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Finite Element Analysis of a Butt Welded Joint

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Abstract: Welding-induced residual stresses and distortion can play a very important role in the reliable design of welded joints and welded structures. In fusion welding, a weldment is locally heated by the welding heat source. Due to the non-uniform temperature distribution during the thermal cycle, incompatible strains lead to thermal stresses. These incompatible strains due to dimensional changes associated with solidification of the weld mental (WM), metallurgical transformations, and plastic deformation, are the sources of residual stresses and distortion.However, the welding process itself is a very complex phenomenon, which has not been fully understood, so that the distribution and magnitude of residual stress is not readily available from the literature. It is therefore, necessary to develop a model for the welding process, which would produces not only qualitative but also quantitative information on residual stresses.In this work, a finite element simulation of the welding process yielding the welding-induced residual stresses in a butt-welded plate is presented. The model was validated by compression of its predictions with numerical simulations. Parametric studies were carried out on the validated model to assess the effects of the amount of heat input, the yield strength of the material as well as the temperature-dependence of material properties on the final residual stresses. Based on these studies, a simplified modeling procedure of reasonable accuracy was proposed

Introduction

Welding

Welding process is used extensively in the fabrication of structures and machines. However, the non-uniform heating and cooling of metal during and after welding operations cause non-uniform thermal expansion and contraction, generating plastic deformation in the weld neighborhood. This results in residual stresses and permanent distortion of the weldment during cooling which can reduce the expected life of a welded component in various modes of failure. The residual stresses transverse to the weld may lead to formation of hot cracks. High tensile residual stresses are known to promote fracture, corrosion cracking and fatigue in a welded structure. On the other hand, compressive residual stresses tend to reduce the buckling strength. Formation of residual stress in weldment can be attributed to three sources, the non uniform simultaneous heating and cooling of the part during welding, variation in shrinkage due to variable cooling rates in different regions of the weldment and the volumetric changes during metallurgical phase transformations. So, the prediction of residual stresses and distortion can make the welding process with minimum residual stress. As the thermal cycles experienced by weld have a major influence on residual stress distribution, it is of great interest to predict the thermal cycles also in a weldment.

The application of Welding process found in the automobile industry, structural work, tanks, boilers, furniture, pressure vessels, building and bridge constructions, railway wagons, aircraft machine frames, ship buildings, pipe-line fabrication in thermal power plants and refineries, etc. There is a big competition between welding and casting process nowadays. Many of the cast products are being fabricated nowadays by welding various parts together.

Finite element analysis

Finite Element Analysis (**FEA**) is a computer-based numerical technique for calculating the strength and behaviuor of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behaviour and many other phenomena. It can be used to analyze either small or large-scale deflection under loading or applied displacement. It can analyze elastic deformation, or "permanently bent out of shape" plastic deformation. The computer is required because of the astronomical number of calculations needed to analyze a large structure. The power and low cost of modern computers has made Finite Element Analysis available to many disciplines and companies.

Heat flow in welding

Heat flow Equations

During arc welding the heat source is moving, two sets of coordinates will be used, one set with x, y, z is stationary with respect to the heat source and one set with ,, y, z, which is moving with respect to the heat source.The differential equation of heat flow expressed in the stationary coordinates is

$$\delta^{2}T/\delta x^{2} + \delta^{2}T/\delta y^{2} + \delta^{2}T/\delta z^{2}) = 2\lambda(\delta T/\delta t) \qquad ... (2.1)$$

Where,

λ- the reciprocal of twice the thermal diffusivity k/Δc
k-thermal conductivity in w/mm^{0}C
Δ-Density of the material in kg/mm^{3}
c- Specific heat capacity in kJ/kg^{0}C

Equation essentially refers to a fixed coordinate system and may be modified to a moving coordinate system by replacing x with ε, where ε is the distance of the point heat source from some fixed position along the x-axis, with dependence on the velocity of the moving heat source.

$$\varepsilon = x - vt \qquad ... (2.2)$$

Equation when differentiated with respect to , and simplified gives, the heat transfer equation in quasi-stationary condition.

$$(\delta^{2}T/\delta\varepsilon^{2} + \delta^{2}T/\delta y^{2} + \delta^{2}T/\delta z^{2})\, k/\rho c = \delta T/\delta t \qquad ... (2.3)$$

like temperature dependent material properties, phase change, distributed arc heat energy, convection and radiation heat losses.

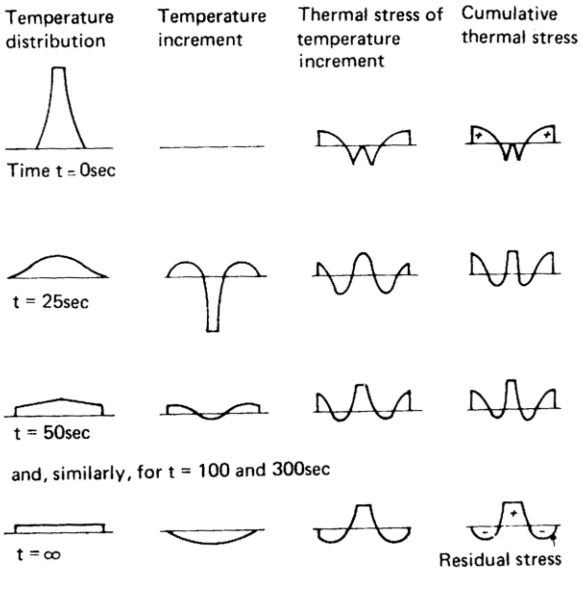

Figure: 1 Temperature and stress at different time intervals.

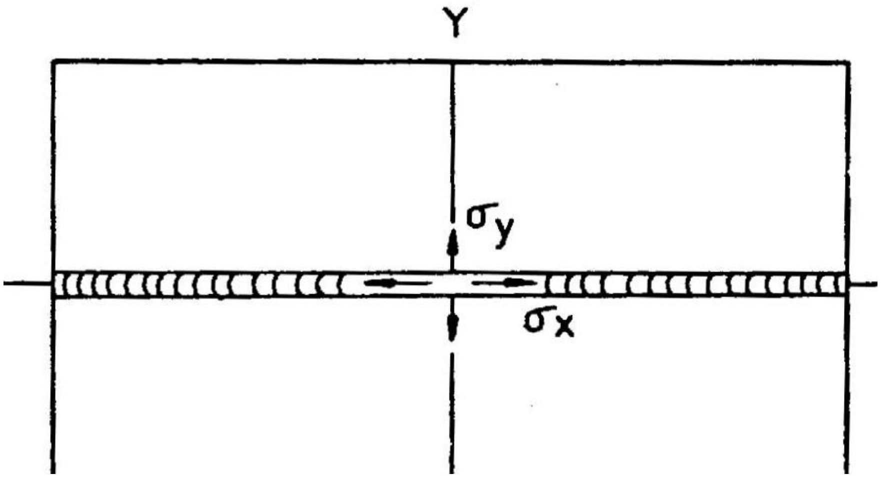

Figure: 2

Mesh Generation

Mesh generation plays a crucial role in accuracy and economy of numerical results. The dimensions of the plate are as follows Length = 80mm, Width = 80mm, Thickness = 8mm. The nodes and elements in the plate model are generated directly and nodes are numbered in such a way that the bandwidth is minimum. This is done to achieve further economy in solution. The total number of elements and nodes are 380 and 651 respectively. The analysis uses Solid 70 for thermal and structural analysis.

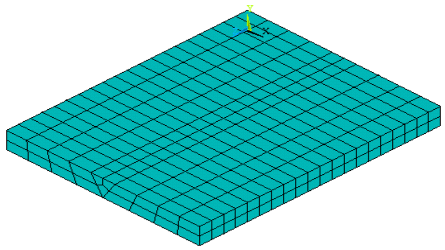

Figure: 3 Isometric view of the plate employed in the study

Results and discussion

The details of a typical thermal and structural analysis of butt welding process are discussed in chaper-3. Chapter-4 has presented the solution methodology for the investigation. Thermal and structural analysis are carried out by varying the important parameters that are primarily responsible for determining the quality of weld. The results of software analysis and analytical analysis were plotted using graphs and the impact of variation of each parameter on the temperature, and residual stress in the welded region has been discussed.

Results from structural analysis

The results obtained from the structural analysis are residual stress of the plate. Thermal expansion co-efficient and modulus of elasticity of the material are assumed to be constant and isotropic respectively. Residual stress in the weld zone are affected by the properties like plate thickness, convective heat transfer co-efficient, bulk temperature and metal preheat temperature. While the modulus of elasticity of the material increases, the residual stress in the weld zone also increases and vice-versa. Therefore, residual stress is directly proportional to the modulus of elasticity of the material. The results for the structural analysis are shown in **Figure:** 5.9, **Figure:** 5.10

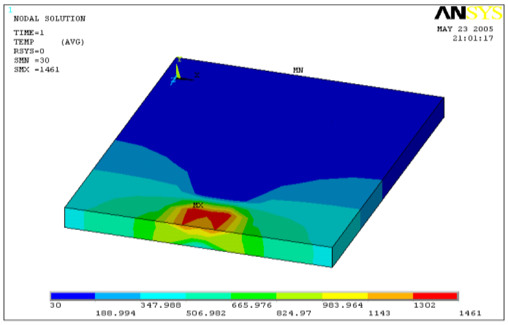

Figure: 4 Temperature distribution for 1 seconds

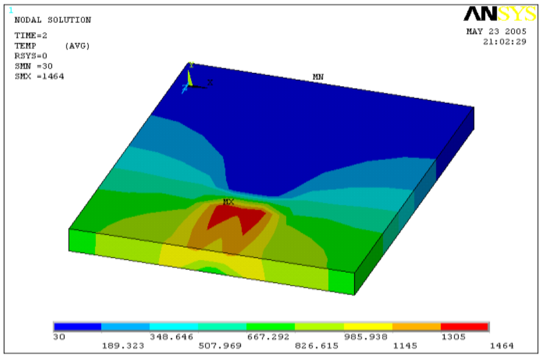

Figure: 4 Temperature distribution for 2 seconds

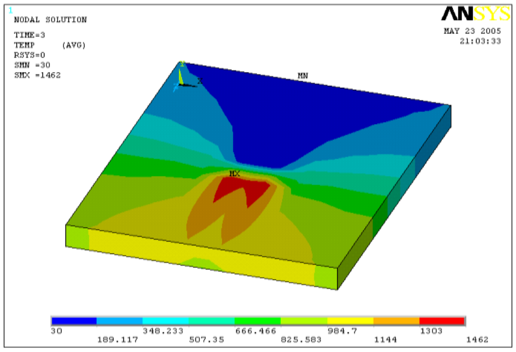

Figure: 5 Temperature distribution for 3 seconds

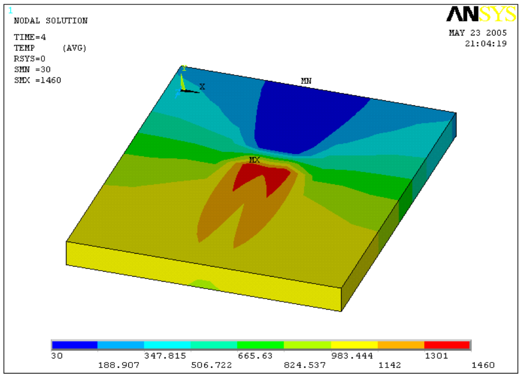

Figure: 6 Temperature distribution for 4 seconds

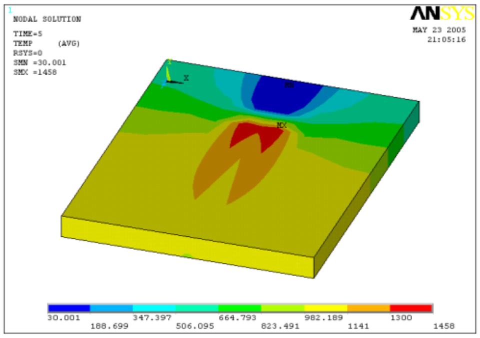

Figure: 6 Temperature distribution for 5 seconds

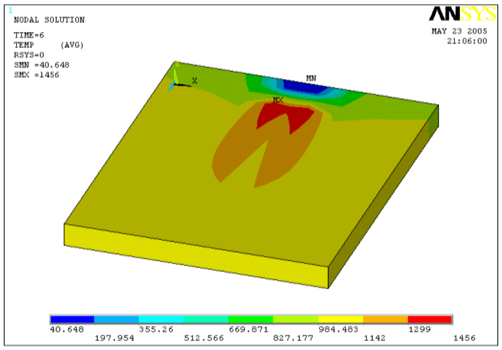

Figure: 7 Temperature distribution for 6 seconds

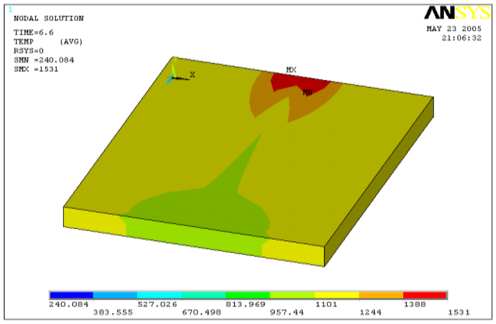

Figure:8 Temperature distribution for 6.6 seconds

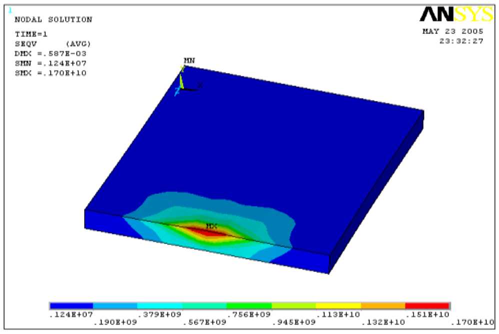

Figure:9 Stress distribution for 1 seconds

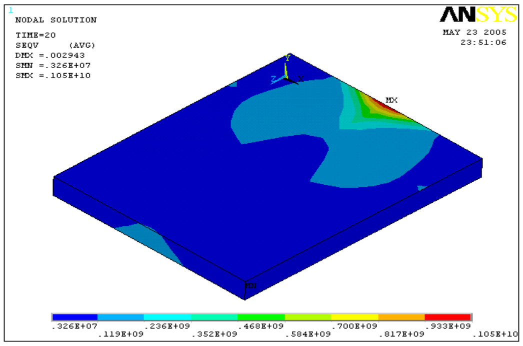

Figure:10 Stress distributions for 20 seconds

Conclusions and scope for future work

Conclusions

Thermal and structural analysis of a three dimensional butt joint weld has been done. The effect of temperature distribution and residual stress were analyzed and the results were plotted. Then the thermal analysis carried out by the software ANSYS 8.1., is compared with analytical analysis carried out using Turbo C. The major conclusions drawn from the present investigations are:

1. The peak temperature obtained from both the analysis is more than the melting point of the selected material. Based on this peak temperature, the welding has been successfully carried out at the particular time.
2. From the thermal analysis the deviation among the two analysis is less than 5%. So, the model has been validated.
3. From the structural analysis, it have been observed that the compressive stresses are acting at the weld zone.

Scope for future work

The following are some of the proposed extensions of this research work possible on butt weld.

1. The analytical analysis for the structural analysis may be carried out.
2. The effect of input parameters can also be elaborately studied, if all the real-time parameters are known.

Appendix

The distributed arc heat is one of the most important parameters for getting accurate solution. The arc heat flux is assumed to be distributed as per Gaussian distribution that has been proposed by Friedman and Krutz which is given by

$$\mathbf{Q(x,z,t)= (3q/\pi r^2)*exp[-3(x/r)^2]*exp[(-3(z_1+ w((r/w)-t)/r)^2].} \qquad \text{..... (4.1)}$$

Where,
$q= \eta*v*I$is the energy input in (Watts) which is given by
In which,
Arc efficiency (η) = 90%
Voltage (volts) (v) = 33
Current in (amperes)(I) = 1170
$q= \eta*v*I$ = (0.9*33*1170)= 34749 watts
Distance perpendicular to the weld line (metres) (x) = 0.045
Thickness of the plate in (metres) (y) = 0.008
Distance along direction of weld line (metres) (z) = 0
radial distance given by $r =\sqrt{(x^2+y^2+z^2)}$.
$(r) = \sqrt{(0.045)^2+(0.008)^2+(0)^2} = 0.045$ metres.
weld speed (m/sec) (w) = 0.01212.
Time in (sec) (t) = 6.6

Substituting all the above values in equation (4.1), then the Gaussian
Distribution is

$$\mathbf{Q(x,z,t)= (3q/\pi r^2)*exp[-3(x/r)^2]*exp[(-3(z+ w((r/w)-t)/r)^2].} \qquad \text{..... (4.1)}$$

$Q=(3*34749/\pi*(0.045)^2)*exp[-3(0.045/0.045)^2]*exp[(-3(0+ 0.01212 ((0.045/0.01212)-6.6)/0.045)^2]$

Gaussian heat distribution (Q) = 160341.88 (w/m^2).

References

1. ANSYS 8.1 Reference manual

2. Andersson B. A. B (1978); Thermal Stresses in a Submerged Arc Welded Joint Considering Phase Transformations. ASME Journal of Engineering Materials and Technology. Vol 100. Pp 356-362
3. Arora.S.C, Domkundwar.A.S (1997); A course in Heat and Mass Transfer, 4th edition, Dhanpat Rai Company.
4. Arno louvo, Mattisirvio and Marti vilpas (1993); Simulation of Weld solidification in Submerged Arc Welding, Modeling of Casting Welding and Advanced Solidification Processes –VI, Edited by Piwonka TS, Publication of the Minerals, Metals and Materials Society. Pp327-336
5. Christensen N., Davies I.e. and GjermundesanK.(1965); Distribution of Temperatures in Arc Welding, British Welding Journal , pp 54-75
6. Das S, Upadhya G, Chandra U, Kleinoskey M J and Tims M L (1993); Finite Element Modeling of a single GMA weldment. Modeling of Casting Welding and Advanced Solidification Processes –VI, edited by Piwonka T S, Publication of the Minerals, Metals and Materials Society, pp593-600
7. Dipl-Ing Michael Rethmeier et al (2000); Minimizing the Temperature Load and the Distortion on Injection Valves with the Aid of the Finite Element Method, Welding and Cutting Journal 52, No: 8
8. Dong.P (2001); Residual Stress Analysis of a Multi-Pass Girth weld: 3-D Special Shell versus Axisymmetric Models, Journal of Pressure Vessel Technology, Vol .123
9. Dong.Y, Hong.J.K, Tsai.C.L and Dong.P (1997), Finite Element Modeling of Residual Stresses in Austenitic stainless steel Pipe Girth welds. Welding Journal.
10. Eagar.T.W and Tsai.N.S (1983), Temperature fields Produced by Traveling Distributed Heat sources, welding Journal.
11. Elijah Kannatey- Asibu, Jr., Noburu Kikuchi, Abdel-Rahim Jallad, (1989), Experimental Finite Element Analysis of Temperature Distribution During Arc Welding, Vol. 111, pp. 9 - 18
12. George E Dieter; Mechanical Metallurgy
13. Gerner A Olsen; Elements of Mechanics of Materials, 3rd edition, Prentice Hall India
14. Goldak.J, McDill.M, Oddy.A, Chakravarti.A, Bibby.M and House.R, (1986), Progress in Computing Residual Stress and strain in welds, Advances in Science and Technology, TWR ‘86
15. Goldak.J, McDill.M, Oddy.A, House.R, Chi.X, Bibby.M, (1986), Computational Heat Transfer for Weld Mechanics, Advances in Science and Technology, TWR ‘86
16. Goldak.J, Chakravarti.A, Bibby.M, (1984),A New Finite Element Model for Welding Heat sources, Metallurgical Transactions B, Vol 15 B, pp 299-305
17. Henshall.G.A, Rosen R.S, Kassner. M.E and Whirley.R.G, (1990), Finite Element Analysis of Interlayer Welds loaded in Tension, Welding Journal, Pp 337s-345s.
18. Holman.J.P; (1997) , Heat Transfer; 8th edition, McGraw hill, Inc
19. Jones WKC, Alberry P J;(1977), A model for Stress Accumulation during Welding, Residual stresses in Welded Construction and their Effects –an International conference –London –15-17 , vol I papers, pp 15-26
20. Joseph Marin, (1966), Mechanical Behaviour of Engineering Materials, Prentice Hall India, pp 143,15
21. Kenneth Easterling; Introduction to the Physical Metallurgy of Welding, Second edition, Butterworth-Heinemann.
22. Krutz GW and Segerlind J, (1978), Finite Element Analysis of Welded Structures, Welding Journal.
23. R.I. Karlsson, B.L. Josefson, (1990), Three –Dimensional Finite Element Analysis of Temperatures and Stresses in a Single-pass Butt Welded Pipe, Journal of Pressure Vessel Technology , Vol 112, pp. 76 – 83.
24. Lars Wikander, Lennart Karlsson and Mats Nastrom (1933); Thermomechanical FE plane models of Welding. Modeling of Casting Welding and Advanced Solidification Processes –VI, Edited by Piwonka T S, Publication of the Minerals, Metals and Materials Society, pp553-560
25. Leggatt R H, and White JD; (1977), Predicting Shrinkage and Distortion in a Welded Plate, Residual Stresses in Welded Construction and their Effects –an International conference –London –15-17, vol I papers, pp 119-132
26. Leung.C.K, Pick.R.J and Mok D.H.B, Finite Element Modeling of a Multi Pass Weld, WRC Bulletin356
27. Leung.C.K, Pick.R.J and Mok D.H.B, Finite Element Modeling of a Single Pass Weld, WRC Bulletin356