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Residual Stress Analysis in Austenitic Stainless Steel Weldment by Finite Element Method

N. Jayakumar[1]*, S. Mohanamurugan[2], R. Rajavel[2] and J. Ashok Kumar[2]

[1]Department of Mechanical Engineering, AMET University, Chennai - 603112, Tamil Nadu, India
[2]Department of Automobile Engineering, Saveetha University, Chennai - 600072, Tamil Nadu, India

Abstract

Residual stress in weldments is one of the major concerns in manufacturing industries especially in welding. They occur, sometimes during the initial processing of metals and sometimes during rolling, forging, casting etc. In welding these stresses develop due to non uniform cooling of the welded zone. Tensile stresses are primarily responsible for crack initiation and product failure. Residual stress may also lead to premature failure of the welded joints when subjected to hazardous conditions. There are various physical methods of detection of residual stress in weldments such as x-ray diffraction and deep hole drilling. Nevertheless, numerical method is also one of the most popular methods among researchers to solve various complex engineering problems. In this work, numerical simulation is carried out by creating a 2-D model of the Austenitic stainless steel weldment with various boundary conditions using ANSYS 15.0 software and the results are studied. The details of residual stress are explained with relevance to failure occurrence.

Keywords: Finite Element Method, Residual Stress, Stainless Steel, Weldment

1. Introduction

Residual stresses are self balancing internal stresses arising from non uniform mechanical or thermal straining with some measure of plastic flow. They are mostly related with welding .The mechanical properties of materials such as creep, fatigue life etc are influenced by these residual stresses. On occasions, the effects on these properties are advantageous and other times, these effects are perilous. Hence, we need to inspect and control the residual stresses. There are two different techniques widely used to measure the residual stresses. Among them, the most common technique is a special type of XRD test which is used for measuring the stresses in fine grained crystalline materials. The other method, the hole drilling method, is employed only when the X-ray technique is not helpful.

Residual stresses are those which prevent a body from maintaining equilibrium with its environment. They may be classified by: 1. Cause (thermal or elastic mismatch). 2. The scale over which they self-equilibrate and 3. The method with which they are measured. In this endeavour, a length scale viewpoint is taken up. As shown in Figure 1, residual stresses start off from misfits between different areas. In certain cases, these misfits span over huge distances, for example, the one caused by the non-uniform plastic deformation of a bent rod. They can also arise from sharp thermal gradients, like those caused during welding or heat treatment processes. These stresses could be beneficial, as in the case of shot peening and in toughening of glass, whether they are mechanically induced or thermally induced. The macro stresses are of type 1 as they differ continuously over large spans. This is in disparity to residual stresses which differ over the grain scale or the atomic scale (type 3). In these cases, the misfitting regions span microscopic or submicroscopic dimensions. Low level type 2 stresses almost always exist in polycrystalline materials only because of the fact that the elastic and thermal properties of differently oriented neighbouring grains are different. More noteworthy grain scale stresses take place when the microstructure contains several phases or phase transformations occur. The type 3 category includes stresses due to coherency at interfaces and dislocation stress fields.

*Author for correspondence

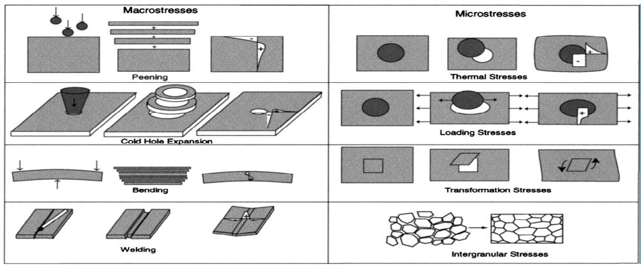

Figure 1. Various forms of residual stress.

2. Residual Stress in Weldment

Residual stress in any material arises from the day it is processed from ingot to the final form. It is generated during rolling, forging, casting etc. Residual stresses would be set up when a component is stressed beyond the elastic limit and when plastic flow occurs. In welding, it would usually be at a macro level. Uneven cooling and heating in the weldment are the major cause of residual stresses in weldment. There is a homogeneous volume change due to local heating and cooling which leads to the building up of elastic stress. To be more precise the various sources of residual stress in weldment would be due to

- Shrinkage process of the seam and HAZ.
- More rapid cooling of the surface.
- Phase transformation.
- Superimposition of residual stress owing to shrinkage, quenching and transformation.

3. Effect of Residual Stress

While it is not intended to reassess the effects of residual stress on performance in a detailed manner, it becomes necessary to consider momentarily the causes why residual stress is calculated. The performance on static loading of brittle materials may be enhanced considerably by the intelligent use of residual stress. Familiar examples are thermally toughened glass and prestressed concrete. In thermally toughed glass, rapid cooling of the glass from high temperature produces compressive surface stresses counterbalanced by tensile stresses in the core. The surface compressive stress means that the surface flaws that might cause failures at very low levels of applied stress experience in-plane compression. Whereas the core experiences counterbalancing tensile stresses, this region is mostly free from defects and so the innate strength of the glass is adequate to avert failure. Once a crack penetrates the core which is under tension, it may grow swiftly. Like glass, concrete is also brittle and hence it has got a low tensile strength. Nevertheless, concrete may be used in tension, as in cantilever beams, when it is prestressed in compression. For materials that are plastically deformable, only the residual and applied stresses can be appended together directly until the yield strength is reached. In this aspect, residual stresses can accelerate or delay the inception of plastic deformation; though, their effect on static ductile failure is often little as the misfit strains are very small and so are washed out by plasticity eventually.

Li Yajiang investigated the distribution of the residual stress in the weld joint of HQ130 grade high strength steel by employing Finite Element Method (FEM) by using ANSYS software. Welding was carried out using gas shielded arc welding with a heat input of 16 kJ/cm. The FEM analysis on the weld joint revealed that there was a stress gradient around the fusion zone of weld joint. The instantaneous residual stress on the weld surface went up to 1000 MPa and it was 600 MPa under the weld. The stress gradient near the fusion zone was higher than any other location in the adjoining area. This was endorsed as one of the important reasons for the growth of cold cracks at the fusion zone in the high strength steel[1].

Yu. V. Taran applied the investigation of diffraction spectra from austenitic stainless steel by means of a martensite phase plastically stimulated during cyclic tensile-compressive loading. The spectra were acquired during *in situ* neutron diffraction stress rig testing on the ENGIN instrument at the ISIS pulsed neutron facility, ensuing the cyclic loading. The subsequent applied stress–elastic strain reactions of the austenitic matrix and martensitic inclusions were attained by Rietveld refinement of the spectra and used to find out the elastic constants and residual stresses of the phases as a function of fatigue level. The data showed that the elastic properties of both phases are similar, which allowed the simple determination of residual stresses[2].

D. H. Bae presented a technique for fatigue strength appraisal of spot welds, which incorporated the possessions of welding residual stress. Residual stress analysis with a welding thermal record was estimated first, and then stress analysis for fatigue was carried out. Firstly, the residual stresses of spot welds were computed using a nonlinear Finite Element Analysis (FEA). To validify the FEA outcomes, the estimated residual stresses were judged against to those calculated by X-ray diffraction. The residual stress distributions illustrated good conformity between calculations and measurements. Then, to assess the fatigue strength of spot welds, stress analyses were carried out under tensile loading on various configurations and contours of spot welds[3].

4. Experimental

4.1 Finite Element Method

The Finite Element Method (FEM) has become a key and vital technology in the modeling and simulation of superior engineering systems in diverse fields like building, transportation, communications etc. In building such modern engineering systems, engineers and designers go through a sophisticated process of visualization, modeling, simulation, analysis, designing, prototyping, testing and finally fabrication. It is to be noted that much effort is involved before the fabrication of the final product or system. This is to make sure that the workability of the finished product, as well as for cost effectiveness. This progression is often iterative in nature, in the sense that some of the actions are repeated based on the results acquired at the present stage, so as to accomplish an optimal performance at the lowest cost for the system to be built. As a result, practices related to modeling and simulation in a rapid and effective way take part in an increasingly significant role, resulting in the use of the FEM being multiplied in to many folds as a result of this. The procedure of computational modeling using the FEM broadly consists of four steps:

- Geometrical Modeling.
- Meshing by discretization.
- Material property specification.
- Specification of boundary, initial and loading conditions.

4.2 Software used

ANSYS 15.0 was used for this work. ANSYS is a general-purpose Finite Element Analysis (FEA) software package. FEA is a method of deconstructing an intricate system into very tiny pieces of user-defined size called elements, numerically. The software executes equations that administer the behavior of these elements and solves them, creating a complete explanation of how the method acts as a whole. These results then could then be presented in graphical or tabulated forms. This type of analysis is used for the design and optimization of a system that is very complex to analyze manually. Systems that fit into this class are too difficult due to their geometry, scale, or governing equations.

ANSYS offers a lucrative way to investigate the performance of products or processes in a virtual atmosphere. This type of product development is known as virtual prototyping. With virtual prototyping techniques, users can iterate various scenarios to optimize products even before they are manufactured. This would make reduction in the level of risk, and in the cost of unsuccessful designs. The multifaceted nature of ANSYS also gives a means to affirm that users would be able to foresee the effect of a design on the whole behavior of the products.

5. Results and Discussions

For the analysis of residual stress in weldments of austenitic stainless steel, we can employ coupled field analysis. A coupled-field analysis is an analysis that takes into account the coupling between two or more fields of engineering. For example, a piezoelectric analysis, handles the interaction between the structural and electric fields. It solves for the voltage distribution due to applied displacements, or vice versa. Other examples of coupled-field analysis are thermal-stress analysis, thermal-electric analysis, and fluid-structure analysis. Some of the applications in which coupled-field analysis may be required are pressure vessels where thermal-stress analysis would be carried out, fluid flow constrictions where fluid-structure analysis would be carried out, induction heating where magnetic-thermal analysis would be carried out, ultrasonic transducers where piezoelectric analysis would be carried out, magnetic forming where magneto-structural analysis would be carried out and Micro-Electro Mechanical Systems (MEMS).

6. Thermal-Stress Analysis using Multiple Physics Environments

For this endeavour, two plates of austenitic stainless steel were butt welded by TIG welding technique. After the welded plates were cooled, cold cracks were observed due to the residual stress in the weldment. This residual stress in the weldment was analysed by thermal stress analysis using multiple physics environment. Table 1 shows the input parameters for the welding. Figure 2 and

Figure 3 show residual stress distribution and types of residual stress in but weld.

Figure 4 shows the boundary conditions for welding and Figure 5 shows the residual stress at a given point on the weldment. From Figure 6, it is obvious that stress concentration is more in the direction of width of the test plates.

Table 1. Input parameters

Parameters	Values
Length	100mm
Width	30mm
Thickness	4mm
Welding Temperature	1500k
Thermal conductivity	35 w/m-k
Specific Heat	800 J/kg-k
Density	7800 kg/m^3

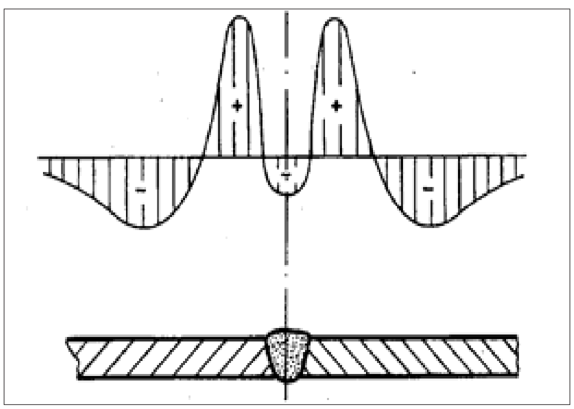

Figure 2. Residual stress distributions in butt weld.

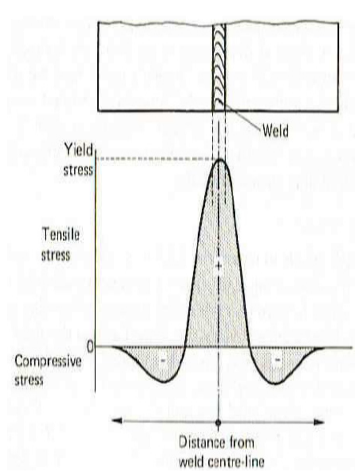

Figure 3. Types of residual stress in butt weld.

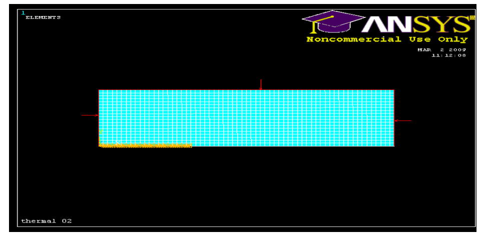

Figure 4. Boundary conditions for welding.

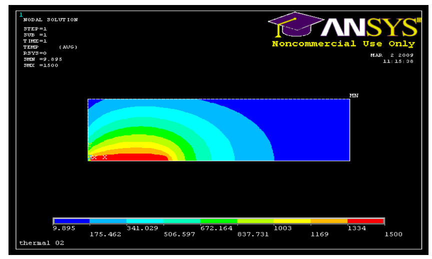

Figure 5. Residual tress at a given region.

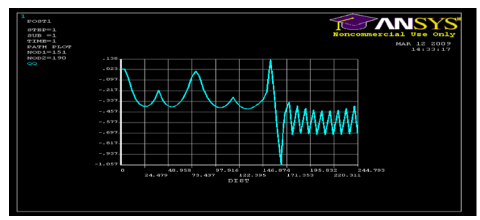

Figure 6. Stress along x-direction.

7. Conclusion

The distribution of the residual stress in the weld zone of Austentic stainless steel was found out using ANSYS finite element analysis software. It is seen that the residual stress, in the direction of the width of test plate has highest influence on the formation of cold cracks. More accurate results are to be obtained.

8. References

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