Modeling and simulation of welded joints of SS304H & P91 Steels: A Review

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Abstract. Most of the structures are fabricated by welded joints in various manufacturing units because of low cost and high strength. Welding process is largely used in almost all manufacturing units. Welded joints usually subject to welding deformation patterns. Welding deformation may lead to low dimensional accuracy, shape and aesthetics of the product, strength of the welded joint. Welding of two different materials having different mechanical properties is called dissimilar welding. Dissimilar welded joints are commonly used in power plants to connect martensitic steel components and austenitic stainless steel piping systems. Our approach involves conducting dissimilar welding on P91 and SS304H steels, and subsequently assessing the properties of the welded joints using simulation software. A 3-D thermal elastic plastic finite element computational process is designed to accurately forecast welding deformation by numerical method. Numerical and experimental outcomes were compared in terms of temperature distributions during welding and in terms of distortion. P91 is a chromium-molybdenum alloy known for its remarkable strength and exceptional resistance to high temperatures. Alloy SS304H represents an adaptation of the chromium-nickel austenitic stainless steel. This variant, Grade 304H stainless steel, offers enhanced heat-resistant properties, increased tensile yield strength, and improved short- and long-term creep strength.

Keywords: Dissimilar Welding, Numerical Simualtion, Modeling, Finite element analysis

1 Introduction

To assess fatigue life improvement by the UIT treatment, it is necessary to accurately estimate residual stress distribution through finite element analysis (FEA). Recent numerical studies emphasized on the influence of mesh type, material properties, boundary conditions, pin tool size, modeling strategy and material hardening rules on computed numerical results [1]. Due to the irregular expansion and contraction of the weld and surrounding base material brought

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on by the heating and cooling cycle during the welding process, welded structures become distorted. The exterior appearance, varied strengths, and precision of assembly of the welded structures are all negatively impacted by welding distortion. Straightening welding distortion frequently results in extra expenses and scheduling delays. As a result, welding deformation prediction and control are now vitally important [3]. Due welded structures have excellent connectivity and great production efficiency, they are frequently utilized in pressure vessels, automobiles, maritime constructions, and other sectors [4]. Evaluating residual stresses in welded joints involving different materials is more challenging compared to similar materials because of differences in their properties. Over the past two decades, researchers have focused on using the Finite Element Method (FEM) to estimate welding residual stresses in both similar and dissimilar welded joints [5]. In an experiment, Deng and Murakawa (2006) used thermocouples to record the temperature distribution in butt-welded pipe joints. They then compared these results with numerical calculations using the finite element method. Their study showed that as the welding flame moves around the pipe, the temperature distribution near the heat source remains relatively stable [6 Assessing residual stresses in welded joints between different materials (dissimilar joints) is more challenging than in joints between similar materials (similar joints) because of differences in their physical and mechanical properties. Over the last two decades, extensive research has focused on using the finite element method to measure welding residual stresses in both types of joints [7]. Assessing residual stresses in welded joints between different materials (dissimilar joints) is more challenging than in joints between similar materials (similar joints) because of differences in their physical and mechanical properties. Over the last two decades, extensive research has focused on using the finite element method to measure welding residual stresses in both types of joints. There are FE models in the literature for simulating the welding process in both butt and T-joints, still utilizing the element birth and death technique [8]. In this study, inherent deformations for various welding joints that are extracted from a large welded structure are computed using the thermo-elastic-plastic finite element method. The suggested elastic FEM is used to forecast welding distortion of the big welded model based on the acquired inherent deformation. In the meantime, research is being done on how the initial gap affects the ultimate welding distortion. Lastly, the experiments are also run in order to confirm the outcomes of the simulations. It is confirmed that the suggested elastic finite element approach is successful by comparing the results with the experimental findings.

2 Dissimilar Welding

Dissimilar welding is the process of joining two different materials or alloys through welding. The process of dissimilar metal welding allows for the product's flexible design by making reasonable use of each material's unique features and employing each one efficiently. Because of its affordability and design flexibility, it is widely used in oil refineries, the chemical and petrochemical industries, power plants (nuclear power plants), aerospace, onshore and offshore, and other engineering applications [9]. a number of inspection-related issues and the prevalence of inaccessible deepwater working environments, subsea applications demand extremely dependable equipment. In order to ensure the equipment's long-term integrity, the production process and materials should be durable [10]. a number of inspection-related issues and the prevalence of inaccessible deepwater working environments, subsea applications demand extremely dependable equipment. In order to ensure the equipment's long-term integrity, the production process and materials should be durable [11]. The main aim of our review is to replace nickel-based alloys with austenitic stainless steels in the applications of nuclear power plants, thermal power plants, etc. Ni-based alloys are employed in power plants for high-temperature applications since they have exceptional creep strength at 700 C.

Below 650 C, high Cr martensitic heat-resistant steels are employed to save on material costs. Advanced ultra supercritical (A-USC) thermal power facilities typically use a combination of nickel alloys and martensitic steels. Because of their superior creep strength compared to ferritic and austenitic steels, nickel alloys are a better choice for high-temperature boiler components and gas turbine applications [12]. Ni-based alloys are used in power plants for high-temperature applications as they possess high creep strength at 700 C.

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3 Review on Different Simulation Methods

The following section provide a complete overview of different simulations approaches followed to forecast residual stresses, temperature distribution, and distortion in welded joints.

3.1 Abacus Code in FEM

Based on Abacus code, to compute the welding deformations of fillet-welded joints, a finite element computational approach for thermal elastic plastic has been developed. Because the mechanical work performed during welding is small in comparison to the thermal energy from the welding heat source, the thermo-mechanical behavior is simulated using an uncoupled formulation. To get temperature histories, the heat conduction problem is addressed separately from the stress–strain problem. Nonetheless, the formulation takes into account temperature-dependent thermo-physical and mechanical features as well as the contributions made by the transient temperature field through thermal expansion to the stress–strain analysis. There are two steps in the solution process. The heat conduction analysis is used in the first phase to compute the temperature distribution and its history. The temperature history is used as a thermal load in the ensuing mechanical analysis in the second step [17]. Metal is melted during the welding process, and once it cools and solidifies, beads are formed in the weld zone that joins the two sections of the steel pipes. The welding process is, in theory, a linked thermo-mechanical process that combines a mechanical analysis that makes use of the temperature history gleaned from the thermal analysis with a thermal analysis that determines the temperature and phase evolution as functions of time. While the stress field has little effect on the thermal field, the thermal field has a substantial influence on the residual stress field.

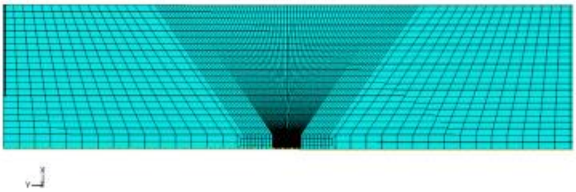

Fig. 1. Finite element Meshing of Dissimmilar Welded Joint

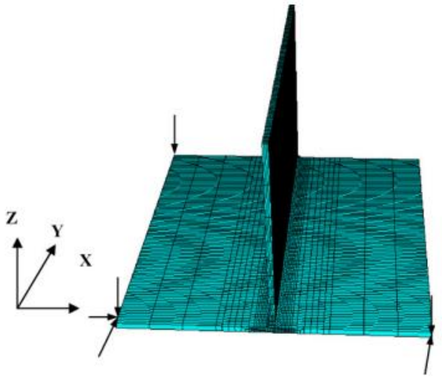

Fig. 2. Simulation Model and Mesh Deviation

As a result, general-purpose FE software code ABAQUS is used to perform a sequential coupling FEM analysis in order to determine the welding temperature and residual stress. There are two steps in the solution process. First, using the specified welding settings and thermal boundary conditions, the temperature histories of each node in the finite element model are calculated. To obtain the temperature histories, the heat conduction problem is solved separately from the stress-strain problem. Second, the mechanical analysis uses the temperature histories from the first step as the thermal loading to determine how the stress evolves [18]. A coupled following thermal stress calculation software is studied to simulate the welding residual stress using ABAQUS 6.5. In the first step of the calculation procedure, the thermal analysis is done. The calculation results files for each node temperature field will be as a mechanical study of a predefined field. analysis, the same unit and node are used in force analysis and thermal analysis. Every temperature point from the predetermined games is read, and interpolation is computed [19]. A thermal finite element computational approach was created based on the use of ABAQUS software to calculate the welding temperature fields during the process of welding three butt-welded connections in one pass. Heat transfer analysis has been used to solve the heat conduction problem and get temperature histories.

Temperature-dependent thermo-physical characteristics and the contributions of the transient temperature field are taken into account in the formulation [20].

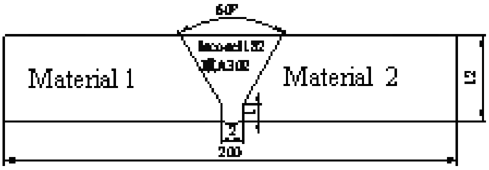

Fig. 3. Geometric model of the welding joint

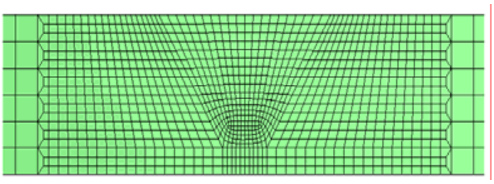

Fig. 4 Meshing of the welding joint

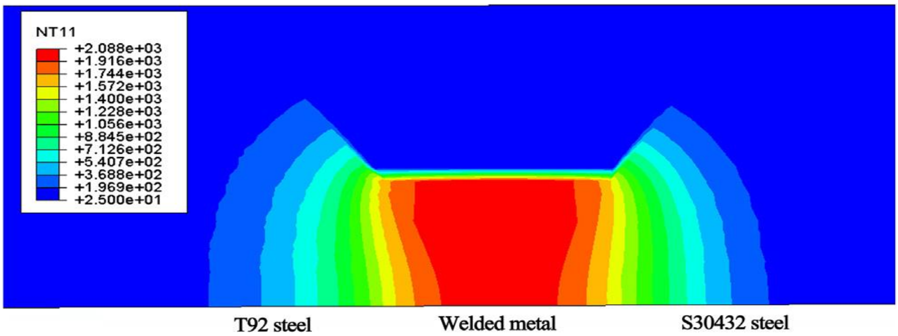

Fig. 5 Temperature contour of the dissimilar welded joint

3.2 FEA using uncoupled technique

The welding process was numerically replicated using FEM thermal stress analysis.
The numerical thermal-mechanical analyses were carried out using an uncoupled technique that comprised of two successive analyses: the first was used to compute the stress-strain fields using the previously computed temperature field as input data, and the second was used to predict the transient temperature field independently. Because it enables the decrease of the computational effort required by a coupled temperature-displacement technique, this is a standard procedure for these kinds of simulations [21].

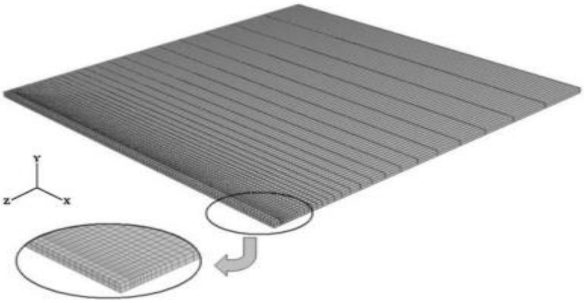

Fig. 6: 3D Model and Meshing in Welding Simulation

3.3 FEA using Marc & Simufact Software

Marc and Simufact welding software, which uses Marc code, have performed the FEM pre-processing, calculations, and post-processing. The DMW mock-up's welding temperature field and residual stress are analyzed using a thermo-elastic-plastic-metallurgic finite element computational process. Using a linked formulation, the thermo-mechanical and metallurgical behavior is computed. Slightly simplified geometries are used for the 3D simulations. Due to the high expenses of computing time and computer resources compared to the case of welding simulation for the whole length plate, the welded plate in the cladding scenario was 200 mm long rather than 780 mm. Nine beads are separated by one cladding layer along the 40 mm thickness of the plate. There were four levels of cladding. A 200 mm weld plate length is considered in the welding process, and a total of 39 simulated passes are made, Because the interpass cooling temperature has a significant role in the final residual stress distribution, cooling time is taken into consideration between the layers' welding, approximately 5 m. The first cladding layer's intersection temperature was 250°C, but the temperatures of the subsequent cladding layers and the butt-weld layer were all below 100°C[22].

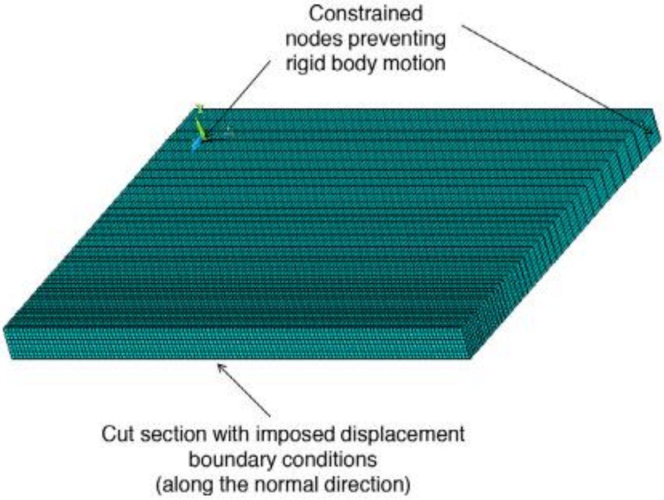

Fig. 7: Mesh and Boundary Conditions of Finite element Model

4 Conclusion

The Following Conclusions are reached from the review of Modelling and Simulation of Welded Joints of SS304H & P91 Steels;

Abaqus as an FEA software for finite element analysis models complicated thermomechanical interactions that exist in the welding process. Abaqus incorporates advanced material models, including non-linear material behaviour, phase transformations, and residual stress prediction, crucial for capturing the intricacies of heat-affected zones and weld bead formation.

The Uncoupled approach allows for separate consideration of the thermal and mechanical analysis, which will increase computational performance and flexibility. Without the computational burden of solving simultaneous thermal stress equations, decoupling these analyses makes it easy to simulate transient heat transfer during the welding process. In order to improve solution accuracy and reduce computational costs, this separation facilitates the optimization of mesh density and time steps for each analysis stage.

Marc and Simufact software excel in finite element analysis (FEA) for welding simulation due to their advanced capabilities in modeling complex material behaviors, efficient parallel processing, sophisticated contact algorithms, specialized modules for various welding processes, user-friendly interfaces, and extensive material databases. These features enable engineers to achieve precise and efficient welding simulations, making Marc and Simufact preferred choices in the field.

The experimental data and the simulated results show that Welding deformation can be accurately predicted using the thermal elastic plastic finite element model. The place where more welding temperature is applied the more heat flux is generated near the welding area. The circular temperature contours surrounding the heat source indicate that the heat source is moving effectively. The aim is to reduce the total heat flux near the welded area due to increase in heat flux leads to increase in residual stressed in the material. Relative stress is significantly influenced by the groove angle. The residual stress distribution across the dissimilar welded joint does not significantly alter when the groove angle decreases. The tensile axial and hoop residual stress on the dissimilar welded joint decrease with an increase in the number of welding layers.

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