International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol.2, Issue.6, Nov-Dec. 2012 pp-4235-4238 ISSN: 2249-6645

Free Expansion and Thermal Stress Analysis of a Corner Welded Joint bv Finite Element Method

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ABSTRACT: *In Arc welding heat is transferred to the joint by an electrode. During manual metal Arc Welding this heat is transferred by melting the electrode. The stresses generated in welded plate are due to temperature raise and can be simple and thermal stresses. The stresses generated will cause distortion and changing the shape of the welded plates. The study of the distortion and residual stresses is found major importance in the area of shipbuilding boiler works and machine tool structures. The finite element method is one of the numerical techniques used mostly for the stress analysis of welded joints.*

The present paper deals with the simulation of arc welding process for the study of stresses due to free expansion and temperature rise. ANSYS 11.0, commercial software is used for modeling sand simulation of the present problem. The FE analysis is carried two stages in the first stage thermal stresses analysis has been carried to estimate time dependent temperature. The temperature output of the first stage is given as input in the structural analysis i.e. in the second stage. The structural analysis has been carried of the corner joint with and without fixed boundary conditions along the length of the joint. The output of the combined thermal and structural analysis involves von mises stresses, strains and deformation. The results have been compared with theory and are in good agreement for both free expansion and thermal stress analysis.

Keywords: *Arc Welding, Finite Element Method, Free expansion, Thermal stresses & Deformation.*

I. Introduction and Background

Arc welding is a fusion type of welding process used for joining of structural elements for a wide range of applications e.g. guide way for trains, ships, bridges, building structures, automobiles, and nuclear reactors etc. In Arc welding, either direct or alternating electric current is continuously supplied to create an electric arc that generates enough heat to melt the metal and form a weld.

The research activity in welding simulation started decades ago. The Theory of moving Sources of Heat and Its Application to Metal Treatments [1]. Thermo mechanical Analysis of the Welding Process Using the Finite Element Method [2]. Over the past few years, Finite Element Simulation of Welding of Large Structure [3] and Prediction of Welding Distortion [4]. The work done by the Friedman et al has been verified by 3-D computational modeling and Analysis of Residual Stress and Deformation Due to Welding [5].

The transient temperature distributions and temperature variations of the welded plates during welding were predicted and Thermal Analysis of the Arc Welding Process: Part 1. General Solutions [6]. The Effects of Root Opening on Mechanical Properties, Deformation and Residual Stress of Weldments [7]. Effects of welding speed, energy input and heat source distribution on temperature variations in butt joint welding [8]. Simulation on the thermal cycle of a welding process by space–time convection–diffusion finite element analysis [9]. Numerical and experimental investigation into effect of temperature field on sensitization of Alloy 690 butt welds fabricated by gas tungsten arc welding and laser beam welding [10]. Modeling the transient heat transfer for the controlled pulse key-holing process in plasma arc welding [11].

The problem of welding distortion during large steel fabrications leads to dimensional inaccuracies and misalignments of structural members, which can result in corrective tasks or rework when tolerance limits are exceeded. This in turn, increases the cost of production and leads to delays. Therefore, the problems of distortion and residual stresses are always of great concern in welding industry. Even though ample of work has been carried on welding phenomenon still there is a lacuna in the study of the effects of heat input, welding speed, restraint, plate curvature, and gap on arc welding responses. Thus the objective of the present paper is to simulate the complex arc welding process using the finite element code ANSYS and study the Von mises Stresses, Strains, and distortion due to thermo-mechanical response.

II. Finite Element Modeling:

The corner welded joint has been modeled using two number 3-dimensional rectangular plates to obtain an L-shape. The dimensions of both the horizontal and vertical plates are of length of 0.28m, width 0.1m and thickness of 0.006m. The temperature-dependent Material Properties shown in Table –I are given as input. Solid 70 and Solid 185 elements have been used for meshing in the thermal analysis and Structural Analysis is respectively. The number of element divisions in X&Y Directions are 10 and along Z-Direction is 28. The FE mesh of the model in Figure-1.

Table-1: Temperature-Dependent Material Properties

Temperatures (Celsius)	Modulus of Elasticity (MPa)	Poisson Ratio	Thermal Ex. Coef.(10^{-6}/°C)	Thermal Conductivity (W/m°K)	Specific Heat (J/kg°K)
0	314	0.2786	10	51.9	450
100	349	0.3095	11	51.1	499.2
300	440	0.331	12	46.1	565.5
450	460	0.338	13	41.05	630.5
550	410	0.3575	14	37.5	705.5
600	330	0.3778	14	35.6	773.3
720	58.8	0.3738	14	30.64	1080.4
800	58.8	0.4238	14	26	931
1450	1.29	0.4738	15	29.45	437.93
1510	1.0	0.499	15	29.7	400
1580	0.01	0.499	15	29.7	735.25
5000	0.01	0.499	15.5	42.2	400

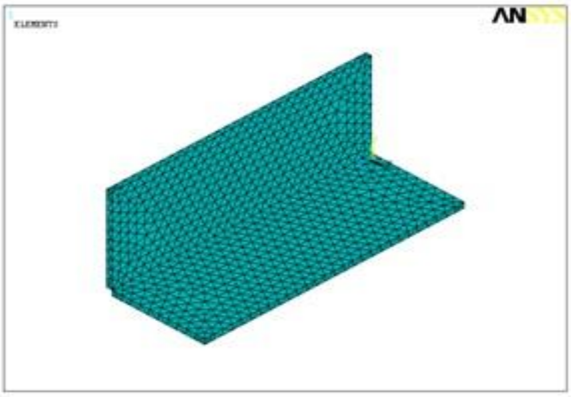

Figure-1: FE Mesh of the model

A heat input of 1200 W is given at the welded joint i.e. between the plates along the centre line. Convection is applied on the exposed surface with a film coefficient of h=5000 w/m^2 ^{0}C and the bulk temperature of 25^{0}C. The surface temperature of the specimen is Zero. The simulation has been carried for thermal analysis in a time period of 1200 seconds. The number of sub steps are 20 the time at the end of load step is 1200seconds on the size of the time step is 60. For simple stresses due to free expansion, no fixed boundary condition is applied along the joints and the joint is constrained along the length for thermal stresses. The Newmark algorithm has been used to run the simulation with transient effects. The temperatures obtained from thermal analysis are imported in to structural analysis for getting thermal stresses and strains.

III. Results& Discussion

The results and discussions drawn from the present work include the temperature distribution with respect to time in thermal analysis and estimation of Von mises stresses, Strains by combined Thermo-mechanical analysis. The variation of temperatures in all(X, Y &Z) directions with respect to time is shown in Figure 2. The temperature rises initially at a slower rate and rapid rate later but the rate is uniformly increasing and is due to cold condition of work piece at initial stages.

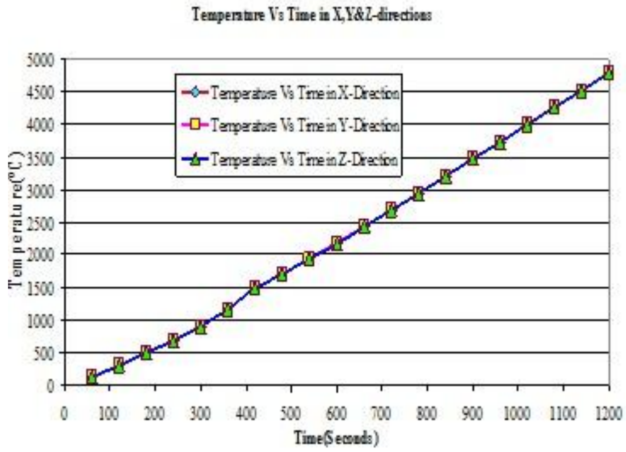

Figure-2: Temperature Vs Time

3.1 Displacements: The displacement of the horizontal plate in X, Y&Z directions with respect to the dimensionless parameter(X/L) for free expansion (simple stress analysis) and temperature stresses are shown in Figure 3 and 4 respectively.

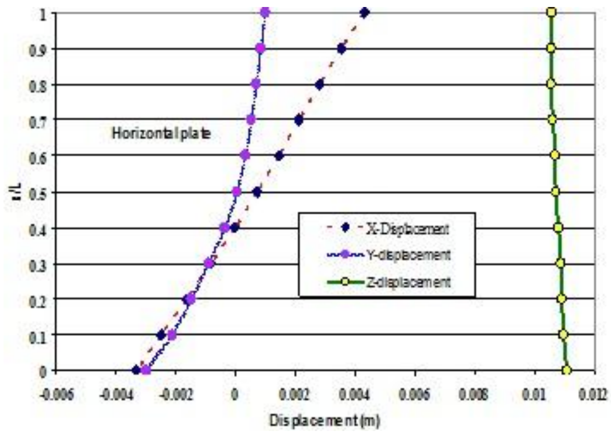

Figure-3: Displacements in Horizontal Plate (Free Expansion)

It is observed that the displacement in z-direction is more for both the simple stress and thermal stress analysis for the horizontal plate (Figure-3 & 4). The deformation is more for free expansion and is less for thermal analysis with structural boundary conditions

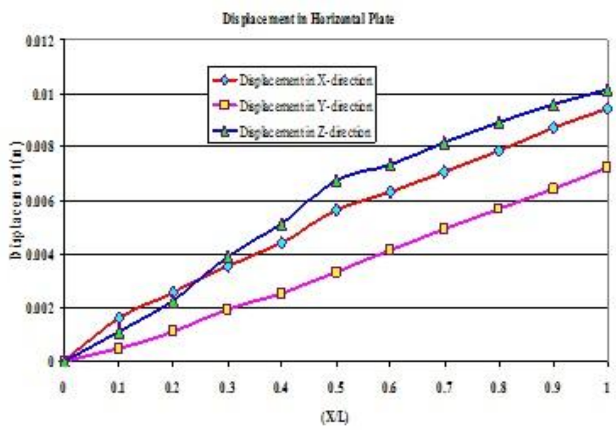

Figure-4: **Displacements in Horizontal Plate**.

This is due to the fact that the welded plate acts like a fin fixed at one end and free at the other end. For the same dimensionless parameter, the maximum deformation in Z-direction for free expansion is 0.015mm and it is 0.01mm. The displacement is continuously increasing from line of welding to the other end for structural boundary condition and is falling along the length for free expansion. The behaviour is opposite in X and Y-directions. The similar trend is also observed for vertical plate.

3.2 Von mises Stresses: The variation of Von mises Stresses are shown in Figure-5 and Figure-6 for free expansion and thermal respectively. For both the analysis, the maximum stresses are found in X-direction i.e. along the width of the plates.

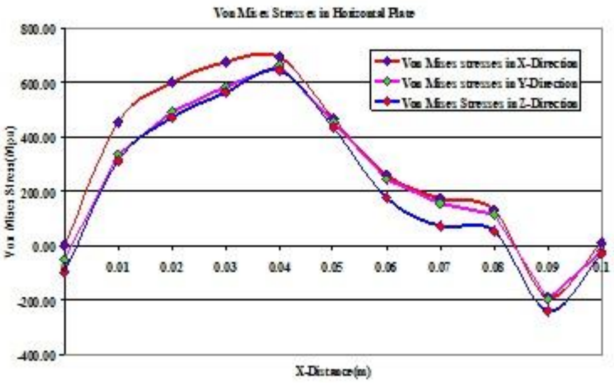

Figure-5: Von mises Stresses in horizontal Plate (Free Expansion)

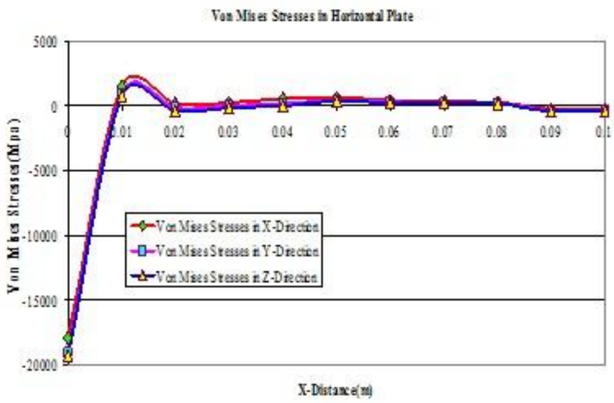

Figure-6: Von mises Stresses in horizontal Plate

The highest stress value of 692 Mpa is found at a distance of 40mm from the origin in X-direction and a minimum value of compressive stress of 240 Mpa at the extreme end of the horizontal plate.

Similarly for thermal analysis, the highest stress value of 1510 Mpa is found at a distance of 10mm from the origin in X-direction and a minimum value of compressive stress 315 Mpa at the extreme end of the horizontal plate.

Because of the thin plate effect, the stresses are uniform in vertical and horizontal plates of the Joint (Figure-7) for free expansion and is different from thermal analysis. The cumulative effect of temperature raise at the welded joint and the heat input at the origin causing more thermal stresses at the origin (Figure-8) due to fixed boundary conditions.

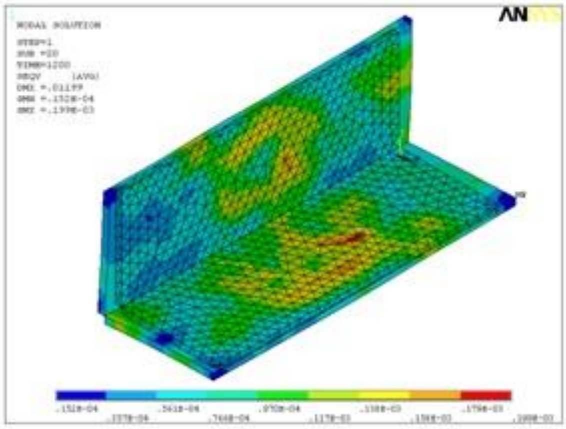

Figure-7: Von mises Stresses (X, Y &Z directions)-Free Expansion

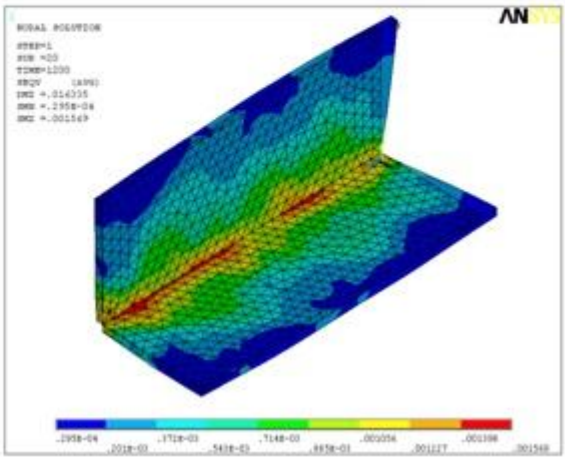

Figure-8: Von mises Stresses (X, Y &Z directions)

3.3 Von mises Strain: The variation of Von Mises strain in X-direction for the horizontal plate for both the analyses are shown in Figure-9 and Figure-10 respectively. It is found that the strain is more in the direction width and is due to the surface exposed to convection.

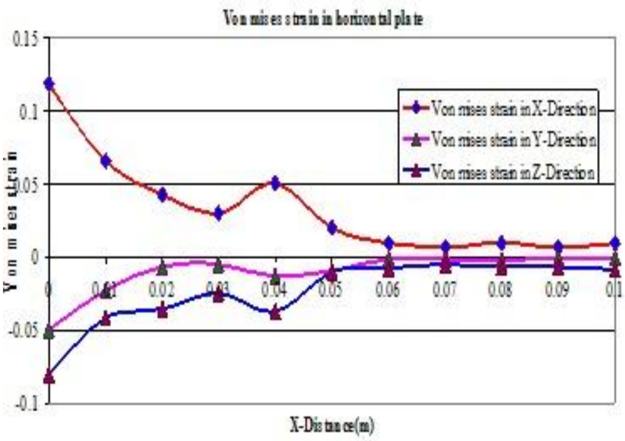

Figure-9: Von mises Strain in Horizontal Plate (Free Expansion)

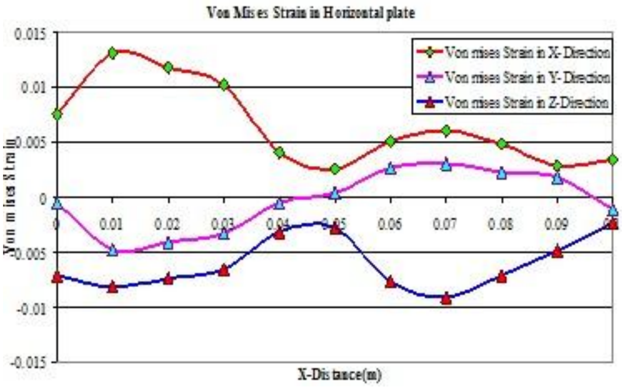

Figure-10: Von mises Strain in Horizontal Plate

Since the heat loss from the surface by convections time dependent and no temperature boundary conditions have applied, the deformation is more X-direction. It is evident that the fin effect is more in X-direction for thermal analysis than free expansion analysis.

IV. Conclusion:

The simulation of arc welding process for the study of stresses due to free expansion and temperature rise has been carried successfully. The temperatures obtained by thermal analysis have been used to obtain stress-strain values and distortion during combined thermo-mechanical analysis. Initially the vonmises stresses and strains have been obtained for free expansion process and compared with the structural boundary conditions. It is observed that the stresses are more for fixed conditions due to fin effect and heat loss through the exposed surface due to convection. The results for thermal analysis have been compared with theoretical values and are found in good agreement.

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