Prediction of Residual Stresses and Distortion in GTAW Process -A Review

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ABSTRACT

Residual stresses and thermal distortion are a common phenomenon observed in any welding method. This is a result of non-uniform stresses generated due to highly localized heating at the joint edges, which fuses the base material and leads to considerable amount of changes in mechanical properties. Thus, it is very important to evaluate these effects in any welded structural members before designing for actual loading condition. Therefore, accurate prediction of these residual stresses and distortion is of critical importance to ensure the in-service structural integrity of welded structures.

The recent advancement in Computational simulation and numerical techniques helps in evaluating the weld distortion and residual stresses. The moving heat flux approach and Element birth/death method makes it easier to analyze the weld distortion. This is done with the use of ANSYS Commercial FE software.

It has been observed from many researchers, the Residual stresses and distortion were predicted using different simulation methods. The minimum longitudinal residual stress and distortion occurred in the specimen containing u- shaped grooves using 2-D and 3-D finite element analysis. The residual stress and the welding distortion in low carbon steel do not seem to be influenced by the solid state phase transformation, because of a small dilation due to martensite transformation. Peak tensile residual stress and angular distortion values were lower in the A-TIG weld joint compared to that of the multi-pass TIG weld joint. This paper focus on overview of Computational simulation and numerical techniques for Prediction of Weld Distortion and Residual Stresses in GTAW Process.

Keywords: Residual stresses, Weld distortion, GTAW Process, Simulation.

I. INTRODUCTION

Welding is a joining process based on the material state change at high temperatures. Welding technology is widely used in a lot of industries as shipbuilding, nuclear or automotive. Welding has interesting properties over other joining technologies, like continuity in the final assembly and ease, speed, as well as versatility in the design and fabrication stage. However this technology in its traditional form reveals disadvantages because the high Residual stresses and distortions can cause major problems in the welded structures. Temperature gradients generate thermal expansion, shrinkage, and micro structural transformations. These inevitable consequences of weld process can generate strains, distortions and fissures or cracks and in this way decrease the life and safety of structure Also these effects are an inevitable consequence of weld process.

Residual stresses are produced in the weldments due to mismatching and non-uniform distributions of plastic and thermal strains. As the temperature of the base metal increases, the yield strength decreases and the thermal stress increases [1]. The mismatching (in the weld in general) occurred due to joint geometry and plate thickness. Welding procedures and degree of restraints are also influenced by the residual stress distributions. High residual stresses in the regions near the weld can promote brittle fractures, fatigue or stress corrosion cracking. In addition, residual stresses in the base plate may reduce the buckling strength of the structures. Several factors may contribute to the formations of residual stress and deformation. The plastic deformation produced in the base metal and weld metal is a function of design (structure), material, and fabrication parameters. The design parameters include the joint type and the thickness of plates. The material parameters reflect the metallurgical condition of base metal and the weld metal. Fabrication parameters include the welding method, heat input, preheating, welding sequence and the restraint condition.

II. RESIDUAL STRESSES AND THEIR MEASUREMENT

Residual (locked-in) stresses in a structural material or component are those stresses that exist in the object without the application of any service or other external loads. Manufacturing processes are the most common causes of residual stress. Virtually all manufacturing and fabricating processes-casting, welding, machining, molding, heat treatment, etc. introduce residual stresses into the manufactured object. Another common cause of residual stress is in-service repair or modification. In some instances, stress may also be induced later in the life of the structure by installation or assembly procedures, by occasional overloads, by ground settlement effects on underground structures, or by dead loads which may ultimately become an integral part of the structure.

The effects of residual stress may be either beneficial or detrimental, depending upon the magnitude, sign, and distribution of the stress with respect to the load-induced stresses. Very commonly, the residual stresses are detrimental, and there are many documented cases in which these stresses were the predominant factor contributing to fatigue and other structural failures when the service stresses were superimposed on the already present residual stresses. The particularly insidious aspect of residual stress is that its presence generally goes unrecognized until after malfunction or failure occurs. Measurement of residual stress in opaque objects cannot be accomplished by conventional procedures for experimental stress analysis, since the strain sensor is totally insensitive to the history of the part, and measures only changes in strain after installation of the sensor. In order to mea-sure residual stress with these standard sensors, the locked-in stress must be relieved in some fashion (with the sensor present) so that the sensor can register the change in strain caused by removal of the stress. This was usually done destructively in the past by cutting and sectioning the part, by removal of successive surface layers, or by trepanning and coring. With strain sensors judiciously placed before dissecting the part, the sensors respond to the deformation produced by relaxation of the stress with material removal. The initial residual stress can then be inferred from the measured strains by elasticity considerations. Most of these techniques are limited to laboratory applications on flat or cylindrical specimens, and are not readily adaptable to real test objects of arbitrary size and shape.

X-ray diffraction strain measurement, which does not require- stress relaxation, offers a nondestructive alternative to the foregoing methods, but has its own severe limitations. Aside from the usual bulk and complexity of the equipment, which can preclude field application, the technique is limited to strain measurements in only very shallow surface layers. Although other nondestructive techniques (e.g., ultrasonic, electromagnetic) have been developed for the same purposes, these have yet to achieve wide acceptance as standardized methods of residual stress analysis.

The residual stresses are determined by both destructive and non - destructive methods and the following:

. X-ray diffraction method
. Neutron diffraction method
. Hole drilling and strain gauge method
. Ultrasonic technique
. Positron annihilation spectroscopy method
. Ring core method

Hole-Drilling Method

The most widely used modern technique for measuring residual stress is the hole-drilling strain-gage method of stress relaxation, illustrated in Figure 1.

Briefly summarized, the measurement procedure involves six basic steps:

- A special three- (or six-) element strain gage rosette is installed on the test part at the point where residual stresses are to be determined.
- The gage grids are wired and connected to a multi-channel static strain indicator, such as the Micro-Measurements Model P3 (three-element gage), or System 5000 (six-element gage).
- A precision milling guide (Model RS-200, shown in Figure 1) is attached to the test part and accurately centered over a drilling target on the rosette.
- After zero-balancing the gage circuits, a small, shallow hole is drilled through the geometric center of the rosette.
- Readings are made of the relaxed strains, corresponding to the initial residual stress. Using special data-reduction relationships, the principal residual stresses and their angular orientation are calculated from the measured strains.

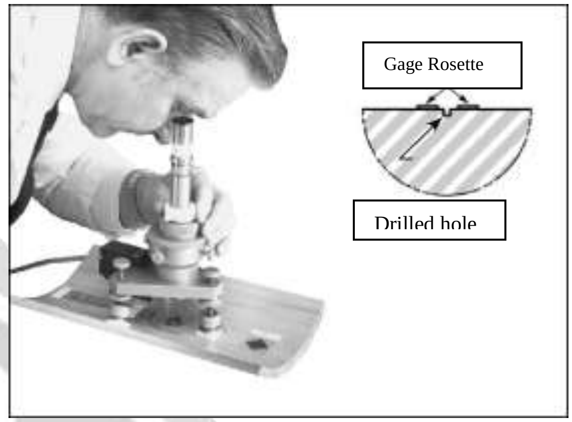

Fig 1. Hole Drilling Strain Gauge Method

III. LITERATURE REVIEW AND DISCUSSION

Dean Deng [1] investigated the effects of solid state phase transformation on welding residual stress and distortion in low carbon and medium carbon steels. In certain steel welded parts, the solid-state austenite–martensite transformation during cooling has a significant influence on the residual stresses and distortion. The martensitic transformation is a diffusionless solid-state shear deformation. Accurate prediction and reduction of welding residual stress and deformation are critical in improving the quality of welded structures. For certain steels, to evaluate the residual stress and deformation accurately, metallurgical phase transformation must be considered. In this study, a finite element computational procedure considering solid-state phase transformation was developed, and the effectiveness of the proposed numerical method for analyzing the residual stress and the distortion in carbon steels specific to tungsten inert gas (TIG) arc welding was demonstrated. The finite element analysis package ABAQUS was used for the prediction of residual stresses & distortion.

Author was developed a three-dimensional finite element model considering phase transformation to analyze the tungsten inert gas arc welding process and to simulate the residual stress and the welding distortion. He was found that for low carbon steel, phase transformation has an insignificant effect on the welding residual stress and the distortion because of a small dilation due to martensitic transformation and a relatively high transformation temperature range, where as in medium carbon steel, phase transformation has a significant effect on the welding residual stress and the distortion because of a relatively large dilation and a low transformation temperature. Author observed that a compressive stress in the welding direction is produced in the FZ. From the simulation results, when the residual stresses and the welding deformation of medium carbon steel are predicted using numerical simulation, it is necessary to consider solid-state phase transformation. On the other hand, the solid-state phase transformation can be neglected for low carbon steel. Neglecting the phase transformation in low carbon steel weld structure will make the numerical model simple and reduce the computation time.

Ejaz M. Qureshi [2] Analyzed weld-induced residual stresses and distortions in thin-walled cylinders of diameter 300mm of thickness 3mm in GTA welding process. To precisely capture the distortions and residual stresses, computational methodology based on three-dimensional finite element model for the simulation of gas tungsten arc welding in thin-walled cylinders was presented. The complex phenomenon of arc welding is numerically solved by sequentially coupled transient, non-linear thermo-mechanical analysis. The accuracy of both the thermal and structural models was validated through experiments for temperature distribution, residual stresses and distortion. Computational methodology and techniques based on finite element analysis for the prediction of temperature profiles and subsequent weld-induced residual stress fields and distortion patterns in GTA welded thin-walled cylinders of low carbon steel were developed and implemented successfully with close correlation to the experimental investigations. Author was observed that along and near the weld line, a high tensile and compressive axial residual stresses occurs on the cylinder inner and outer surfaces, respectively. Compressive and tensile axial residual stresses are produced on inner and outer surfaces away from the weld line. Axial stresses are weakly dependent on the circumferential locations from weld start. With some exceptions on weld start and its vicinity, the axial stress along the circumferential direction almost has homogeneous distributions. Hoop residual stresses are sensitive to the angular location from the weld start position. From Fig. 15 and Fig. 16 it is evident that hoop residual stresses on outer and inner surfaces at three different cross sections vary significantly in magnitude.

P. Vasantharaja [3] performed on weld joints of 10mm thick 316LN stainless steel were made by multi-pass TIG and A-TIG welding processes and their residual stresses distribution and distortion values were measured and compared. Author was prepared V-groove edge preparation for making multi-pass TIG weld joint, square-edge preparation was sufficient for making single pass A-TIG weld joint. Ultrasonic nondestructive technique based on the critically refracted longitudinal waves (LCR waves) has been used for the quantitative surface/sub-surface residual stress measurements in the weld joints. Distortion measurements were carried out before and after welding using height gauge. He was observed Peak tensile residual stress and the angular distortion values were lower in the A-TIG weld joint compared to that of the multi-pass TIG weld joint.

The weld joints made by TIG and A-TIG welding processes exhibited different microstructures, peak tensile residual stress and angular distortion values. The A-TIG weld joint exhibited lower peak residual stress and distortion values due to lower weld metal volume caused by the absence of filler metal addition and straight sided edge preparation, single pass welding and more intense heat source. The multipass TIG weld joint was subjected to multiple cycles of heating and cooling, with the V-groove edge preparation and filler metal addition exhibited higher residual stresses and angular distortion values. Type 316LN stainless steel A-TIG weld joint with lower residual stress and distortion values is expected to perform better during service besides requiring significantly lower cost of fabrication.

S.A.A. Akbari Mousavi [4] Attempts were made to analyze the residual stresses produced in the TIG welding process using 2D and 3D finite element analyses. The effect of geometry configurations on the residual stress distributions are predicted from the 3D computer analysis using a thermoelastoplastic constitutive equation and compared with the X-ray diffraction method. Author was considered the effects of conduction, radiation and convection due to both air and inert gas flow rate. Heat capacity, thermal conductivity, elastic modulus, yield stress and other material properties are assumed to be temperature dependent. He was also considered the effects of the fluid flow, plasticity and external constraint on the residual stress distributions. Simulation results show that the peak of the tensile residual stress obtained for the u-grooved configuration is less than that predicted for the v-grooved configurations. The predicted residual stresses were in good agreements with those obtained by the X-ray diffraction experiments. It was also shown that the magnitude of the transverse residual stresses increases about threefold if mechanical constraints are applied. The constrained structure also produces less distortion than the un-constrained structure. The best agreement between the residual stress distributions and the X-ray experiments is obtained using the kinematic and isotropic hardening constitutive equations.

The minimum longitudinal (and transverse) residual stress and the minimum length of the tension zone were obtained with test specimens containing u-grooves. The least tension zone and the minimum tensile longitudinal (and transverse) residual stress were produced in specimens containing 50◦ v-grooves. The minimum von- Mises strains and distortions occurred in the specimens containing u-shaped grooves. The effect of mechanical constraints on both the 50◦ u and v grooved specimens was examined. The results showed that the magnitudes of the transverse residual stresses increased about threefold. In addition, the constrained weld structures had less distortion than the non-constrained weld structures. Mechanical constraints had no major effect on the magnitude of the peak longitudinal residual stress; however the longitudinal stress distribution patterns changed significantly. The numerical results for residual stress distributions obtained using the kinematic and isotropic hardening constitutive equations were in a good agreement with those obtained by the X-ray experiments.

Dean Deng [5] investigated the influence of solid-state phase transformation on the evolution of residual stress distributions in butt-welded modified 9Cr–1Mo steel pipes. Welding of the Cr–Mo steels plays a very crucial role in the power and petroleum industries. Manufacturing processes, such as welding, frequently introduce unwanted residual stress in structures, leading to brittle fracture, hydrogen embrittlement (HE), and a deterioration of fatigue life. Generally, in order to improve the toughness and to remove welding residual stress after welding, the Cr–Mo steel weldment should be subjected to post-weld heat treatment.

Author was predicted welding residual stresses in multipass butt-welds for modified 9Cr–1Mo steel pipe considering solid-state phase transformation effects as shown in figure 2, a thermal elastic plastic finite element model taking into account metallurgical phase transformations was developed. The effects of volumetric change and yield strength change due to austenite–martensite transformation on welding residual stress were investigated by means of numerical analysis as shown in figure 3. Experiments were also carried out to verify the effectiveness of the proposed numerical model. The residual stress distribution was simulated by an uncoupled thermo-mechanical finite element formulation using the ABAQUS code.

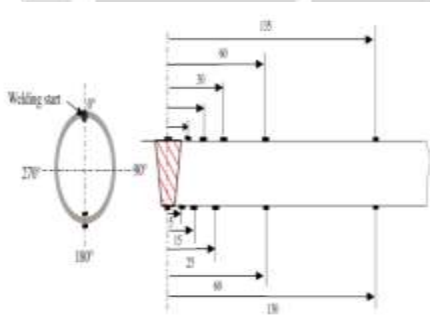

Fig. 2. Measurement locations of the strain gauges along the axial direction

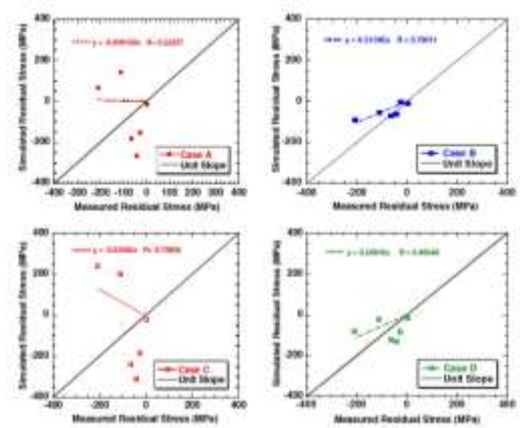

Fig. 3. Plots of the predicted vs measured values of axial residual stress

IV CONCLUSIONS

1. As per the survey several methods are available to predicted the Residual stresses and Distortion in GTA welding process.
2. As per the review among available methods, ultrasonic based residual stress measurements are non destructive and offer quantitative estimation of surface, sub-surface and bulk residual stresses.
3. As per the review the residual stress and the welding distortion in low carbon steel do not seem to be influenced by the solid state phase transformation, because of a small dilation due to martensite transformation.

4. As per the review Peak tensile residual stress and angular distortion values were lower in the A-TIG weld joint compared to that of the multi-pass TIG weld joint.

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