

OPTIMIZATION STUDY ON WELD-INDUCED DISTORTION USING OPEN-SOURCE FEA Z88 SOFTWARE

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ABSTRACT

Distortion is a significant defect that can occur during the welding process. This study aims to compare the accuracy of distortion results obtained through Finite Element Analysis (FEA) using open-source software with classical calculations. The purpose is to evaluate the capability of the open-source software, specifically Z88 Aurora, in performing FEA on welded parts. A simulation focusing on Gas Metal Arc Welding (GMAW) and T-joint welding, commonly used in the construction sector and shipbuilding structures, has been selected. The finite element method is utilized to predict the distortion caused by welding, and numerical computations are conducted with appropriate parameters such as boundary conditions and welding temperature. The Z88 Aurora software is employed for the finite element analysis. Before obtaining results, several steps are involved in the computational analysis. These steps include creating the design, importing it into Z88 Aurora, performing pre-processing tasks, and conducting post-processing operations. A proper definition of boundary conditions, material selection, and parameter setting is crucial for achieving desired results. ASTM A572 is the material used in the simulation, with a steel plate thickness of 6mm. The obtained computational results will be compared to the classical method to assess their acceptability. The expected outcome of this study is to determine the compatibility and capability of Z88 Aurora software in simulating and analysing welding-induced distortion.

Keywords: Distortion; Finite Element Analysis; Welding; Z88 Aurora Software

1.0 INTRODUCTION

Welding deformation is a vast problem in the welding process. By using simulation, this problem can be prevented in the early stage of the welding process. The gas metal arc welding (GMAW) technology is used in the construction of ships due to its adaptability, rapidity, and relative simplicity of robotic automation adaptation. Extremely high temperatures and subsequent shrinkage during the complicated welding procedure result in significant deformation and residual stresses. It has been shown that manufacturing distortions significantly impact the load-carrying capacity of plating, particularly for plates exposed to strains above their buckling strength [1]. Peric et al. state that residual stress appears around the heat-affected zone due to the localized heating and rapid cooling, resulting in welding deformations in the structure [2]. Predicting the structure's deformation is one of the most critical difficulties in welding. The weld designer's experimentation often resolves this issue [3].

Distortion occurs when the heated weld zone shrinks unevenly, causing shrinkage in one area of the weld. It can be concluded that it occurs due to local non-uniform heating and cooling cycles during the welding joining process. "distortion" refers to the permanent alterations on the bonded plate during the welding process [4]. The deformation issues can reduce the structure's strength in and around the welded joint. It has become a massive concern for the shipbuilding industry and other similar production businesses that rely heavily on welding for massive sections [5], [6]. Distortion makes the linked part susceptible to fracture, buckling, and fatigue and increases corrosion. Distortion can also be a concern during fabrication, resulting in dimensional inaccuracies and structural member misalignment. If the tolerance limits are exceeded, corrective actions or repairs are required. On the other hand, an accurate prediction tool is needed to analyse possible deformation and residual stress that may arise during production [7].

In the last year, rapid computer technology progressed in many numerical simulation and application advancements to anticipate residual strains and welding distortion at an early stage of the process [8]. Various types of simulation software, such as SYSWELD, ABAQUS, NASTRAN, and others, have been created and confirmed to be capable of simulating the welding process. Ramos et al. used SYSWELD to model various types of welds in T-joint configurations and concluded that the computational coupled analysis of the welding process, capable of determining distortion and detailed residual stress field, is made possible by the current state-of-the-art simulation tools for the welding process [9]. Welding simulation allows for resolving welding distortion issues while eliminating costly and time-consuming testing.

Chen et al. previous study compares numerical and experimental investigations on a long-stiffened steel plate specimen. For the experiment and simulation, the researcher used plates ranging in thickness from 6mm to 9mm and different lengths of the long scale, the 'F5' labeled series refers to 500mm long, and the 'F7' series refers to 700mm. Each specimen has different welding parameters, as shown in Table 1 below. The simulation was carried out using the ANSYS software. Good agreement between measured and simulated temperatures was obtained, indicating that the current finite element technique is acceptable for simulating the welding process. The proposed reduced material model is suitable for finite element analysis of welded steel structures.

Furthermore, the welding parameters influence the structural reactions more than the plate dimension [10]. From other studies, Chen et al. also develops a novel efficient analytical modelling for the welding process simulation. In conclusion, the numerical technique utilized in the study might be a helpful tool for refining welding operations on stiffened panels. Future studies include experimental validation and comparison with modelling findings for welding distortion and residual stress [11].

Table 1: Welding conditions and speeds are listed below (average).

No.	Specimen	Current, <i>A</i>	Voltage, <i>V</i>	Speed, <i>mm/s</i>
1	F556536	185	25	4.7
2	F559539	195	24	5.0
3	F756736	184	30	2.5
4	F759739	185	25	4.0

Fu et al. investigated welding-induced residual stress and deformation using experimental tests and numerical simulations under various material models. The study aims to explore the influence of the material model on residual stress and Distortion in T-joint welds, a sequentially linked thermo-mechanical finite element model with high-temperature effects, temperature-dependent material properties, and a moving volumetric heat source. The simulation results were validated with the experimental test results [12].

In the previous study, Seles et al. presented an efficient finite element procedure for predicting welding-induced residual stresses and distortions in large structures based on the approach using some Abaqus software features, Abaqus Welding Interface, which improves computational efficiency and speeds up the welding simulation analysis. Validation was accomplished by comparing experimental measurements to the heat generation rate approach results with the element birth and death technique. The proposed procedure's results agree with the heat generation rate method and experimental data [13].

Previous research conducted by Sulaiman et al. investigates the ability of linear thermal elastic numerical analysis to anticipate welding distortion brought on by the Gas Metal Arc Welding (GMAW) process. The relatively new finite element method (FEM) software developed by ESI Group and referred to as WELD PLANNER was used to model welding deformation. This cutting-edge Welding Simulation Solution was used to predict welding distortion in butt and T-joints that were 4 mm thick. Both the computational and the experimental experiments made use of low-carbon steel. Several tests were carried out to determine the level of distortion by using a completely automated welding method. When the results from the simulation and the tests were compared, it was found that this piece of computer code offered a rapid analysis time for estimating weld-induced distortion with acceptable accuracy [14].

Tian et al. analyse the thermal-mechanical behaviour of a T-welded joint during the welding process using a thermal-elastic-plastic finite element (TEP-FE) model. Experimental data have validated the established thermal-elastic-plastic finite element (TEP-FE) model. The angular distortions produced from the welding experiment and numerical modelling are in good agreement [15]. Another study found that the nonlinear finite element technique models established in the study are remarkably accurate in predicting weld-induced initial defects in steel-stiffened plate structures [16]. Zhang et al. also used thermal-elastic-plastic finite element (TEP-FE) in the study to compute a stiffened panel's welding distortion and residual stress under various mechanical boundary conditions. The results reveal that mechanical boundary conditions primarily affect welding deformation and have little effect on stiffened-panel residual stress [17]. In the previous study, Sepe et al. observed that in the case of different T-joints, the finite element model could provide a high level of accuracy in terms of temperature distributions and distortion before and after the welding operation [18]. Another researcher also developed another type of calculation procedure. The inherent strains were computed using basic mechanics concepts. Appropriate correlation equations were developed between these intrinsic stresses and nondimensionalized factors taken from considerable experimental distortion data produced in the past by different researchers. This procedure shows the capabilities to reduce the time consumption by the conventional analysis method [19].

Z88 Aurora has known as free software, but it is considered a new software that has been developed to simulate finite element analysis. In this case study, Z88 aurora is used to study the capability and accuracy of this software to simulate the welding distortion of a T-Joint structure. The result obtained from the software was then validated using analytical analysis.

2.0 PROBLEM STATEMENT

The aim of this study is to assess the likelihood of deformation and residual stresses that may occur during manufacturing processes through the utilization of the open-source software Z88 Aurora. By conducting predictive simulations, it becomes possible to anticipate and mitigate potential deformations, which, if left unaddressed, could lead to additional financial expenses. Furthermore, the study seeks to obtain Finite Element Analysis results using the open-source software Z88 Aurora and compare them with traditional analysis methods.

3.0 SIGNIFICANCE OF RESEARCH

The findings of the study will benefit society considering that simulation plays a really important role before manufacturing or producing a welded component. Using free open-source simulation software that is verified as capable of analyzing several processes is helpful to the industry and students. Other than that, it also helps and shows that free software is also capable of producing results as accurately as other software that requires subscriptions.

4.0 RESEARCH METHODOLOGY

The finite element method (FEM) is a widely recognized technique for solving engineering and mathematical differential equations computationally. The application of FEM to welding processes, which involves plastic, elastic, and thermal analyses, is a complex task that requires computational analysis and calculations. Simulation software plays a crucial role in facilitating the examination of welding processes. Z88 Aurora is a cross-platform simulation software program that can be utilized for solving diverse engineering problems, including welding processes, through numerical simulation using the finite element technique. The full dimensions of T-joint geometry as illustrated in Figure 1 accordingly.

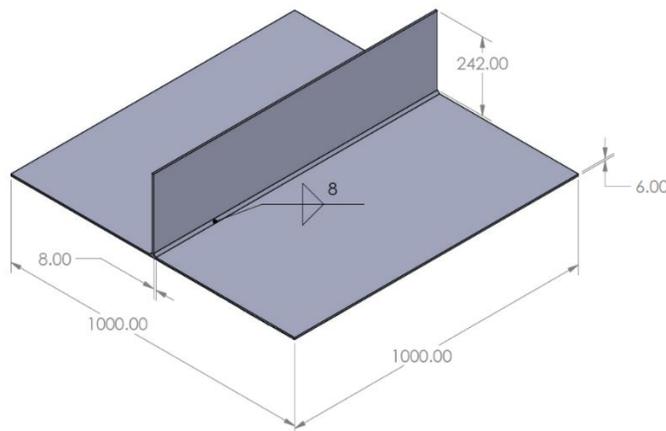


Figure 1: T-Joint welding model

4.1 Analytical Calculation Method

Both single-sided and asymmetrical double-sided welding causes angular distortion at the T-joint as shown in Figure 2. The width and depth of the fusion zone in relation to plate thickness, the joint, the order of the welding passes, the thermo-mechanical properties of the material, and the characteristic welding process parameters, such as heat input per unit length of weld and heat source density distribution, all affect how much angular shrinkage occurs [20].

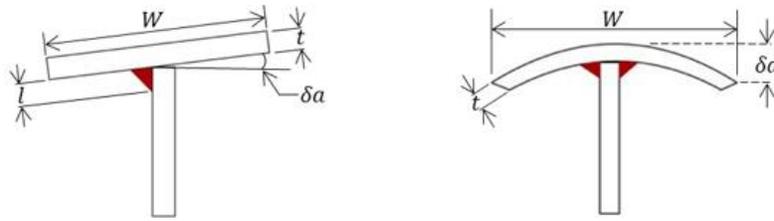


Figure 2: Angular Distortion at a T-joint with two fillets[20]

$$\delta a = \frac{0.0076 \cdot W \cdot l^{1.3}}{t^2} \quad (1)$$

Where,

- δa = Angular distortion, *mm*
- W = Width of the flange, *mm*
- t = The thickness of the plate, *mm*
- l = Size of the leg weld, *mm*

From equation 1, replacing all variables' values with $W = 1000$, $t = 6$, and $l = 8$, the value of Distortion for T-joint fillets models in Figure 2:

$$\delta a = \frac{0.0076 \cdot 1000 \cdot 8^{1.3}}{6^2}$$

$$\delta a = 3.18 \text{ mm} \quad (2)$$

4.2 Modelling and Simulation

This study utilizes SolidWorks to create the joint section, and the resulting CAD model is subsequently analysed using Z88 Aurora's static thermal analysis. The simulation process comprises three main steps: modelling, analysis, and post-processing. In the modelling phase, the model's shape, material types, and heat input are specified. Z88 Aurora then performs a thorough examination of the configured model through pure thermal analysis. The post-processing phase presents the results of the simulation analysis. Figure 3 illustrates the flow of the Z88 Aurora simulation procedure.

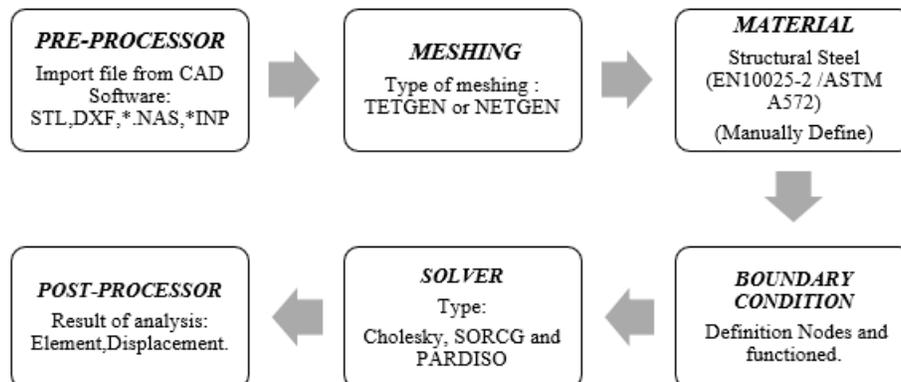


Figure 3: The flowchart for the simulation process in Z88 Aurora.

After completing the modelling process in SolidWorks, the file was exported to the STL format to ensure compatibility with Z88 Aurora Software. The STL format is native to the stereolithography CAD software developed by 3D Systems and is also referred to as Standard Triangle Language (or Standard Tessellation Language). Upon transferring the design to Z88 Aurora, the pre-processing phase begins, which involves determining the mesh, material, and boundary conditions. In this study, a netgen mesh generator is utilized to create a tetrahedral mesh with a mesh size of 20. The material of the model is defined as structural steel (S235JR), and its properties are specified in Table 2. Next, various boundary conditions are set to obtain accurate results, as detailed in Table 3. Within the calculation module of Z88 Aurora Software, different solver types are available for thermo-mechanical simulations. For this study, the PARDISO calculation module is selected. The number of equations within the system decreases due to the reduction of the Degree of Freedom (DOF) when analysing finite elements for pure thermal aspects. In the thermo-mechanical analysis conducted in Z88 Aurora, only thermal expansion and thermal conductivity properties are required. Once the thermal and mechanical boundary conditions are applied, the solver automatically executes the desired simulation. The results are then displayed and evaluated, representing the final stage of the process. The 'Post-Processor' option is utilized to obtain the required and desired outcomes. Various approaches for data interpretation, such as contour plotting on the model and tabular findings, are available.

Table 2: Material properties of the ship panel, S235JR.

Properties, Unit	Value
Young modulus, MPa	206000
Density, kg/mm	7.85E-9
Poissons ration	0.30
Heat conductivity, W/mm•K	5.00E-2
Heat expansion, 1/K	1.2E-5

Subsequently, the simulation results are displayed and evaluated, marking the final stage of the process. The 'Post-Processor' option is employed to effectively obtain the desired outcomes. Various methods for data interpretation are available, including contour plotting on the model and generating tabular findings.

5.0 RESULTS AND DISCUSSION

The workpiece is clamped on the flange and the boundary condition is applied in the simulation as shown in Figure 4. The red nodes indicate that it is fixed due to clamping on the top of the flange.

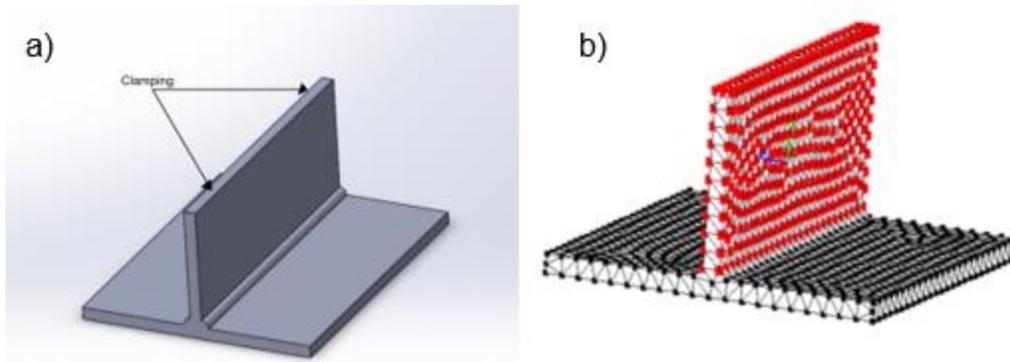


Figure 4: (a) Clamping Condition and (b) Boundary Condition for the simulation.

From Figure 4 the deformation of the part can be seen after the simulation had been run using the Z88 Aurora software. The temperature that had been applied is 1400°C, it is based on the common temperature used for GMAW welding. The T-joint simulation result has been compared with the analytical analysis result. The analytical value for the models using the fillet welds relationships has been obtained from equation 2, which was 3.18mm. Figure 5 shows that the simulation's angular distortion for the simulation was 2.77mm. The red region is the maximum value of distortions that occur. The result percentage of errors as shown in Table 3 between the simulation and analytical was 12.06%.

Table 3: Distortion result of T-joint Structure

Theoretical, mm	Simulation, mm	Percentage error, %
3.18	2.77	12.06

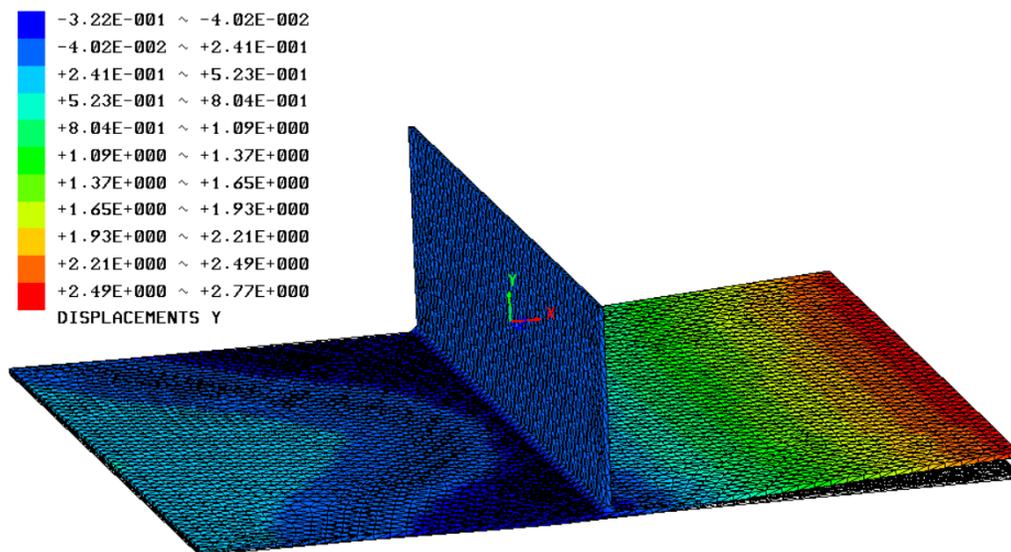


Figure 5: Distortion results of T-joint fillet welding using FEA Z88 Aurora

6.0 CONCLUSION AND RECOMMENDATION

Based on the findings of this study, it is observed that welding-induced angular distortion demonstrates a significant level of consistency. The maximum angular distortion can be computed through both analytical analysis and simulation using the open-source software Z88 Aurora. In terms of predicting and modeling distortion, the simulation analysis conducted with open-source software showcases a commendable level of competence and accuracy. Comparisons between the simulation and analytical analyses reveal a minimal percentage error, which remains well below the maximum acceptable value of 30%. Thus, it can be concluded that the open-source software is capable of determining welding distortion in large, welded structures, such as ship panels. As a recommendation, employing a smaller mesh size in the simulation could potentially enhance accuracy. Z88 Aurora utilizes thermo-mechanical calculations to forecast distortion in welded components, requiring the coefficient of thermal expansion, Young's Modulus, and Poisson's Ratio for the analysis.

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