Finite Element Analysis of Residual Stresses in Shield Metal Arc Welding of Ferritic Stainless Steel – A Review

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Abstract — In various steel fabrication industries which involves shipbuilding and high speed train guideway, the main and important issue of residual stresses and distortion was there. So Finite Element Analysis investigation on residual stresses which occurs after welding process in sheet metal is reviewed in this article. Distribution of residual stresses which arises after welding is quite complex. This article also includes the analyzation of residual stresses using X-ray diffraction technique. Shielded Metal Arc Welding which is also known as Manual Metal Arc Welding is studied and in this process stainless steel temperature field is gained.

Keywords*-Finite Element Analysis, ANSYS, X-RAY diffraction, Residual stresses, SMAW*

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I. INTRODUCTION

Welding is the simplest, fastest and more effective technological process which is used in various industries such as shipbuilding, pipelines construction, offshore structure, etc. It is the known fact that welding process relies on localized heat input due to which residual stresses arises in sheet metal. Generally this stress occurs in mostly thin plates. This welding residual stresses may be very complex enough and their distribution is very difficult to predict. In any step of manufacturing process this stresses may arise and main reason behind it is inhomogeneous deformation. For the measurement of residual stresses in any weld region various techniques are used out of which X-ray diffraction technique is widely used.

X-Ray diffraction (XRD) is the most accurate and best developed method for quantifying the residual stresses produced welding in steel plates. X-ray diffraction is capable of high spatial resolution on the order of millimeters and depth resolution and also can be applied to wide variety of sample geometries. X-ray diffraction method of residual stress measurement have been widely used for more than forty years in automotive and aerospace applications. X-ray diffraction methods are well established having been developed and standardized by the SAE and ASTM. X-ray diffraction method is also known as "$\sin^2\psi$ method" and hence was used to study the longitudinal and transverse stress components in any welded butt joint.

Finite Element Analysis (FEA) investigation on residual stresses is carried out using commercial software package ANSYS. In recent years, due to high expansion of computers computation possibilities many of the researchers identified the Finite Element Analysis as a reliable method for this purpose. In last three decades, finite element method has been progressively applied to metal cutting simulations. The finite element method is a way of getting a numerical answer to a specific problem. Finite element analysis to simulate the transient thermal conditions of the weld would prove to be the most accurate and flexible method of modelling. The goal of FEA is to predict the various parameters such as stresses and temperatures. For the simulation of the manufacturing process Mechanical APDL (ANSYS Parametric Design Language) was developed and implemented.

Shielded Metal Arc Welding (SMAW) is also known as Manual Metal Arc Welding (MMAW), flux shielded arc welding or stick welding. As the name itself indicate manual metal arc welding process which was consumable electrode coated in flux to lay the weld. SMAW is one of the world's most popular welding process because of its versatility and simplicity of its equipment and operation. Like other welding methods shielded metal arc welding can be dangerous and unhealthy practice if proper precaution are not taken. SMAW is often used to weld carbon steel, low alloy as well as high alloy steel, stainless steel, cast iron and ductile iron. SMAW dominates other welding process in maintenance and repair industry. This process uses an open electric arc which presents a risk of burns which are prevented by personal protective equipment in the form of heavy leather gloves and long sleeve jackets.

II. LITERATURE REVIEW

Andrea Capriccioli and Paolo Frosi explained the multipurpose finite element procedure for the welding processes simulation where Finite Element model for thermal and mechanical welding simulation was presented using ANSYS. Iterative method and the birth and death technique was adopted here. Finite Element Method performed here is to analyze laser and TIG welding. A 3D ANSYS models use both brick and nonlinear contact elements and elastic and plastic materials. ANSYS which included birth and death technique it strongly reduced the CPU time [1].

Ali Moarrefzadeh studied the Shielded metal arc welding and thermal profile for stainless steel was carried out. An electric current, in the form of either alternating current or direct current from a welding power supply, is used to form an electric arc between the electrode and the metals to be joined. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapors that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination. Two major numerical formulations are used in finite element simulations Lagrangian and Eulerian. Lagrangian formulation is broadly used in problems related to mechanics of solids whereas Eulerian formulation is more suitable for fluid-flow problems [2].

Dragi Stamenkovic and Ivana Vasovic they carried out Finite Element Analysis of residual stress in butt welding of 2 similar plates using ANSYS in their experiment. Shielded metal arc welding of carbon steel plates were studied. For the prediction of residual stresses in butt welding of same plates and for performing welding simulation FEA was utilized here. They described in computational analysis it is assumed that changes in mechanical state do not cause any change in thermal state but a change in thermal state causes a change in mechanical state. Heat input during welding is also modelled in ANSYS. In order to obtain results using FEM very close to results obtained in experiments different mesh sizes should be taken into account [3].

G. Janakiram, S. Vijay and Dr. M. Venkateswara Rao studied on Analysis of temperature distribution of different welded joints in shipbuilding and explained and explained that thermal stresses which are developed during welding can be used for thermal analysis and structural analysis of shipbuilding. The welding here carried out was Gas Tungsten Arc Welding (GTAW) which is also known as Tungsten Inert Gas (TIG) welding and it produces electric arc which is maintained between non consumable tungsten electrode and part which is to be welded. In ANSYS12 the model was created using SOLID 10 node 87. With the help of Mechanical APDL thermal stress analysis of welded joints was done in shipbuilding [4].

M. Sailender, Dr. N. V. Srinivasulu, Dr. Sriram Venkatesh and Dr. G.C.M. Reddy described the experimental analysis of effect of various parameters in temperature distribution in submerged arc welding (SAW). They said prediction of temperature, distortion and shrinkage of steel welding is through experimentally and numerically analyzing such FEA. Once the technique to predict the distortion and shrinkage is identified then the problem can be controlled strongly. Many of the trials were taken for experimentation and after choosing final parameters it gave more efficient penetrated welding. Objective of this research was to study temperature results experimentally and then simulate the complex welding by using finite element code ANSYS. Also the aim of this thesis was to find a relationship between welding parameters and thermo elastic-plastic responses. SAW process is used where high metal deposition at high rate is major criteria which could not be possible by regular welding process [5].

M. Beghini, L. Bertini and D. Cantemir researched on the effect of thermal properties on transient temperatures during welding of perforated plates. They developed the procedure of finite element for welding distorsion in large plates. Their result was the material density and equivalent thermal conductivity have little effect on thermal analysis results and the temperature dependence was affecting slightly the results [6].

Cristian Simion, Corneliu Manu, Saleh Baset and ulian Millard studied about distortions generated by welding process using ANSYS-FEA. Welding simulation consists of mainly two phases i.e., a transient heat flow analysis and quasistatic plastic structural analysis. For good welding simulation fine mesh should be developed. In welding process main phenomena are heat input, heat flow, solidification, microstructure change and plastic deformation and stress/strain accumulation. Birth and death technique was used for bringing the weld material into analysis [7].

Li Chaowen and Wang Yong in Three-dimensional finite element analysis of temperature and stress distributions for in-service welding process developed the 3D FE model for bead-on-plate in-service welding. For the prediction of temperature distribution and stress fields this model was generated. The commercial FE code SYSWELD was used for thermal and mechanical analysis and FE mesh for single-pass welding was used for study [8].

Zhenzhen Lei, Hond Tae Kang and Yonggang Liu presented the work on Finite element analysis for transient thermal characteristics of resistance spot welding process with three sheet assemblies. In this project simulation is achieved on the basis of electrical-thermal field analysis and finite element model and its meshing was done. From temperature distribution analysis it is concluded that highest temperature begins at two faying surfaces between workpiece-workpiece symmetric to the center of entire sheets because of contact resistance and equal sheet thickness which differs from temperature distribution of two sheet assemblies [9].

Fanrong Kong and Radovan Kovacevic studied on 3D finite element modeling of the thermally induced residual stress in the hybrid laser/arc welding of lap joint where he developed 3D thermal–mechanical finite element model for investigation of the temperature field and transient thermal stress field. For the measurement of residual stresses X-ray diffraction test was carried out [10].

Junjie Ma, Fanrong Kong and Radovan Kovacevic studied a zero-gap lap joint configuration FEA of laser welding of high-strength steel and its experimental work. For predicting the temperature evolution in the laser welding of galvanized high-strength steels three dimensional finite element model was created. Temperature data measured by thermocouples are used to verify the boundary conditions of the thermal model. The results show that a lower welding speed or higher laser power can mitigate or reduce the weld defects in the weld zone caused by the pressurized zinc vapour [11].

J.J. del Coz Díaz, P. Menéndez Rodríguez, P.J. García Nieto and D. Castro-Fresno compared TIG welding distortions between austenitic and duplex stainless steels using FEM. Aim of this paper is to establish a set of approximations and simplifications in numerical modelling of stainless steel welding for reducing the huge computation time due to coupled and non linear formulations. Finally numerical results from the finite element method were compared experimental values measured in specimens. As final conclusion, the optimum value in the calculations for this parameter was about 2/3 of the fusion temperature, specifically 1173 K (for duplex steel) and 1073 K (for austenitic steel) [12].

Zhigang Hou, I11-Soo Kim, Yoanxun Wang, Chunzhi Li, and Chuanyao Chen studied the Finite Element Analysis for the mechanical features of resistance spot welding (RSW) process here two dimensional axisymmetric model of thermo-elastic-plastic FEM was developed with the help of ANSYS. With the help of thermal-electrical simulation of RSW a transient temperature field was obtained and which was applied as nodal loads on the model. During simulation the temperature dependent material properties and their plastic behavior were taken into account. Deformation took place during welding due to thermal expansion and contraction were calculated. Also in the weldment stress and strain distribution were determined [13].

Ali. Moarrefzadeh explained about Manual Metal Arc Welding (MMAW) Process and its Finite-Element Modeling as well. A 3D mathematical model for the metal transfer process in MMAW was formulated in this article and a complete model describing the MMAW welding process is developed. With the use of this 3D model case of an axisymmetric arc was studied [14].

N. Akkus, G. Genc and S. Sen carried out Experimentation as well as Finite Element Analysis of Residual Stresses. They derived the relation between the welding temperature and the residual stress at various welding speeds. When the experimental studies are examined they found that at the arc welded joints conducted at higher welding advance speeds, there is less residual stress and temperature decreases. During welding process, measurement of temperature was done by using thermocouples. After welding process, it is waited for a while for cooling of sheet metal down to room temperature. And residual stress occurred due to heat flux was investigated by using hole drilling method [15].

Jun-Young Nam, Duck-hee Seo, Sang-yun Lee, Woon-ki Hwang and Bo-young Lee studied about the effect of residual stress on Stress corrosion crack with the help of ANSYS. Welding passes identifies the tendency of residual stresses and was confirmed that as the number of weld pass increases value tension residual stress will increase by FEM analysis. In this study it was considered that welding residual stress is direct factor of generation and growth of stress corrosion crack [16].

B.S.Yilbas, A.F.M.Arif, B.J. Abdul Aleem, stated that the morphological and metallurgical changes in welding region are examined using the optical microscopy. In laser welding of low carbon steel and stress analysis solid region temperature variation along the X-axis becomes similar for all y-axis locations. This results in similar von misses stress distribution [17].

J.T. Assis, V Monin, J.R.Teodosio and T. Gurova measured the residual stresses in weld area with the help X-ray technique. Stress measurements were made with a portable X-ray apparatus. Stress components were measured by the "$\sin^2\psi$-method", using the double exposure technique [18].

Vladimir Ivanovitch Monin, Ricardo Tadeu Lopes, Sergio Noleto Turibus, Joao C. Payao Filho and Joaquim Teixeira de Assis applied the X-ray diffraction technique to duplex stainless steel to find residual stresses which arise after welding. In both the ferrite and austenite phases residual stress state is characterized by tensile stresses. Lower level of residual stresses in austenite than ferrite phase of duplex stainless steel is due to larger plastic deformation of austenite. Hence it is confirmed that residual stress arises after the shrinkage during cooling of weld zone [19].

A. Equations

The main equation to determine any stress component σ_ϕ is given by

$$\sigma_\phi = -\frac{E}{1+\nu}\,\frac{ctg\theta(\theta_{\varphi,\psi2}-\theta_{\varphi,\psi1})}{\sin^2\psi_2-\sin^2\psi_1}$$

where E, ν are elastic constants, θ is diffraction angle, φ and ϕ are azimuth and polar angles [18].

B. Figure shows portable X-Ray apparatus

Fig 1. General view of the portable X-ray apparatus: 1-high voltage source; 2-X-ray tube; 3-collimator–cassette unit; 4-control unit; 5-analysed sample [18].

III. CONCLUSION

A 3 dimensional finite element analysis for prediction of residual stress and temperature profile was carried out with the help of ANSYS. A single pass shielded metal arc welding was followed in welding process of butt joint. During welding induced thermal stresses are further used for thermal analysis and structural analysis. Experimentally the residual stress measurement was done using X-ray diffraction technique.

Analyzed results helps us to understand the phenomena of governing the welding of joints. After understanding the welding mechanism it can be better addressed in early stages of design.

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