# Finite Element Analysis of Welding induced Residual Stresses for Duplex Stainless Steel Weld Joint using Contour Method

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## Abstract

In fusion welding, thermal cycle leads to undesirable metallurgical structure and causes residual stresses gets induced near the weld zone which plays an important role in determining the reliability of the weld joint. In this present work, the prediction of residual stresses in a welded joint has been done using Contour method. The measurements of the cross-sectional residual stress profile in a Duplex stainless steel 2205 welded with ER 2209 filler material are validated in the longitudinal direction. This method is simple in principle and easy in use. According to this method, the weld metal containing residual stresses is cut along the plane perpendicular to the weld line. The deformations occurring at the cut surfaces as a result of relaxation of the residual stresses are measured. The measured deformations are given as displacement boundary conditions to a finite element model to calculate the corresponding stresses normal to the cutting plane. This superposition principle assumes that the material behaves elastically during relaxation of residual stresses and that the cutting process does not introduce any new stresses to influence the measured displacements. It requires only one straight cut through a sample on the plane of interest, followed by measurement of the surface contour produced by relaxation of the internally stored stress field. This study indicates that the contour method is a powerful novel technique to obtain an accurate full three-dimensional map of residual stress field.
**Keywords: Residual Stresses, Contour Method, Surface Fitting, Duplex stainless steel, FEM**

## I. Introduction

Residual stresses are introduced in the engineering components by various manufacturing process. Welding is the primary manufacturing process for joining metals in automobile, aerospace and marine industries. [1] During welding there is a significant change in the material properties and distortion takes place due to the severe thermal cycle loading. Due to these stored residual stresses near the weldment and heat affected zone, crack initiation takes place at the surface. The crack further gets rooted due to the environment such as corrosion, low temperature brittle behaviour, stress corrosion cracking and hydrogen embrittlement. This leads to the sudden failure in the weld joints. [2, 3] Thus the prediction of residual stresses in engineering components is essential to predict the failure criteria. Though many methods are available for measuring residual stresses such as x ray diffraction, hole drilling method, ultrasonic method etc., these methods have lots of limitations while achieving the accuracy of result. [4,5] Contour method was developed for measuring the residual stresses for the entire cross section of the material by using this method, the equilibrium residual stress pattern can be arrived in the form of a profile. Contour method was first introduced by Prime in 2001. The application of contour method follows the principle of Bueckner's elastic super position principle. It states that "If a cracked body subjected to an external loading or prescribed displacements at the boundary has forces applied to the crack surfaces to close the crack together, these force must be equivalent to the stress distribution in an uncracked body of the same geometry subjected to the same external loading". During welding residual stresses get stored in the weld and the heat affected zone. [6,7] The stored residual stresses are released when the weld region is cut into two halves in the transverse direction of weld, and plastic deformation induced in the cut surface due to residual stress relaxation. Contour method follows the above principle to study the effect of residual stresses due to welding. During wire cut EDM operation, the residual stresses are released in the form of normal and shear stress components over the surface. [8, 9] This stress relief causes distortion on the cut surface. Some of the assumptions made in the implementations of the method are (i) Stress relief after cutting is purely elastic. (ii) The cutting process does not introduce any stress. (iii) The cut surface is perfectly flat. (iv) Only normal stress from the cut surface is evaluated in the analysis. Shear stress component during relaxation has not been considered in the analysis. This study indicates that the contour method is a powerful novel technique to obtain an accurate full three-dimensional map of residual stress field.

 

## II. EXPERIMENTAL SETUP & MATERIAL SELECTION

### A. *X ray Diffraction Technique:*

A.The expensive apparatus is needed to measure the surface residual stresses. The stress can be measured only up to 0.025mm from the surface. This technique requires electrolytic polishing to measure stresses on the subsurface layers. Samples must be polycrystalline and fine grained.

### B. *Hole Drilling Method:*

Residual stresses may be induced during drilling the hole. This approach can be used when the stress field is uniform over the depth. The hole itself causes a stress concentration that limits the stresses that can be measured to 50% of the yield stress before plastic deformation occurs.

### C. *Finite Element Method:*

Several studies have been made using FEM to predict the residual stresses. However these methods are based certain assumptions which lead to inaccurate predictions. The analysis is based on quasi steady state i.e. the heat source is moving with at constant velocity. But in real welding process the speed is not constant in the case of manual arc welding. In FEM the thermal and structural analysis are uncoupled. The distortions of the part during welding do not affect the temperature distribution. However in reality thermal effect and mechanical distortions occur at the same time .The decoupling of analysis become acceptable if one assumes that the distortion during welding is negligible. But distortion plays a major role in the analysis of residual stresses.

### D. *Contour Method:*

The contour map of the residual stress pattern is arrived only by using dissection technique. The residual stress stored in the entire cross section can be measured. But this method is limited to simple cross sections. Complicated weld joints cannot be analysed using this technique.

### E. *Role of Alloying Elements:*

Chromium is used to increase the corrosion resistance of duplex stainless steel. It is a ferrite stabilizer which promotes the BCC structure of iron. It also increases the oxidation resistance at elevated temperatures. Molybdenum supports chromium in pitting corrosion resistance. Higher content of molybdenum forms intermetallic phases. Therefore, it is restricted to 4% in DSS. To get the balanced microstructure, nickel is necessary which is used as an austenite stabilizer. It promotes the change of crystal structure from BCC to FCC. The addition of nickel delays the formation of intermetallic phases in FCC structure. Nitrogen increases the pitting and crevice corrosion resistance of duplex stainless steel. Toughness of duplex stainless steel increases due to nitrogen addition. Also it delays the formation of intermetallic phases. Nitrogen is an austenite stabilizer, which increases the strain hardening rate of austenite. Thus the ferrite stabilizers, chromium and molybdenum are balanced by austenite stabilizers, nickel and nitrogen to develop the dual phase structure. Figure 1. Represents the SEM image of DSS 2205.

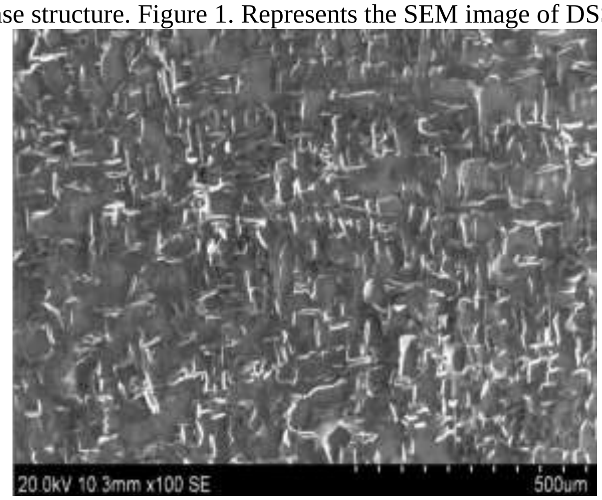


Fig. 1: Microstructure of DSS 2205

### F. *Weldability of Duplex Stainless Steel:*

Weldability of duplex stainless steel is good enough when compared with ferritic steels but not better than austenitic steels. High ferrite content leads to poor low temperature toughness and high austenite content possess low strength and reduced resistance to chloride stress corrosion cracking. ER 2209 weld filler metal is used to weld duplex stainless steels. This filler metal contains 9% nickel which is more than the base metal. Higher nickel content stabilizes the reaustenitization process.

### G. *Effect of Heat Input in Welding DSS 2205:*

Due to the importance of maintaining a balanced microstructure and avoiding the formation of undesirable metallurgical phases, the welding parameters and filler metals employed must be accurately specified and closely monitored. It should be in the range of 0.5 to 2.5 KJ/mm. Low heat input induced inadequate formation of austenite even with high nitrogen alloys, under very rapid cooling rates. High heat input gives the precipitation of intermetallic compounds with the ferrite under slow cooling rate.

## III. EXPERIMENTAL PARAMETERS

TIG welding was used to join the DSS 2205 plates with a welding speed of 2.08 mm/sec. Tack welds were made at short distances to avoid distortion. To avoid carbide precipitation 99.996% pure argon was supplied as a shielding gas which protects the weld zone from oxygen contamination. During welding tungsten electrode was kept at an angle of 60º and the filler wire was kept at an angle of 15 to 20º. After welding the T joint, it was cut into two halves across the weld using brass wire EDM with a wire diameter of 0.2 mm. This process achieves good surface finish and also does not introduce any stress due to cutting time of 6 hrs. Deionized water was used as a dielectric system which acts as a coolant during cutting. Figure 2 indicates the Wire cut EDM of DSS 2205T-Joint.

Fig. 2: Wire cut EDM of DSS2205T- Joint

After cutting using wire EDM, the cut surfaces of the cross section were measured using coordinate measuring machine (CMM) in 640 locations. Then the measured locations were plotted in three dimension graph using MATLAB. The graph shows that the maximum deformation is at the cross section of weldment and heat affected zone which clearly indicates that the maximum residual stress get stored at the region of the weld. Figure 3 shows the profile generated from measurements taken on the one halves of the cut joint. These profiles are useful to understand the residual stress variation pattern across the weld


Fig. 3: Contour measurement using CMM

## IV. RESULTS & DISCUSSION

The meshing of finite element model which is having the measured displacement as boundary conditions. With the applied boundary conditions the stresses induced in the vicinity of the cut were used as a measure to predict residual stresses. Figure 4 shows the meshed FEM model of horizontal weld plate and Figure 5 represents the residual stress vs weld distance in which variation of stresses superimposed over the cross section of the plate. The stress pattern is tensile in nature near the weld zone and HAZ and it changes to compressive nature away from the weld. The maximum residual stress reaches 170 MPa nearly half of the yield stress of the metal.

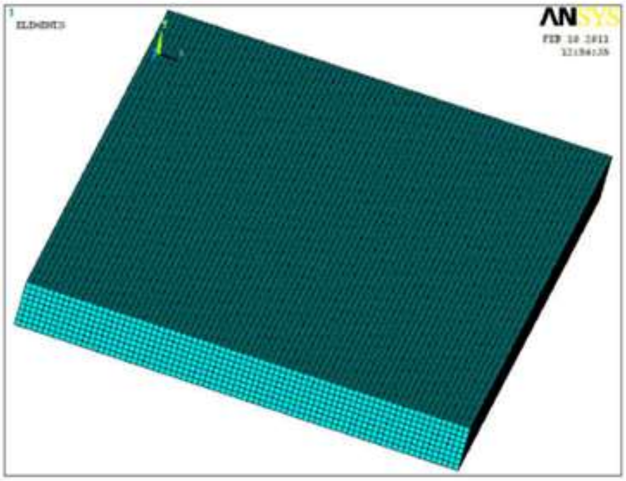


Fig. 4: Meshed FEM model of horizontal weld plate

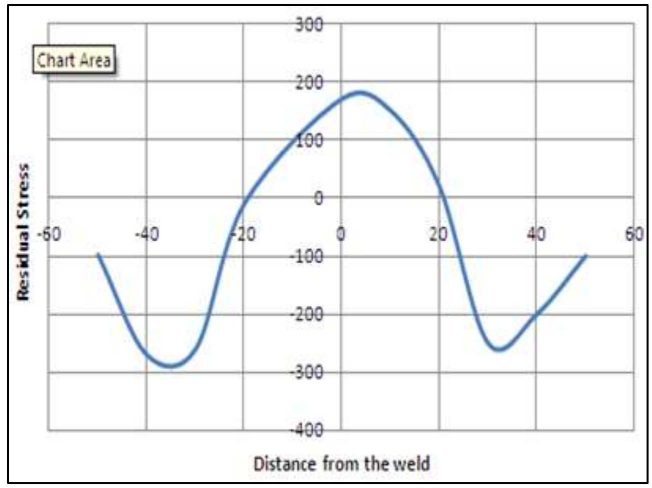


Fig. 5: Residual Stress Vs Weld Distances

## V. CONCLUSION

The present work deals with the prediction of residual stress using the contour method in conjunction with the finite element method. This method proves to be very effective in quantifying the weld induced residual stresses, so that attempts can be made to reduce the residual stresses to a safer level. It does not require any expensive facility like x-ray diffraction, neutron diffraction etc. the material used in the study is DSS 2205 which is characterized by high coefficient of thermal expansion which necessitates to study in depth to predict the stress levels so as to take subsequent actions to avoid failure in service . Further study is to be taken to effectively use the finite element tool to get better estimation of the residual stresses.

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