Gas Metal Arc Welding Sequence Effect On Residual Stress And Distortion By Using Finite Element Analysis

M.Viswanath[a], P.Vijayanand[b], V.Suresh[c], S.Naresh Kumar[d], A.Seshappa[d]
[a]M.Tech (CAD/CAM) Student, Department of Mechanical Engineering, Holy Mary Institute of Technology & Science, Hyderabad- 501301. Email:vissuchowdappa@gmailcom
[b] Associate Professor, Department of Mechanical Engineering, Holy Mary Institute of Technology & Science, Hyderabad- 501301.
[c] Professor, Department of Mechanical Engineering, Holy Mary Institute of Technology & Science, Hyderabad-501301.
[d]Assistant Professor, Department of Mechanical Engineering, Vardhaman College of Engineering, Hyderabad-501218.

Abstract

It is a familiar reality that fusion welding is living being extensively used in a extensive spectrum of fabrication industries. In spite of its being a versatile joining process of materials of any thickness, it suffers from some serious setbacks which impair the life of weldements in service. Of utmost concern are the evolution of inevitable residual stresses and distortion in weldements which are the direct result of complex non-uniform thermal cycles experienced during fusion welding. In excess of the past few decades, finite element method has gained ground as a well-established method to numerically analyze welding related problems. Numerical simulation based on finite element modeling is used to study the influence of welding sequences on the distribution of residual stress and distortion generated when welding a flat-bar stiffener to a steel plate. The simulation consists of sequentially coupled thermal and structural analyses. In Transient thermal analysis, time-dependent temperature distribution is determined. Temperatures from thermal analysis are applied as loads in a structural analysis yielding the three-dimensional residual stress and distortion fields. The effect of four welding sequences on the magnitude of residual stress and distortion in the plate is investigated.

Keywords—*Numarical Simulation,residual stress and distrotion, in the thermal and structural analysis.*

I. INTRODUCTION

Welding is the process of joining similar and dissimilar materials to join most prominent process for large components into complex assemblies or structures. A necessary condition for welding is that the two or more surfaces to be joined must be brought into intimate contact. When fusion takes place, the joint is achieved by melting of two or more work piece materials in a localized region. In contrast, the solid-state joining processes rely on plastic deformation of the surface asperities along the contact surface representing the original weld interface or the impending weld joint.

Gas Metal Arc Welding (GMAW): A process in which a continuous and consumable wire electrode and a shielding gas (usually an argon and carbon dioxide mixture) are fed through a welding gun.

Gas Tungsten Arc Welding (GTAW): A process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by a shielding gas, and a filler metal that is fed manually is usually used.

Effect of welding sequence on residual stress in thin-walled octagonal pipe−plate structure

A three-dimensional finite element approach based on ABAQUS code was developed to investigate the effect of welding sequence on welding residual stress distribution in a thin-walled 6061 aluminum alloy structure is discussed in Ref. [1]. To obtain sound numerical results, in this study the thermo-mechanical behavior was simulated using a direct-coupled formulation. Nine different simulation sequences were carried out by single-pass TIG welding of an octagonal pipe−plate joint, and the distributions of longitudinal and transverse residual stresses both on the outer and inner surfaces of the pipe were analyzed.

Effect of welding Residual stress and Distortion on ship hull structural performance-

The finite element method is used to investigate the effects of welding-induced residual stress and distortion on the strength and behavior of ship hull structures is briefly discussed by Liam Gannon [2]. A finite element welding simulation consisting of sequentially coupled transient thermal and nonlinear structural analyses is used to predict the three-dimensional residual stress and distortion fields in welded stiffened plates. The strength and behavior of stiffened plates under axial load is characterized by normalized plots of average axial stress versus axial strain, commonly referred to as load-shortening curves. To conclude, a hull girder ultimate strength analysis is carried out using Smith's method with load-shortening curves generated by several different methods in this study [2]. Results indicate that welding-induced residual stress and distortion decrease the ultimate strength of flat-bar, angle, and tee-stiffened plates investigated in this study by as much as 17%, 15% and 13%, respectively.

Gas Metal Arc Welding

The gas metal arc welding (GMAW) process has become a popular method for joining components of steel structures and is the most common joining method used in the shipbuilding industry. Arc welding relies on intense local heating at a joint where a certain amount of the base metal is melted and fused with additional metal from the welding electrode. The intense local heating causes severe thermal gradients in the welded component and the uneven cooling that follows produces residual stresses and distortion. Distortions can be especially problematic in the block assembly method used in shipbuilding. Excessive distortion of welded components results in misalignment of parts and often requires costly remedial measures such as flame straightening and cold bending to reduce distortion to an acceptable level.

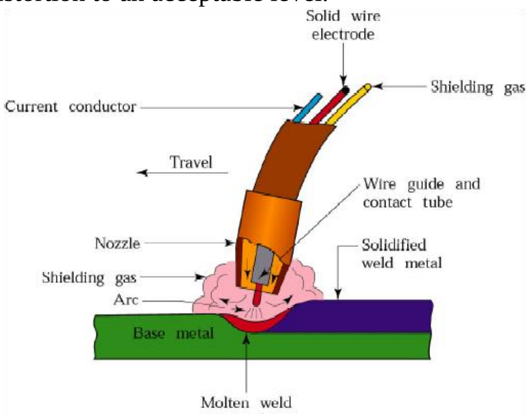


Fig1.Gas metal arc welding process

Table 1: Chemical composition of SM400A steel by wt%Chemical composition (mass %)

C	*Si*	*Mn*	*P*	*S*
0.23	*-*	*0.56*	*<0.035*	*<0.035*

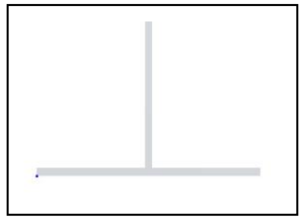


Fig. 2.Stiffened plate dimensional view

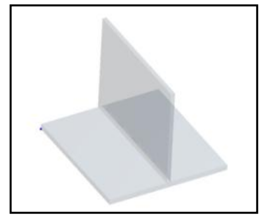


Fig. 3. Stiffened plate sectional view

Commercial finite element software's play an important role in solving many welding related problems. In early research works, finite element codes were written to compute transient thermal and stress fields in a weld mint, using popular programming languages such as C, C++, and FORTRAN etc. While using these programming languages for writing finite element codes, certain difficulties are experienced by the researchers especially in the description of complex shapes and in post processing the results. With the advent of powerful CAD packages and meshing algorithms, popular general purpose standard finite element software's such as ABAQUS, ANSYS, MARC, NASTRAN etc. have been introduced and they are being increasingly used by the welding researchers for the past few decades.

ANSYS is the shortened term obtained from "System Analysis". It contains many bench mark tests drawn from a variety of resources such as NAFEMS (National Agency for Finite Element Methods and Standards), based in the United Kingdom, to validate the performance of elements under distorted or irregular shapes, different meshing schemes, different loading conditions, various solution algorithms, energy norms etc. ANSYS Mechanical software is a Comprehensive finite element analysis (FEA) tool for structural analysis, including linear, nonlinear, dynamic, hydrodynamic and explicit studies. It provides a complete set of elements behavior, material models and equation solvers for a wide range of mechanical design problems

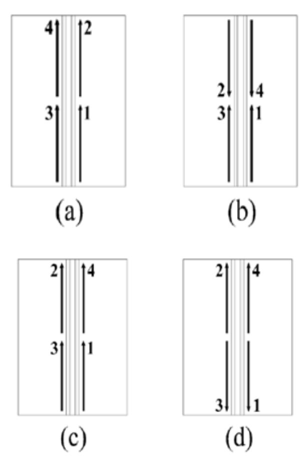


Fig. 4: Welding sequences

Commercial Finite Element solvers

Commercial finite element software's play an important role in solving many welding related problems. In early research works, finite element codes were written to compute transient thermal and stress fields in a weld mint, using popular programming languages such as C, C++, and FORTRAN etc. While using these programming languages for writing finite element codes, certain difficulties are experienced by the researchers especially in the description of complex shapes and in post processing the results. With the advent of powerful CAD packages and meshing algorithms, popular general purpose standard finite element software's such as ABAQUS, ANSYS, MARC, NASTRAN etc. have been introduced and they are being increasingly used by the welding researchers for the past few decades.

ANSYS is the shortened term obtained from "System Analysis". It contains many bench mark tests drawn from a variety of resources such as NAFEMS (National Agency for Finite Element Methods and Standards), based in the United Kingdom, to validate the performance of elements under distorted or irregular shapes, different meshing schemes, different loading conditions, various solution algorithms, energy norms etc. ANSYS Mechanical software is a comprehensive finite element analysis (FEA) tool for structural analysis, including linear, nonlinear, dynamic, hydrodynamic and explicit studies. It provides a complete set of elements behavior, material models and equation solvers for a wide range of mechanical design problems.

Ansys, Inc. is an engineering simulation software (computer-aided engineering, or CAE) developer headquartered south of Pittsburgh in the South Pointe business park in Cecil Township, Pennsylvania, and United States. One of its most significant products is Ansys CFD, a proprietary computational fluid dynamics (CFD) program.

ANSYS program is organized into different processors such as described below:

i. Preprocessor
ii. Solution Processor
iii. Post Processor and
iv. Time History post processor.

While the geometry of the weld joint specimen, element type, appropriate material properties, meshing patterns, boundary condition and load application can be dealt with at the preprocessor level, the type of solution (steady state or transient or modal or harmonic etc.), solver type, other solution options etc. can be specified at the solution processor. After obtaining solution of the model, the distributions of either temperature or heat fluxes or nodal displacements (distortions), principal strains or stresses in the model can be viewed in the postprocessor. The variation of any appropriate quantity of interest with time at a specified location in the model can be obtained in the time history post processor. ANSYS program has been used to compute the temperature distributions, temperature histories, thermal strains and residual stresses in weldements.

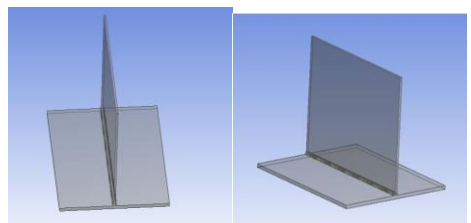


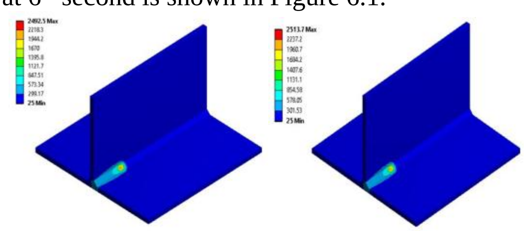
Fig. 5 Geometry modeled

Results And Discussion

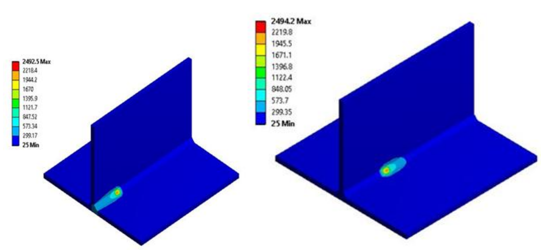
By finite element analysis, welding simulation is carried out for four welding sequences of GMAW (Gas metal arc welding) and the effect on the residual stress and distortion are presented in this section. The longitudinal and transverse residual stresses; and the distortions occurred due to the welding sequences were presented and discussed.

Temperature distributions

Transient thermal numerical simulation is carried out for four welding sequence and temperature contour in (°C) at 6th second is shown in Figure 6.1.



Sequence A **Sequence B**



Sequence C **Sequence D**

Fig. 6:Temperature Contours

It is observed that temperature distributions around the source are typical of the fusion zone (FZ) and the heat affected zone (HAZ). It is also noticed that the heat source preheats a small region of weld plate ahead of the moving heat source. The peak temperature at the center of fusion zone is in proportion to the heat input. The heat generated by the moving heat source along the weld is gradually propagated towards all directions in the plate through conduction, convection and radiation.

The peak temperature achieved for each welding sequence is summarized in Table 3. Peak temperature is high for welding sequence B, low for welding sequence A and C.

Table 2: Peak temperature achieved for each welding sequence

Welding sequence	Peak temperature achieved (°C)
A	2492.5
B	2513.7
C	2492.5
D	2494.2

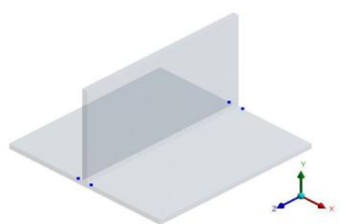


Fig. 7 :Location for temperature time histories

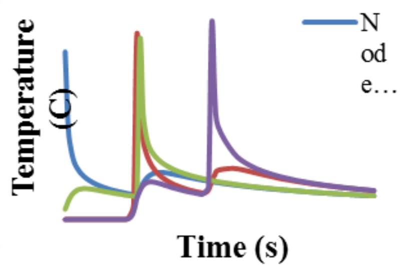


Fig. 8:Temperature histories at point A, B, C and D for welding sequence A

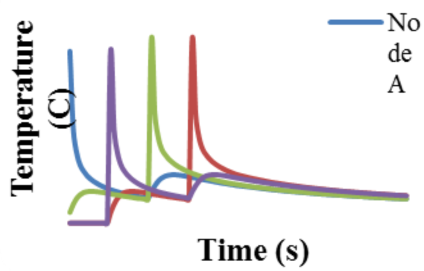


Fig .9 :Temperature histories at point A, B, C and D for welding sequence B

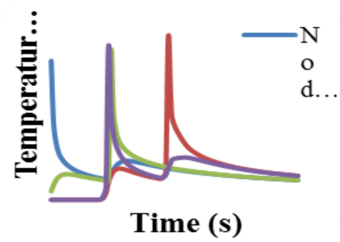


Fig. 10:Temperature histories at point A, B, C and D for welding sequence C

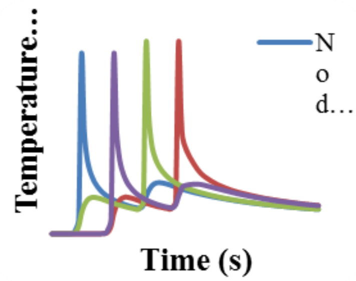


Fig. 11 :Temperature histories at point A, B, C and D for welding sequence D

Residual stress distributions

Although residual stresses caused by welding are three-dimensional, the longitudinal and transverse component of residual stresses is considered to have the greatest influence on the strength of stiffened plates. It is evident that tensile residual stresses are resulted in the weld zones, which are balanced by the compressive residual stresses at the opposite sides. It is also obvious that the tensile residual stress zone is enlarged in accordance with the increase in the HAZ at higher heat input.

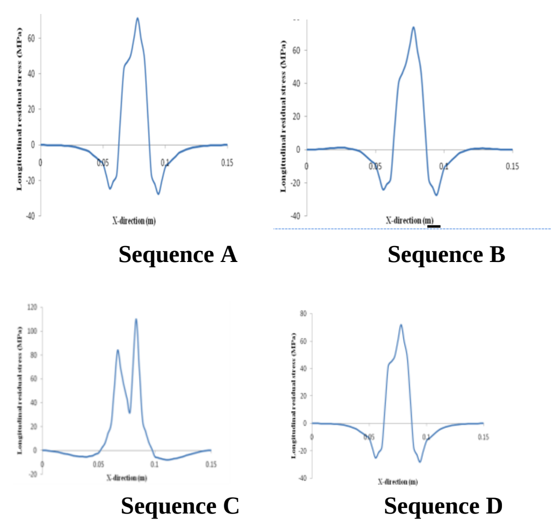


Fig. 12 : Transverse residual stress distribution for welding sequences

To compare four welding sequences, maximum values of longitudinal and transverse residual stresses as well as von misses stress for each welding sequence were summarized in Table 3.

Table 3:Maximum longitudinal and transverse residual stress values for each welding sequence

Welding sequence	Maximum longitudinal stress (MPa)		Maximum transverse stress (MPa)		Maximum Von- misses stress (MPa)
	Tensile	Compressive	Tensile	Compressive	
A	824	818.4	661	702.3	1310.9
B	953.8	840.2	676	702.8	1310.4
C	824	823	664	702	1312.5
D	840.3	519.3	529.8	598.8	1208.5

Maximum tensile and compressive longitudinal and transverse residual stress occurs for welding sequence B. Maximum von misses stress occurs for sequence C whereas for sequence A and B are also closer to maximum. For sequence D, tensile and compressive transverse residual stress and von misses stress are less than other three sequences.

CONCLUSIONS

A finite element model capable of simulating the thermo-mechanical welding process was developed. The finite element simulation was then used to examine the distortion and residual stresses generated during welding for four different welding sequences and their possible effect on the strength of the stiffened plate and distortion was discussed. The following conclusions are drawn from this study.

In case of longitudinal residual stress, peak value occurred for sequence B whereas other three sequences did not show significant variation.. In case of transverse residual stress, it is low for sequence D whereas other three sequences did not show significant variation In case of welding-induced distortion, welding sequence A and sequence C resulted in large distortion and welding sequence D resulted in minimum distortion. Considering both residual stress and distortion as a result of welding, welding sequence D is identified as the preferred welding sequence with the lowest welding-induced residual stress and distortion

REFERENCES

[1] Effect of welding sequence on residual stress in thin-walled octagonal pipe−plate structure College of Materials Science and Engineering, Hunan University, Changsha 410082, China2. State Key Laboratory of Advanced Design and Manufacture for Vehicle Body, HunanUniversity, Changsha 410082, China.

[2] Effect of welding Residual stress and Distortion on ship hull structural performance- By Liam Gannon Submitted in partial fulfillment of the requirements for the degree ofDoctor of Philosophy at Dalhousie University Halifax, Nova Scotia.

[3] Numerical Analysis of Effect of Process Parameters on Residual Stress in a Double Side TIG Welded Low Carbon Steel Plate Vishnu V.S1, Nadeera M 2, Joy Varghese V.M3 1, 2 Dept. Of CIM, T.K.M College of engg. / Kerala University, India 3 . Dept. of ME, SCT College of engg. / Kerala University, India.

[4] Investigation of Arc Welding Variables Influenced by Temperature Cycle Developed in High Carbon Steel Welded Butt Joints and its Effect on Distortion. By Jaidee Dutta, Narendranath S Dept.ofMech Engg. NIT, Karnataka, Surathkal, Mangalore-575025, India.

[5] SCHENK T, RICHARDSON I M, KRASKA M, OHNIMUS S. A study on the influence of clamping on welding distortion [J]. Computational Materials Science, 2009, 45: 999−1005. [3] JIANG W C, ZHANG Y C, WOO W C. Using heat sink technology to decrease residual stress in 316L stainless steel welding joint: Finite element simulation [J]. International Journal of Pressure Vessels and Piping.

[6] Rosenthal D. (1941). Mathematical theory of heat distribution during welding and cutting. Welding Journal, 21(5), 220s-234s.

[7] Rosenthal D. (1946), the theory of moving sources of heat and its application to metal treatments. Trans. AIME, 41(11), 849-866.

[8] Friedman E. (1978), Analysis of weld puddle distortion, Welding Journal Research Supplement, pp 161s-166s.

[9] Oddy A. S. et al. (1992). “Transformation plasticity and residual stresses in single-pass repair welds”, ASME Journal Pressure Vessel Technology, 114, 33-38.