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A Review On Residual Stress Analysis Of Thick Wall Welded Pressure Vessel

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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. However, due to the presence of residual stresses in and around the weld zone the strength and life of the component is also reduced.

This paper aims to classify the different residual stresses measurement methods and to provide an overview of some of the recent advances in this area to help researchers on selecting their techniques among destructive, semi destructive and non-destructive techniques depend on their application and the availabilities of those techniques. In the end, this paper indicates some promising directions for future developments.

Key words: Residual stress; Finite Element Model; Welding Joint

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 is associated with a temperature cycle involving temperature up to the melting point of the material. Welding residual stresses not only cause of distortion but also significant affect the performance of welded parts. Specially 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 that 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.

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.

Murakeuva et al.(2004) [1] investigate the influence of solid state phase transformation on the residual stress distribution in butt welded modified 9cr -1MO steel 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 residual stress analysis was 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.

Chang and Teng (2004) [2] used finite element model to analyses the thermo mechanical behaviour and evaluate the residual stresses in butt-welded joints. The residual stresses at the surface of the weldments were measure by x-ray diffraction. ASTM A36 steels were choose for this study. Two plates, each of size 110×30×4.5 mm, with a single V-groove joint between them. The welding process was arc welding with Tungsten Inert Gas (TIG). Longitudinal residual stress was calculated by using the $\sin^2 \Psi$ method. Longitudinal residual stresses calculated by the finite element method were about 407.1 MPa. Transverse residual stresses calculated by finite element method were about 46.8 MPa. The results of finite element analysis were compare with experimental residual stress data to confirm the accuracy of the method. The aim was to present data that may confirm the validity of currently employed fabrication processes in welded structures and even improve them.

Dean et al. (2004) [3] investigate the influence of solid-state phase transformation on the residual stress distribution in butt-welded modified 9Cr -1Mo steel pipe. In this study, the residual stress distribution simulated by an uncoupled thermo mechanical finite element formulation using ABAQUS. The finite element model had taken into account for residual stress analysis. The volumetric change and yield strength change due to marten site transformation was developed. According to the result, it was clear that the volume change due to marten site transformation had a significant influence on welding residual stress. It was not only change the magnitude of residual stresses but also alters the sign of residual stress in welded zone.

Yajiang et al. (2004) [4]investigated distribution of the residual stress in the weld joint of HQ-130 grade high strength steel investigated by means of finite element method (FEM) using ANSYS software. Welding was carried out using gas shielded arc welding with a heat input of 16 kJ/cm.

Experimental results reveal that there was a stress gradient around the fusion zone. The instantaneous stress on the weld surface is 800–1000 MPa and below the weld was 500–600 MPa. This gradient was high near the fusion zone and this was one of the reasons for the formation of cracks in the fusion zone in high strength steels.

Dinbassa (2007)[5] studied weld design of heavy-duty vehicle bodies including problems such as residual stresses and shape distortion associated with the construction of welded structures. The objective of this study was to propose solution for problems observed in the weld design and process of heavy-duty vehicle body building industry. The results of study were-

1. Proper engineering weld design performed especially on critically loaded components and cross frame weld joint.
2. It was highly recommendable to the local body builders to establish quality control section that corresponds to their fabrication capacity.
3. In national level weld codes, standards and specifications wrote or adapted by responsible government institutes or professional associations.

Dean et al. (2007)[6] used an effective and efficient thermal elastic finite element analysis based on ABAQUS code to predict welding residual stresses for 2.25 Cr-1 MO steel pipes. 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 had significant effect on welding residual stress in 2.25 Cr-1 Mo steel pipe. The simulated results conformed to experiment measurement and the effectiveness of the developed FEM producer confirmed.

Qureshi et al. (2008) [7] used computational methodology based on finite element simulation and parametric study was conduct to analysis the effect of varying tack weld orientation on residual stress field. The analysis performed by using ANSYS, a commercial finite element code. It was conducted that identical axial residual stress field were 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 pronounced whereas on the inner surface only the effect of weld start pronounced.

Yaghi et al. (2008)[8] developed finite element method 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 finite element simulation consists of a thermal analysis and a sequentially coupled structural analysis. Residual axial and hoop stresses predicted through the pipe wall thickness as well as along the outer surface of the pipe.

Chang and Lee (2009) [9] performed residual stress analyses for T-joint fillet welds made of similar and dissimilar steels. Three-dimensional uncoupled thermo mechanical finite element model that could accurately capture residual stresses in a weld piece developed in order to predict the residual stress states in the fillet-welded T-joint. Experimental results measured by strain gauges method. The length of the weld, the width of the flange and height of the web were assumed 600, 500 and 120 mm, respectively. The plate thickness was 15 mm for the flange and 19 mm for the web. The welding parameters chosen for this analysis were as follows: welding method, Flux coated arc (FCA) welding process; heat input, 1300 J/mm, and welding speed, 6 mm/s, respectively. Results show that the maximum longitudinal residual stresses near the weld toes of the similar steel welds increase with increasing yield stress of the steel welded. For the dissimilar steel welds, the overall trend, shape and magnitude of the residual stress profiles in flange and web are similar to those of the corresponding similar steel welds

Far and Farhani (2009)[10] used finite element techniques to analyse the thermo-mechanical behaviour and residual stresses in butt-welded pipes. The residual stress was also measure in some welds by using the hole-drilling method. The hoop and axial residual stresses in pipe joints of 6 and 10 mm thickness of different groove shapes and pass number were study. Two pipes, with outer diameter of 320 mm, thickness of 10 mm and length of 500 mm were prepared with V-grooved edges Welds carried out in a robotic TIG welding system with advanced control system. The results of the finite element analysis compared with experimentally measured data to evaluate the accuracy of the finite element modelling. Based on this study, a finite element modelling procedure with reasonable accuracy was developing. The developed finite element modelling used to study the effects of weld groove shape and weld pass number on welding residual stresses in butt-welded pipes.

Monin et al. (2009)[11] investigated geometrical distortions of A131 two steel plates with dimensions 2200×800×19mm with single-V preparation joint welded by Metal inert gas (MIG) welding by four steps. Distribution of residual stresses (475 MPa) in welded joint was measure by x-ray diffraction method. The measured residual stress distributions compared with residual stress state obtained by means of finite element analysis using ABAQUS software. A good agreement obtained between experimental and analytical data.

Yaghi et al. (2009) [12] investigated residual stresses in multipass circumferentially butt-welded P91 ferritic steel Pipe had been determined numerically and experimentally. The welded joint of pipe with an outer diameter of 290 mm and a wall thickness of 55 mm typical of used in power generation plant components. An asymmetric thermo mechanical finite element model used to predict the resulting residual hoop and axial stresses in the welded pipe. Residual stresses were measure using the X-ray diffraction technique along the outer surface of the pipe and using the deep-hole drilling technique through the wall thickness at the centre of the weld. Good correlation demonstrated between the residual hoop and the axial stresses obtained by numerically and experimentally. It was importance to use experimental and numerical approach to determine the residual stress distribution in welded components.

Brar and Kumar (2010)[13] developed a 3-dimensional finite element model was by making an approximate geometry of the butt welded joint and then the finite element analysis was performed, so that we could understand the complete nature of residual stresses in butt welded joint of AISI 304 stainless steel plate. In this paper, butt welding simulations were performed on two AISI 304 stainless steel plates by submerged arc welding (SAW), manual metal arc welding (MMAG), gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW). Analysis of butt-welded joint by Solid Works simulation showed that butt weld produced by GMAW that resulted in lowest value of residual stress in plates.

Purmohamad et al. (2010)[14] investigated residual stresses developed during the circumferential butt gas tungsten arc welding (GTAW) process of Incoloy 800H pipes were simulated using the finite element software ANSYS. A decoupled thermo structural model developed in three dimensions to validate the thermo structural model, both temperature and residual stress distributions within the pipes measured using thermocouples and strain gages, respectively. Good agreements were found between the experimental and simulation results. The model used to predict distribution of residual stresses (100 MPa) during the GTAW of Incoloy 800H pipes and to study effects of process parameters on the residual stresses. Pipe with outer diameter of 60.3 mm, thickness of 5.54 mm and length of 80 mm were use. Several single-V groove weld joints were prepared. The residual stresses of the welded pipes measured using the hole drilling method. Four rosette-type strain gages (SG1, SG2, SG3, and SG4) were install on the outer surface of the pipes at different distances from the weld line.

Jeyakumar et al. (2011) [15]performed finite element analysis to access the residual stress in the butt weld joints of 2.25 Cr1Mo low alloy ferritic steel plate and ASTM 36 steel plates utilizing the commercial software package ANSYS. Temperature dependant properties of the material specified. 2D Results found to be in good agreement with existing 3D finite element analysis and experiments results. Dimension of 2.25 Cr1Mo plate was 300×72×6 mm and 60$^{\theta}$ weld groove angle, arc efficiency was 0.7, voltage was 30 volt and current was 200 ampere. Temperature of the filler material was 1783 Kelvin. Two-dimensional results were good agreement with 3D FEA results varies from 274 MPa (Tensile) to -181 MPa (Compressive) and 35o MPa (Tensile) to -200 MPa (Compressive) MPa in ASTM 36 steel Plate.

DISCUSSION

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 part 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 materials. During welding process residual stress are developed in the HAZ (Heat affected Zone). Residual stress remains in a body that is not being subjected to external forces. Residual stresses caused by forming or processing operations, or by the service environment.

Measurement of residual stress is important in predicting service life, analyzing distortion, and determining the reasons for failure. For research work objective must be clear like- finite element analysis and experimental method are used to measurement of residual stress developed in welding zones. Developed finite modeling used to study the effect of weld groove shape and weld pass number on residual stresses in welded joint. Reasonable accuracy developed between finite element modeling and experiment method and parameter having significant effect on magnitude and distribution of residual stress in butt welded joint.

CONCLUSION

To understand the behavior of residual stresses thick plate butt-welded pressure vessel using the Shield Metal Arc welding (SMAW) and Submerged Arc welded (SAW) process.

1.Finite element analysis using software was carried out to calculate the residual stress values in the welded plates because). FEA is applicable to any field problem, such as heat transfer, stress analysis, magnetic fields and so on...There is no geometric restriction, it can be applied the body or region with any shape. Boundary condition and loading are not restricted may be applied to any portion of the body. Material properties may be change from one element to another element and the material anisotropy is allowed. Different element behaviour and mathematical descriptions can be combined in single FE model. An FE structure closely resembles the actual body or region to be analyzed.FEA is mostly used in the analysis and optimizing of phase to reduce the amount of prototype testing and to simulate designs that are not suitable for prototype testing. At last, FEM is cost saving, time saving, reducing time to market, creating more reliable and better quality designs.

2. Hole drilling methods are easy and fast methods, they can be used for wide range of materials, but they are semi destructive method and it has limited strain sensitive and resolution. Hole-drilling is suggested to measure the residual stresses in specimens with high hardness and high toughness. However, the tool wear will further cause the induced stress to increase and therefore cause significant measurement errors. EDM hole drilling provides as an alternative method for the measurement of residual stresses where HS hole-drilling is failed to employ in the stain gage method. It has got the advantage of no constraint on mechanical properties of ferrous materials, and has proven its capability to drill highly precise holes on various metals. The hole drilling method is a cheap, fast and popular semi destructive method. Hole drilling method can be used for large thickness of pressure vessel and metal sheets.

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