

ANALYSIS OF WELDING DISTORTION IN SEAM AND SKIP ARC WELDINGS USING FINITE ELEMENT METHOD

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ABSTRACT

A three-dimensional non-linear coupled field finite element model of the seam and skip welding induced temperature distribution and distortions in T-welded plates has been carried out in this paper. The results of finite element analysis were compared with those obtained by the coordinate measuring machine. The finite element analyses overestimated the distortion magnitude for larger plates, but underestimated the distortion magnitude for the small plate. The use of a planned welding sequence can reduce welding distortion.

Key words: seam and skip arc welding, distortion, finite element analysis

1. INTRODUCTION

Welding is a process of joining different materials. Welding involves highly localized heating of the metals being joined together. The temperature distribution is non-uniform in the welding process. Usually, the weld metal and the heat affected zone (HAZ) are at temperatures above that of the unaffected base metal. Upon cooling, the weld pool solidifies and shrinks, exerting stresses on the surrounding weld metal and HAZ. If the stresses produced from thermal expansion and contraction exceed the yield strength of the parent metal, localized plastic deformation of the metal occurs. Plastic deformation results in lasting change in the component dimensions and distorts the structure. This causes distortion of weldments. Distortion in weldments takes place by three-dimensional changes that occur during welding: longitudinal shrinkage that occurs parallel to the weld line, transverse shrinkage that occurs perpendicular to the weld line and angular shrinkage that consists of rotation around the weld line. Some of the factors affecting the distortion are: amount of restraint, welding procedure, parent metal properties, weld joint design and part fit up.

The prediction of welding distortion and residual stresses has been the subject of interest for many investigators. The analysis of welding induced distortion is a coupled field analysis between thermal and structural modules. In thermal analysis, many researchers followed analytical method and finite element method for obtaining temperature distribution in welding simulation. Analytical work on welding analysis can be divided into two categories. The first deals with the modeling of the temperature field, whereas the second deals with the modeling of the stress-strain field. Although modeling of the temperature field is practical and reasonably accurate, analysis of thermal stresses and incompatible strains is much less satisfactory [1, 2, 3]. The results obtained from finite element models are known to be reliable and have been verified with experiments. The degree of accuracy is strongly related to the number of degrees of freedom of the finite element model [4]. Welding sequence implies the order of making the welds in a weldment. The weld metal is placed at different points about the structure so that as it shrinks at one place and it will counteract the shrinkage forces of weld already made [5].

In this study, a three-dimensional non-linear coupled field finite element model of the seam and skip welding induced temperature distribution and distortions in T-welded plates has been presented. The results of finite element model were verified with those of experiments.

2. FINITE ELEMENT MODELING

In this work, modeling, thermal and structural analyses were carried out using commercial finite element analysis (FEA) software ANSYS 7.1. A non-linear transient thermal analysis was carried out to get the effect of moving heat source. A three-dimensional thermal solid brick element with 8 nodes (SOLID 70) and with each node consists of one degree of freedom (temperature) was considered for discretisation. The T-joint after discretisation looks like as shown in figure 1. Temperature dependent material properties such as thermal conductivity, film coefficient and enthalpy were applied to these elements. The material of weld plates is mild steel.

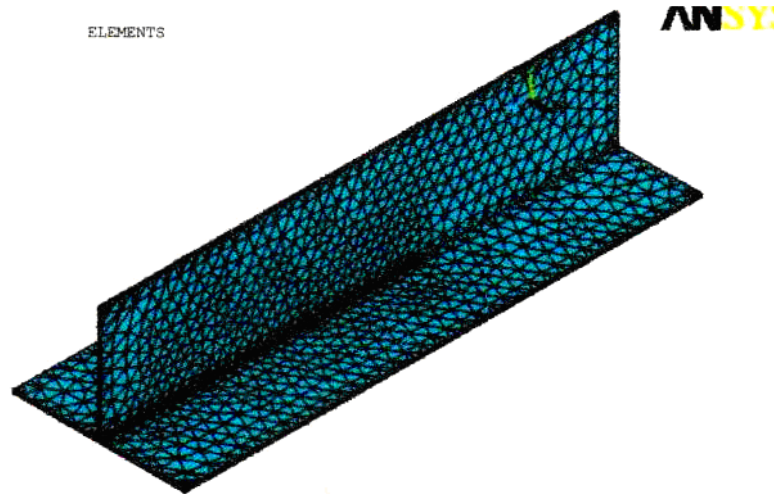


Figure 1: Discretisation of T-joint

Initially the work was started with tack welding at either ends of the plates. It was assumed that the T-joint initially at atmospheric temperature of 30°C. A nonlinear steady state thermal analysis was carried out to get temperature distribution. Initially temperature loading was applied on the first node in longitudinal direction along the weld line, a steady state thermal analysis (SSTA) was conducted at point of time by giving the results of transient thermal analysis (TTA) after second tack welding. The resultant of this analysis gave the temperature distribution at that instant of time. Then temperature has to be moved to the next node depending upon the speed of welding, the joint was subjected to free convection for specific time. So, the transient thermal analysis was conducted with temperature distribution from previous SSTA file as input. Then the arc was applied on the next node on welding line. Again a SSTA thermal analysis was applied with temperature distribution from previous TTA. But ANSYS does not have the capability to take the result file of TTA as initial condition for successive SSTA. So, manually temperature distribution at significant parts was given so that the moving heat source effect was obtained. Similarly a loop of SSTA and TTA as shown in the flow chart (figure 1) completes the welding process and tries to simulate the actual welding process with moving heat source.

The same model that has been used for thermal analysis was imported into structural analysis phase and discretised by using structural solid element (solid 45) with 8 nodes and 3 degrees of freedom. The T-joint was constrained in all degrees of freedom at place of welding and for calculating thermal strain. For obtaining distortions the only load applied was the result file that was obtained from respective thermal analysis. This thermal analysis file consists of temperatures at each node of the model. By providing all constraints as above the analysis was conducted as nonlinear static analysis. In this manner the distortions of the required joint was obtained.

3. EXPERIMENTAL PROCEDURE

The Indarc AC transformer was used for manual metal arc welding. Input power rating is 380 – 400 V, 50 Hz, 50A and the output power rating is OCA 80 – 100V, 25 – 100 A with maximum weld current of 250 A at 80 V OCV. The material of the workpiece is mild steel and the electrode is mild steel (IS 814 ER4211). The dimensions of electrode are 3.15 mm dia and 350mm long. The gap between electrode and workpiece is 2mm. The angle of electrode with workpiece was 60°. After taking standard precautions, the two pieces one on the other vertical at the centre was assembled to form T joint.

In the case of single pass seam welding, down-hand welding was employed. Weldment was laid from left hand to right hand side of the joint. On reversing towards next side of the joint welding was done from right hand side to left hand side. In case of skip welding, the whole length of workpiece is divided into five equal parts i.e., 90mm each on longitudinal direction of weld line. Depending upon the sequence taken, the welding was done on respective parts along the length. The welding was repeated by varying one dimension at a time viz., width of base plate and thickness of the base plate keeping all other dimensions constant.

After completion of welding and cooling to room temperature, the slag was removed with help of a chipping hammer and weld spatter were cleaned using wire brush. The vertical displacements at various locations in the back side of the plate surface were measured using a coordinate measurement machine (CORDAX RS-30 DCC, Sheffield Measurement System). The frame keeps a constant reference and level for the table that supports the panel. It also provides a precision traveling mechanism for locating the measurement points. When the plates were finished with any weld pass off the measurement system, the weldment was placed on the table at three ball-joint supports, which were fixed at three adjustable corner locations. These three-point supports always could maintain a reference triangular plane for the plate when the table was jacked up to the reference settings in the frame. Each time after loading and unloading of the plates, the displacements of weld plates were measured in the same reference and leveling condition

4. RESULTS AND DISCUSSION

The fillet size of T joint was $0.75t$, where t is the thickness of plate. Weld current and voltage were 95A and 80V respectively. The efficiency of the heat source was taken to be 75%.

4.1 Effect of base plate width on distortion in the seam welding

Analysis was started by taking the width of the base plate as 50mm keeping the height of vertical plate and thickness of both the plates 3mm constant. The maximum nodal distortion in the transverse, vertical and longitudinal directions is plotted in figure 2. The amount of distortion is nearly constant upto 90mm width of base plate. Above 90mm of width of base plate the distortion increases with increase in width. In the longitudinal direction, the distortion was found to be high for all the widths. Shrinkage of the finished fillet welds would cause the plate to bend in a global nature and the plate to warp, which is a local distortion behavior. This weld shrinkage also induces compressive stresses, in addition to the bending induced stresses in the plate. Greater displacements are also shown for a longer panel due to global bending.

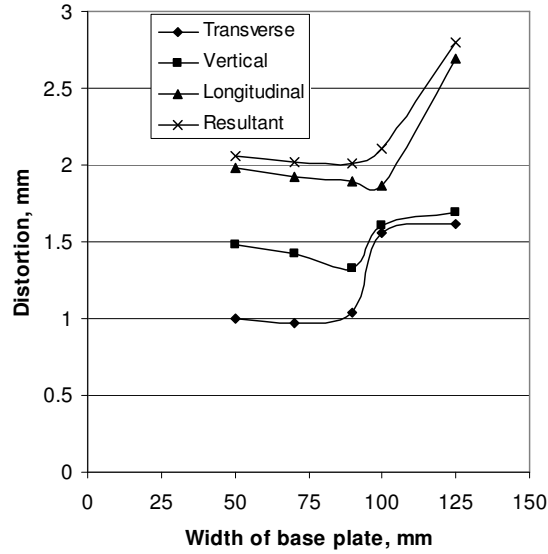


Figure 2: Effect of width of base plate on distortion

The distortions in the transverse and vertical directions measured along the longitudinal direction of experiments and FEA are shown in figure 3 under constant heat input. The resultant distortion of the plate obtained by FEA is shown in figure 4. The predicted results agree reasonably well in distortion shape with the experimental curves. The maximum error is 3.78% between experimental and FEA results. The finite element analyses overestimated the distortion magnitude for larger plates, but underestimated the distortion magnitude for the small plate.

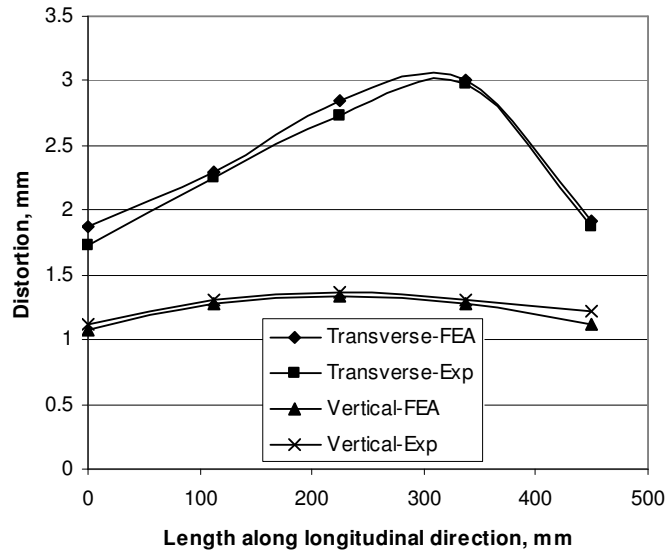


Figure 3: Distortion variation along the longitudinal direction from FEA and experimental data

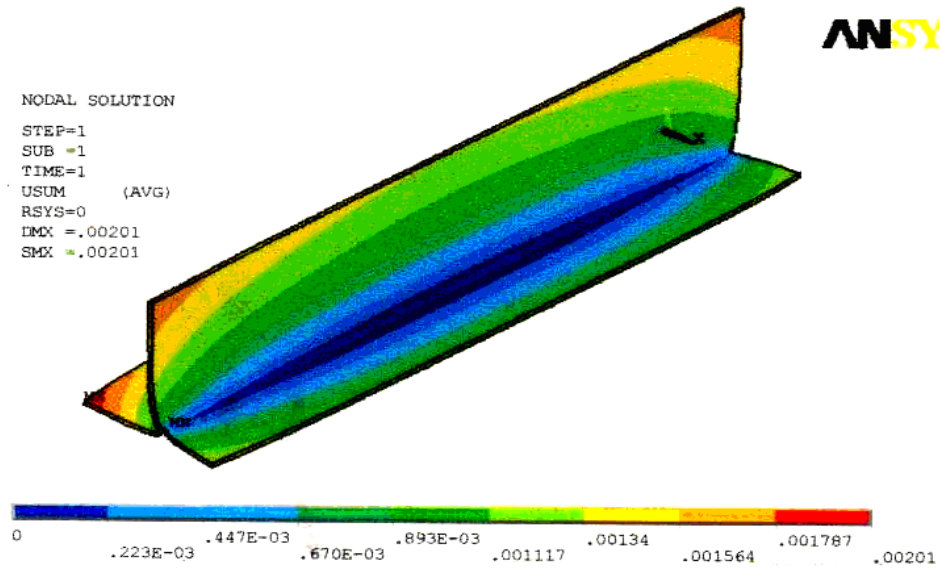


Figure 4: Resultant distortion of T-joint

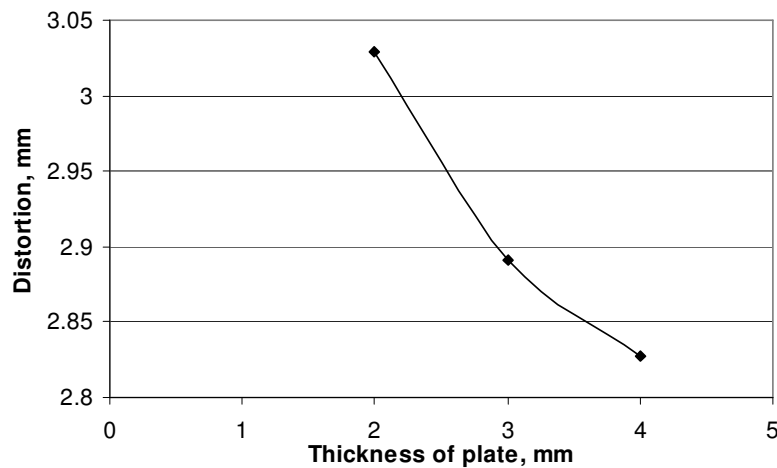


Figure 5: Effect of thickness of base plate on the distortion

4.2 Effect of thickness of base plate on the distortion

The effect of variation thickness of base plate is shown in figure 5. The resultant distortion decreases with decrease in thickness of base plate. In this study, plates with smaller plate thicknesses were also analyzed by the finite element method. It was found that weld shrinkage alone would not cause the plate to buckle regardless of the plate width unless the plate was thinner than 2.0 mm. However, the plate could buckle if the global bending due to welding was large and the plate was wide. This means that only excessive curvature caused by the global bending effect may cause plate buckling in wide plates.

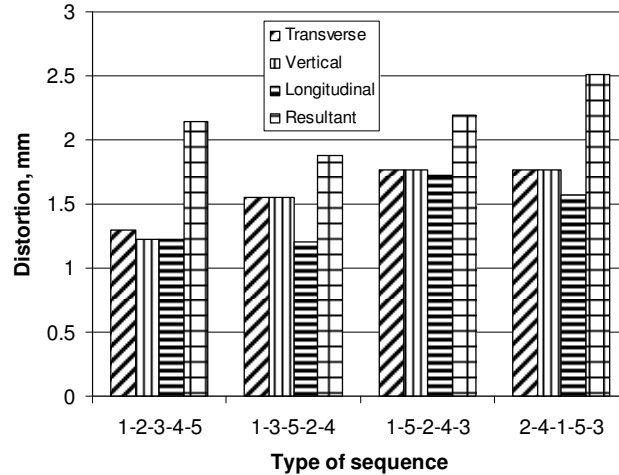


Figure 6: Effect of welding sequence in skip welding

4.3 Effect of sequence of skip welding on the distortion

The effect of sequence of welding on the distortion is shown in figure 6. Joint rigidity can be defined as the resistance to angular bending of a T-joint under a unit moment applied to the joint. The rigidity is more for the sequence of 1-3-5-2-4 in skip welding. The resultant distortion is minimum at skip sequence of 1-3-5-2-4. The welding sequence of 1-3-5-2-4 intends to balance the thermally induced stresses around the neutral axis of the component.

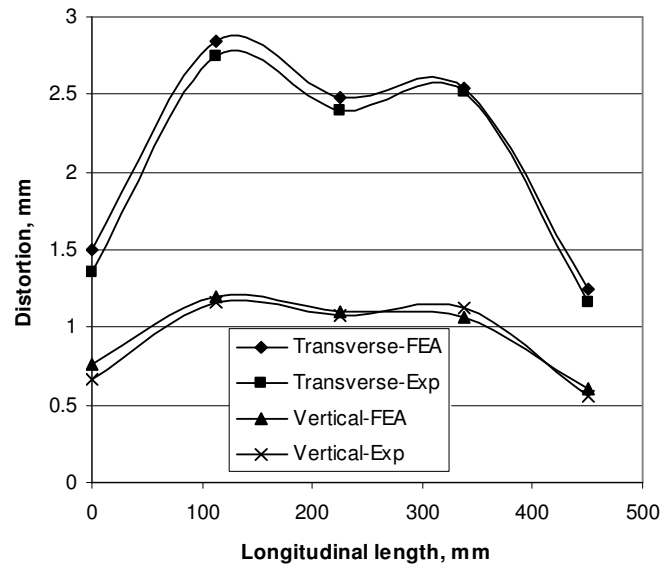


Figure 7: Distortion variation along the longitudinal direction from FEA and experimental data of welding sequence 1-3-5-2-4

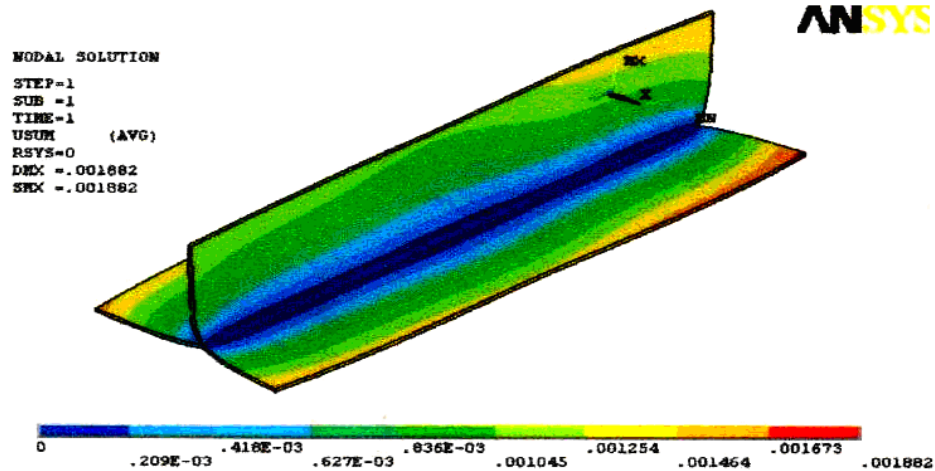


Figure 8: Resultant distortion of T-joint of welding sequence 1-3-5-2-4

5. CONCLUSION

The larger the plate size, the smaller the maximum shrinkage strain magnitude to cause onset bifurcation due to wider shrinkage strain distribution and greater dimensional instability of the plate.

The use of a planned welding sequence can reduce welding distortion on fabrications such as lattice beams where a planned sequence can be of great benefit. The precise sequence to minimize distortion will vary from assembly to assembly and is best designed from experience.

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