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# EFFECT OF WELDING SEQUENCES ON RESIDUAL STRESS IN SINGLE PASS BUTT WELDING OF SAE 1020 STEEL

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## ABSTRACT

*Accurately predicting welding residual stresses and developing an available welding sequence for a weld system are pertinent tasks since welding residual stress is inevitably produced in a welded structure.*

*This study analyzes the thermo mechanical behavior and evaluates the residual stresses with various types of welding sequence in single-pass, multi-pass butt-welded plates and circular patch welds. This is achieved by performing thermal elasto-plastic analysis using finite element techniques. Furthermore, this investigation provides an available welding sequence to enhance the fabrication process of welded structures.*

***Keywords*: Butt-weld, Residual stresses, Welding sequences, weldments.**

## I. INTRODUCTION

Welding is widely used in automotive industries to assemble various products. It is well known that the welding process relies on an intensely localized heat input, which tends to generate undesired residual stresses and deformations in welded structures, especially in the case of thin plates. Therefore, estimating the magnitude of welding deformations and characterizing the effects of the welding conditions are deemed necessary. With modern computing facilities, the finite element (FE) technique has become an effective method for prediction and assessment of welding residual stress and distortions. [1]

In large steel fabrication industries such as shipbuilding, marine structures, aero-space industry, high speed train guide ways and pressure vessels and piping in chemical and petrochemical industry the problem of residual stresses and overall distortion has been and continue to be a major issue. [2] However, residual stresses can occur near the weld bead due to localized heating by the welding process and subsequent rapid cooling. High residual stresses in regions near the weld may promote brittle fractures, fatigue, or stress corrosion cracking. Meanwhile, residual stresses in the base plate may reduce the buckling strength of the structure members. Therefore, welding residual stresses must be minimized to control them according to the respective requirements. Previous investigators have developed several methods, including heat treatment, hammering, preheating, vibration stress relieving, and weld sequencing to reduce the residual stresses attributed to welding [3]. In these methods, to choose an available welding sequence is more simple and efficient for reduction welding residual stresses. Because many welded structures which cannot be post-weld manufacturing measures after welding contain residual stresses of varying degree [4].

When welding a long butt-welded joint various types of welding sequences are used in order to reduce residual stress and distortion. The selection of a proper welding sequence is an important practical problem. However, accurately predicting the residual stresses of welding sequences is extremely difficult because the thermal and mechanical behaviors in welding include a local high temperature, temperature dependence of material properties, and a moving heat source. Therefore, this investigation performs a thermal elasto-plastic analysis using finite element techniques to analyze the thermo mechanical behaviour and evaluate the residual stresses with various types of welding sequence in single-pass butt-welded plates. Furthermore, this study provides an available welding sequence to improve the fabrication process of welded structures.

## II. LITERATURE REVIEW

Pertaining to the above problem a detailed literature survey is carried out, the details of the same are presented below.

S. Ziaee et. al, (2008) The effect of layered, block and cascade welding sequences on the thermo-mechanical response of shell weldments is studied by use of a 3-D thermo-viscoplastic model. An Anand model is used to simulate the rate dependent plastic deformation of welded materials. At the same time, modeling of the welded region in the present study has been done on the basis of the "isothermal melting pool" approach. The temperature dependency of the thermal and mechanical properties of materials is considered in the analysis and the effect of the welding speed and welding lag, and the inter-pass temperature is introduced into the model as well.

Tso Liang et. al, (2003), this study analyzes the thermo mechanical behavior and evaluates the residual stresses with various types of welding sequence in single-pass, multi-pass butt-welded plates and circular patch welds. This is achieved by performing thermal elasto-plastic analysis using finite element techniques. Furthermore, this investigation provides an available welding sequence to enhance the fabrication process of welded structures.

Dragi Stamenković et. al, (2009), manual Metal Arc Welding of carbon steel plates was studied. The finite element analysis of residual stresses in butt welding of two similar plates is performed with the ANSYS software. This analysis includes a finite element model for the thermal and mechanical welding simulation. It also includes a moving heat source, material deposit, temperature dependant material properties, metal plasticity and elasticity, transient heat transfer and mechanical analysis. The welding simulation was considered as a sequential coupled thermo-mechanical analysis and the element birth and death technique was employed for the simulation of filler metal deposition.

Gurbindar Singh Brar, (2013), welding is one of the most reliable and efficient permanent metal joining processes in the industry. When two plates are joined by welding, a very complex thermal cycle is applied to the weldment. Thermal energy applied results in irreversible elastic-plastic deformation and consequently gives rise to the residual stresses in and around fusion zone and heat affected zone (HAZ). Thus Finite element analysis was performed to understand the complete nature of residual stresses in manual metal arc welded joint of AISI 304 stainless steel plate. Variation of residual stress in the plates in the heat affected zone was also being studied.

Awang M, (2002), the arc welding process is simulated using Finite Element Method (FEM) program ANSYS®. The simulations were carried out using a two-step process; non-linear heat transfer that produces the dynamic temperature distribution throughout the weld seam and the plates, and the elasto-plastic analysis, which yields residual stresses, strains, and displacement. The "birth and death" element feature was used in the finite element model to simulate the welding process. The responses along several longitudinal cross sections were obtained after the plate cooled down to room temperature. The results show that all parameters, except for the gap between the plates have a significant effect on the responses.

Reenal Ritesh Chand et. al, (2014), in this study, the three-dimensional) moving distributed heat source model based on Goldak's double-ellipsoid heat flux distribution is implemented in Finite Element (FE) simulation for the GMA welding process. The thermal elastic–plastic analysis using FEM (Finite Element methods) has been carried out to analyze the thermo-mechanical behaviors and evaluate the residual stresses and welding deflection for butt joint plate, while assigning restrains (clamped) at the different position on the plate. Four different cases of simulation are being carried out; in each case that the plate is clamped at different positions. The temperature distributions, fusion and heat affected zones as well as residual stress and deflection for different cases is obtained and compared.

## III. ANALYSIS MODEL

### 3.1. Thermomechanical model :

Welding residual stress distributions are calculated by a finite element method.

#### 3.1.1 Thermal model

In the thermal analysis, a total of 160 load steps increase from 0.001 to 10 s were required to complete the heating cycle. Only 30 load steps increment were typically required for the weldment to return its initial (room) temperature. The time increments were automatically

optimized for each time step by the computer program. The modified Newton–Raphson method was used in each time step for the heat balance iteration. This study simulates weld thermal cycles for SAE 1020 steel are shown in Fig. 1. The convective heat coefficients on the surfaces were estimated (using engineering formulae for natural convection) to be 15 W/m2 K.

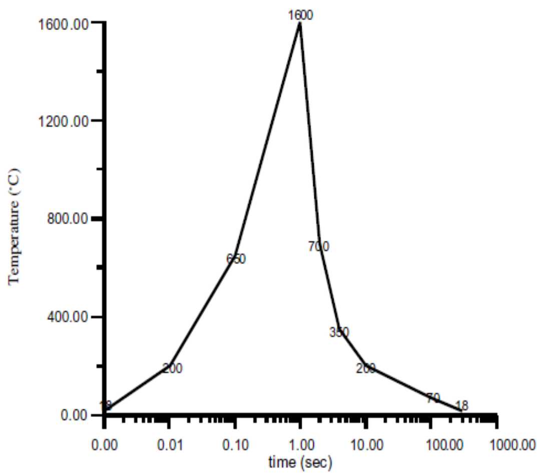


**Fig. 1 Simulated weld thermal cycles for SAE 1020 steel.**

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**3.1.2. Mechanical model :**

In the mechanical analysis, the temperature history obtained from the thermal analysis was input as a thermal loading into the structural model. The thermal strains and stresses can be calculated at each time increment. Also, the final state of residual stresses will be accumulated by the thermal strains and stresses. During each weld pass, thermal stresses are calculated from the temperature distributions determined by the thermal model. The residual stresses from each temperature increment are added to the nodal point location to determine the updated behavior of the model before the next temperature increment. The material was assumed to follow the von Mises yield criterion and the associated flow rules. Phase transformation effects were not considered in the current analysis due to lack of material information, especially at high temperatures, such as the near-melting state.

## IV. ANALYSIS OF THE SINGLE-PASS BUTT WELD.

### 4.1. Specimen and material properties

Fig.2. illustrates two thin-wall plate sections that are joined by a single-pass butt-weld. The length, the width and thickness of the plate are assumed to be 200, 100 and 5 mm, respectively. The plate material is SAE 1020, and the mechanical properties (Fig. 3) are dependent on the temperature history indicates, mechanical properties of metals change under various conditions when temperature increases, the modulus of elasticity, yield stress and thermal conductivity decrease while the thermal expansion, specific heat and Poisson ratio increase. Furthermore, the width of weld zone was assumed as that of the heat source. Autogeneous weldment was assumed. These means that weld metal, HAZ, and base metal share the same mechanical properties.

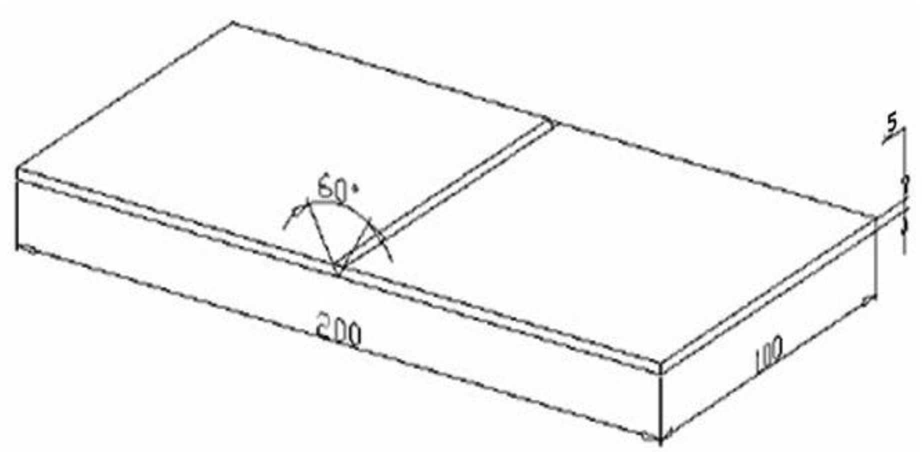


**Fig.2. Geometry of single pass butt weld specimen.**

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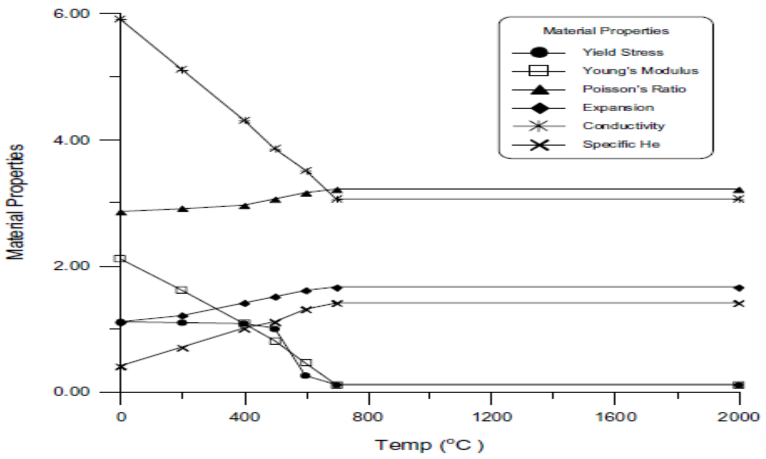


| Symbol | Material Properties | Unit |
|---|---|---|
| ● --$\sigma_y$ | Yield Stress | $\times 10^{8}$ $Pa$ |
| □---E | Young's Modulus | $\times 10^{11}$ $Pa$ |
| ▲---$\upsilon$ | Poisson's Ratio | $\times 10^{-1}$ |
| ◆---$\alpha$ | Expansion | $\times 10^{-5}$ $m/m-K$ |
| ✳---k | Conductivity | $\times 10\, W/\ K, m^2$ |
| ✕ ---c | Specific Heat | $\times 10^{2}$ $J/K, Kg$ |

**Fig. 3. The mechanical properties of weldments.**

**4.1.2. Welding conditions :**

The welding parameters chosen for this analysis were as follows: welding method, gas tungsten-arc welding; welding current, I ¼ 110 A; welding voltage, V ¼ 2 0 V; and welding speed, v ¼ 5 mm/s, respectively. The heat sources are applied along the weld path for practical welds.

**4.1.3. A finite element model for the single-pass butt welding :**

This work develops a two-dimensional symmetrical plane stress model to estimate the residual stresses of the single-pass butt-weld using the finite element method. The model employs two-dimensional four-node plane elements, including the finite element meshes for the butt-welded joint. Fig.4. is a Finite element meshes for the butt-weld, along with the refined meshes used in the weld area.[5].

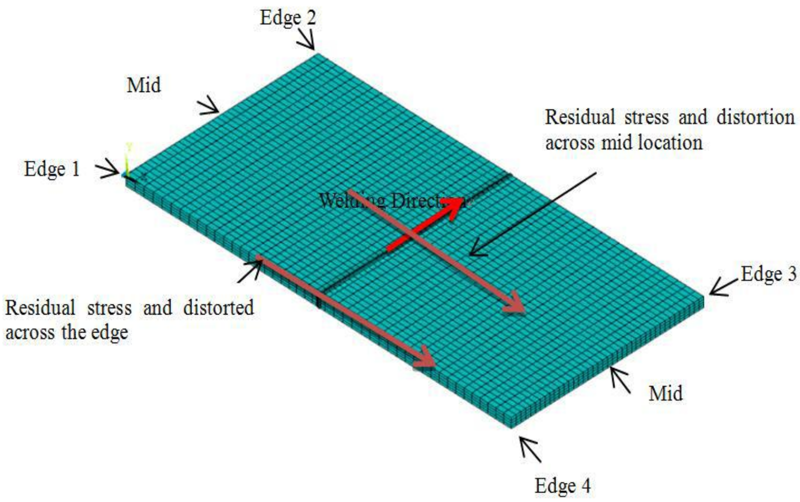


**Fig.4 Finite element meshes for the butt-weld, along with the refined meshes used in the weld area.**

### 4.1.4. Mesh sensitivity study :

To examine the adequacy of element sizes, the effect of mesh refinement in the weld area was studied. The new model with refine meshes consists of 600 elements and 671 nodes. Results from two mesh densities with the same material model and geometry.

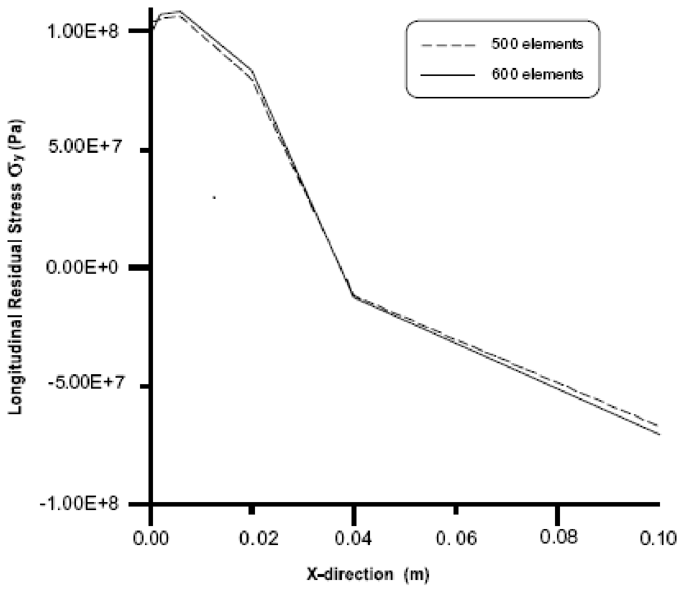


**Fig.5 Distributions of the longitudinal residual stress rY along the X-direction and Y –direction**

Fig. 5 and display the distributions of the longitudinal residual stress rY along the X-direction (at Y ¼ 150 mm) and Y -direction with 500 and 600 finite elements mesh model. Very litter difference in the results between these two different mesh models was found. It appears that the main characteristics of the residual stress results from the different meshes are almost the same. Therefore, the original FEM model without mesh refinement in the weld joint can be worked for this study.

## V. RESULTS AND DISCUSSION

### 5.1 Single-pass butt-weld.

#### 5.1.1. Longitudinal residual stresses

A stress acting parallel to the direction of the weld bead is termed a longitudinal residual stress, as denoted by the letter Y .

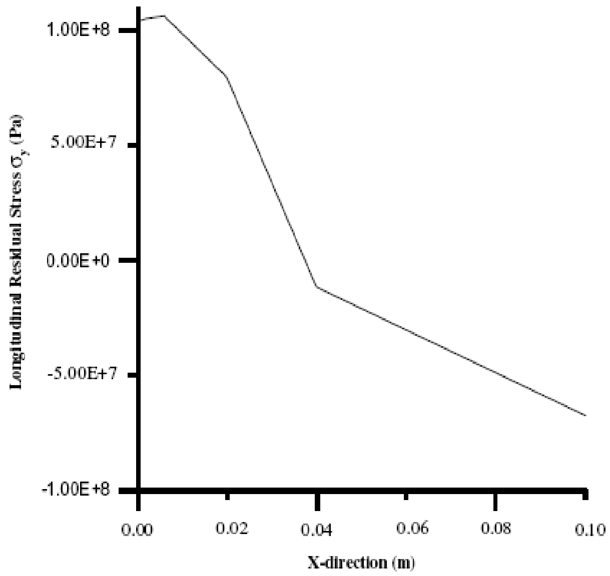


**Fig.6. Distributions of the residual stress σY along the X-direction**

Fig.6 illustrates the distributions of the residual stress σY along the X-direction (at Y ¼ 150 mm). High tensile stresses arise in regions near the weld due to a resistance contraction of the material as cooling commences. Compressive stresses occur in regions removed from the weld for self-equilibriating purposes. The maximum stress value is as high as the material yield stress. Although residual stresses caused by welding are three-dimensional, the longitudinal component of residual stresses is considered to have the greatest influence on the strength of stiffened plates in ship hulls. Since the load is predominantly applied in a longitudinal direction due to bending of the hull girder, these residual stresses may result in early yielding of some regions of the longitudinally stiffened plates and consequently cause a reduction in the effective cross-sectional area and moment of inertia leading to the possibility of premature failure.

**5.1.2. Transverse residual stresses**

A stress acting vertical to the direction of the weld bead is known as an transverse residual stress, denoted by the letter σX . Fig. 7. represents the distributions of the residual stress rX along the Y -direction. As this figure reveal, the stress distributions are symmetrical at the middle of the plate, while the tensile stresses occur at the at the end of the weld.[6].

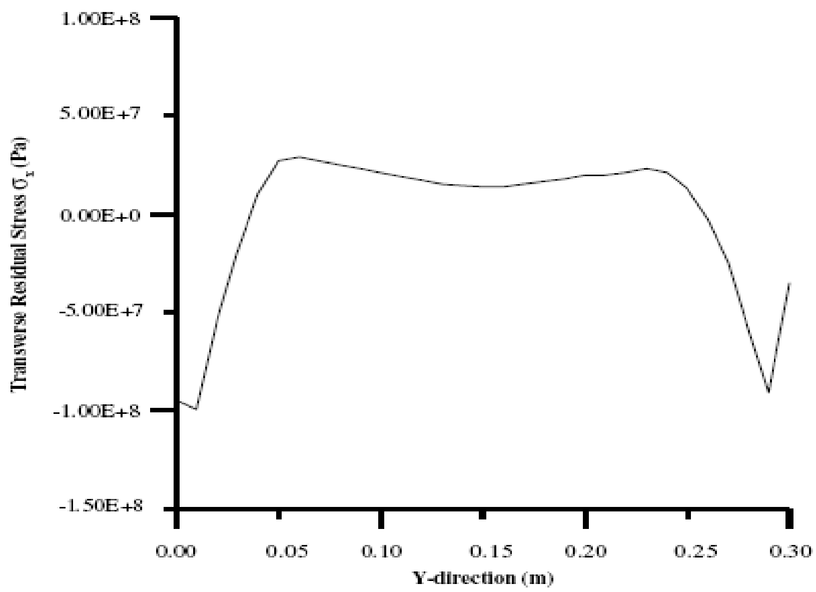


**Fig.7. Represents the distributions of the residual stress σX along the Y -direction.**

**5.1.3 Effect of welding sequences for the single-pass butt weld :**

Reducing the residual stresses in weld structures during an early stage of design and fabrication is of priority concern. For this reason, the effects of welding sequence on the residual stresses are characterized in the following. This research investigates the effect of progressive welding, back step welding and symmetric welding on residual stresses for a thin-wall butt-weld as revealed in following figure.

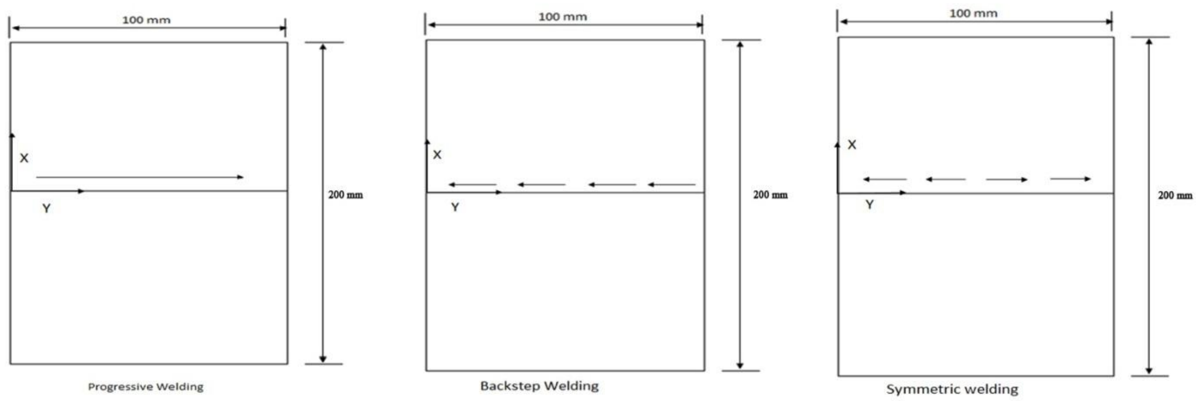


**Fig.6. The different welding sequence for butt welds.(Progressive , Back-step and Symmetric Welding**

## VI. SUMMARY AND CONCLUSION:

The finite element method is employed herein to evaluate residual stresses in single-pass butt welds as well as to discuss how welding sequences affect residual stresses.

An extremely large tensile stress occurs near the weld bead and a compressive stress appears away from the weld bead in longitudinal residual stresses along the X-direction for single-pass and multi-pass butt-welds.

The residual stresses are almost uniformly distributed along the welding direction in longitudinal residual stresses along the Y -direction for single-pass butt-welds, except those near the two ends of the weld.

A tensile residual stress is produced at the center region of the plates, and then suddenly becomes compressive near the two ends of the weld in transverse residual stresses along the Y -direction for single-pass butt welds.

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