Simulation is used to carry out the thermal and mechanical analysis. To study the residual stresses in butt-welds, a 3D finite element model has been developed and the movement of the electrode has been simulated using the death and birth of elements. For this purpose a coupled thermo-mechanical solution method has been used. A sequentially coupled analysis of thermal and mechanical analysis has been performed. In the thermal analysis, the welding process is simulated by applying a distributed heat to the weld elements, which is a triangular function of heat per unit volume against time. The heat flux is assumed to reach its peak value from zero in a straight line during the up-ramp of the triangular time function, followed by a straight line from its peak value back to zero. From that time, the heat flux remains zero, until the end of the particular weld cycle, during which time the weld is allowed to cool down to an inter pass temperature of between 200 and 300oC, until the next Weld pass cycle begins. The model is allowed to cool down to room temperature at the end of welding. A technique called ‘element birth’ is used in the FE simulation to represent the laying of weld beads to avoid any displacement or strain mismatch at the nodes connecting the weld elements to those of the base material. Element birth allows the complete FE mesh to be generated before the analysis is actually conducted. As part of the technique, in the thermal analysis, the FE elements which correspond to the weld passes before being laid are given a value for thermal conductivity equivalent to that of air. At the time of application of each weld pass, the thermal conductivity is made to change from air value to that of steel. The thermal analysis uses an eight-node continuum solid quadratic axisymmetric diffusive heat transfer quadrilateral element type.

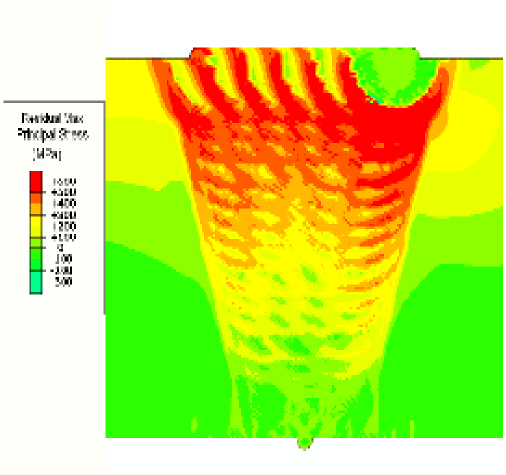

Fig 3:- finite element residual maximum principal stress contours at the weld and HAZ

VI. CONCLUSION

The finite element study covers that two thick cylinder large diameter cylinder of ASTM A 516 Grade 70 material and effect of wall thickness and number of beads is illustration using the calculated stress .Tensile stresses occurs near to the inside surface of the cylinder and peak circumference stress occurs near to the outside surface of the cylinder .Residual stress are generally influenced by the cylinder diameter at the inside and outside of the walled finite element model.

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