Engineering Solid Mechanics 1 (2013) 91-98

Contents lists available at GrowingScience

Engineering Solid Mechanics

homepage: www.GrowingScience.com/esm

Influence of heat transfer types on residual stress distribution of a welded plate using finite element

A. R. Hosseinzadeh* **and Mohammad Rezaeiha**

Department of Mechanical Engineering, Bu-Ali Sina University, Hamedan, Iran

A R T I C L E   I N F O

Article history:
Received March 20, 2013
Received in Revised form
August, 21, 2013
Accepted 3 September 2013
Available online
4 September 2013

Keywords:
Radiation
Convection
Welding
Finite element
Heat transfer

A B S T R A C T

Generation of residual stress and structure deformation are the most important problems in the process of structure welding. Residual stresses inside and around the welded joints are harmful for integrity and proper functioning of the welded part. Tensile residual stresses near the weld zone may cause in developing brittle fracture, reduction of fatigue life or crack propagation caused by corrosion stresses. Welding residual stresses may even reach the yield stress of the part and can affect the thermal or mechanical working properties of it. Different thermal and mechanical approaches have been developed in the past in order to reduce these residual effects. Thus, both radiative and convective heat transfer methods have important roles in distribution of residual stresses during the welding process. In this study, convection and radiation effects on distribution of residual stress inside a welded part have been investigated for three different cases. In the first case, convection heat transfer was ignored and only effect of radiation on residual stress distribution was considered. In the second case, just the convection heat transfer applied on the model during the welding process. In another case, effects of radiation and convection heat transfer methods were investigated, simultaneously. Results of the current study showed that both radiative and convective heat transfer mechanisms have a significant share on distribution of residual stresses inside the welded part. It was also shown that the share of convection is greater than that of radiation heat transfer method.

1. Introduction

Residual stresses play a determinant role in many failure processes of engineering structures (Withers & Webster, 2001). If unknown, they can cause failure when combined with applied stresses (Totten, 2005). Residual stresses are often generated by thermal gradient in material neighborhood of component parts. Various techniques exist for generating residual stress in engineering structures such as shot peening, forging, quenching (Mahmoudi & Hosseinzadeh, 2012) and welding. Welding has been used by human to create a permanent connection in metal structures traditionally.

* Corresponding author.
E-mail addresses: a.r.hosseinzade@basu.ac.ir (A. R. Hosseinzadeh)

doi: 10.5267/j.esm.2013.09.001

Nowadays, welded components are widely used in industries. Residual stresses and their distortions in specimens are unavailable and relatively hard to determine in welding. Effect of residual stresses (by any generation source) in structures and distortions are too important, thus, determining the distribution of residual stresses is necessary. However, accurate prediction of residual stresses and distortions induced by the welding process is extremely complex because for this prediction various parameters in the thermal and mechanical behavior of specimen must be considered. These factors include moving heat source, local high temperature and temperature dependence of material properties; in predicting thermo mechanical behavior finite element simulation of the welding process is highly effective (Teng et al., 2001).

Various research results have been published by finite element method on the welding simulation to predict residual stress distributions in the weld structure (Ueda & Yamakawa, 1971; UEDA et al., 1993; Wang et al., 1996; Lindgren, 2001). Previously, Glodak et al. (1984) recommended an effective 3D heat source model for calculating the temperature field from the welding process. This model has been very common for simulation of welding in different papers. In fact, for the correct modeling of welding process both of radiative and convectional, heat transfer must be considered in simulation. Each parameter has a great influence on the results. This means both of radiative and convective heat transfer methods have important roles in distribution of residual stresses during the welding process.
In this paper, simulation of a three pass welded plates (see Fig. 1) is accomplished by an uncoupled thermal and mechanical analysis which temperature histories of nodes (output of thermal analysis) are applied as initial conditions in other mechanical analysis and finally residual stresses are obtained from thermal and mechanical analyses in each simulation. Convection and radiation effects on distribution of residual stresses inside a welded part were investigated for three different cases. In the first case, convection heat transfer was not considered and only effect of radiation on residual stress distribution was applied. In the second case, just the convection heat transfer applied on the model during the welding process. In original simulation of welding procedure, effects of radiation and convection heat transfer methods were investigated simultaneously. By comparing the results of these three cases, it is possible to find the share of each heat transfer method on distribution of residual stresses inside the welded part.

2. Finite element

The history of finite element goes back to hundreds of years ago, but during the past half century, the method has become popular. Finite element is one of the numerical methods and it finds an exact solution for a lot of problems where analytical methods are unable to solve the resulted problems. For this reason, numerical methods are essential in solution procedure. For better exposure, in Fig. 1 the TIG welding process on a plate is shown. As seen (also see Fig. 2) welding is performed in three passes. After finishing each pass, we need to wait for several minutes until the weld region cools. During the weld process, plate must be clamped correctly. These applications has been simulated carefully. Note that in this study, ABAQUS 6. 10- 1 has been used for simulation of welded plate.

Fig. 1. a view of welded plate after welding under clamps

3. Material

In this survey, the material of the plate was chosen from 316L stainless steel. These material properties were derived in references. A view of size and position of weld region and three passes are shown in Fig. 2 for welding simulation.

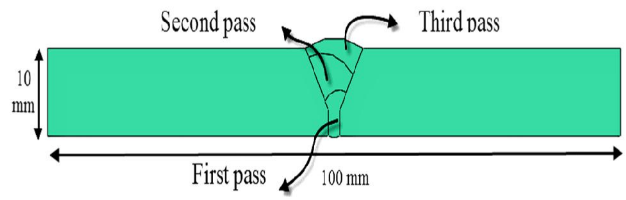

Fig. 2. The geometry of weld model used for simulation

4. Uncoupled temperature-stress analysis

In simulation of plate, welding an uncoupled temperature-stress analysis was employed. In other words, this analysis has two main steps. In the first step, a heat transfer analysis was carried out and convectional and radiation heat transfer was simulated. Then, a stress analysis was done and temperature histories in previous step were applied to the model. This means output of the first analysis was temperature distribution in plate after welding procedure. Then, after finishing the stress analysis, desired stresses were obtained. Each step is described in forthcoming sections. On the other hand, equations recommended by Goldak et al. (1984) in heat source motion were used in simulation of heat generation in birth of weld elements by using a subroutine.

Note that three separate simulations were accomplished and for the real simulation of welding process, both heat transfer methods were considered. In other one, convection heat transfer was ignored and only the effect of radiation on residual stress distribution was considered, In third case, just the convection heat transfer was applied for the model during the welding process.

5. Thermal analysis

In the thermal step, the plate model and welding region was exactly modeled. Fig. 3 shows the plate and welding zone and boundary conditions during welding.

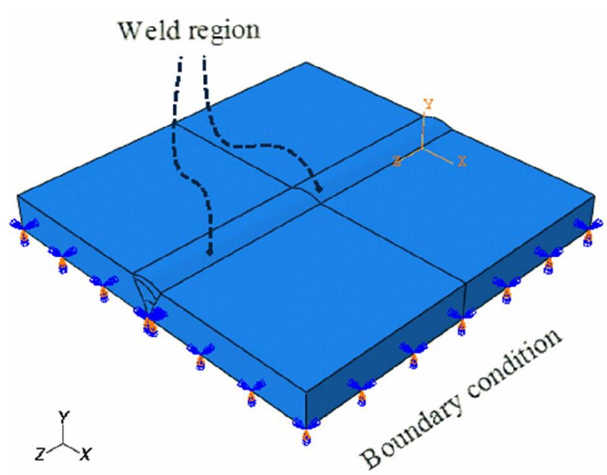

Fig. 3. A view of simulated plate and boundary conditions used

After modeling, thirty four steps were required to complete the modeling. It is necessary to mention that in simulation of current study, “birth and death” technique was employed to generate the welded region. At first, elements considered for weld zone must be removed. In next steps, each part of passes must be generated or born. This means all elements must be created; including those weld fillers to be “born” in later stages of analysis.

After removing elements in first step, in next stages, first pass of weld must be born. For first welding pass, ten transient heat transfer steps were accomplished. Totally, times of steps estimated about 200 seconds (in other words, each step take a time about 20 second for generating the elements). This time determined by experimental procedure of welding. After finishing the first pass generation, one step of about 500 seconds was considered for cooling the specimen. Then, the second pass was completed in next ten steps. After finishing the second pass, one step was put for cooling the specimen. Also, third pass was carried out with this procedure. Finally, at the end of welding whole of the specimen was cooled down. For correct simulation in each step, radiation and convective heat transfer must be considered. As said before, to check the effect of each kind of heat transfer, three models were simulated. In continue the results of each simulation will be shown. DFLUX is user subroutine to define non-uniform distributed flux in heat transfer which used in simulation of heat flux motion.

After determining the steps and interactions and loading the situations, meshing on the model was performed. For doing this task, the elements used near weld region were put finer. Fig. 4 shows the elements near weld zone.

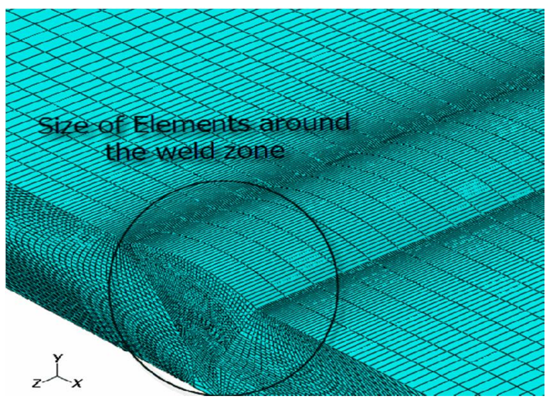

Fig. 4. The mesh used in the 3D simulation near welding zone

By completing the procedure of thermal steps, problem was run to solve. Temperature distributions obtained before cooling are shown in Fig. 5. Unit of temperatures are absolute and by Kelvin indicated.

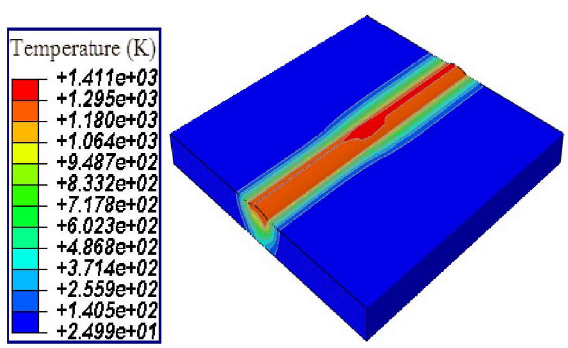

Fig. 5. contour of temperature after weld process

Output of thermal analysis is three .odb files for three separate condition of simulation. These three outputs must be applied as initial conditions in three-stress analysis to achieve those desired results for every three samples.

6. Mechanical analysis

In the mechanical analysis, the temperature history of nodes obtained from the thermal analysis input as a thermal loading into the structural model. Thus, at each time increment, strains and stresses can be measured. In addition, the final residual stresses condition will be achieved by the thermal strains and stresses. This means during each weld pass, thermal stresses are calculated from temperature distributions determined by the thermal mode. The residual stresses from each temperature increment are added to each point to determine match mechanical behavior of the model before the next temperature increment. The material was assumed to follow the Von Mises yield criterion. Phase transformation was not considered in the current work in all simulations especially near yield stresses such as the near-melting state because the lack of material information. Figure 6 shows the residual stresses distribution after finishing the cooling process in main simulation that all heat transfers are considered.

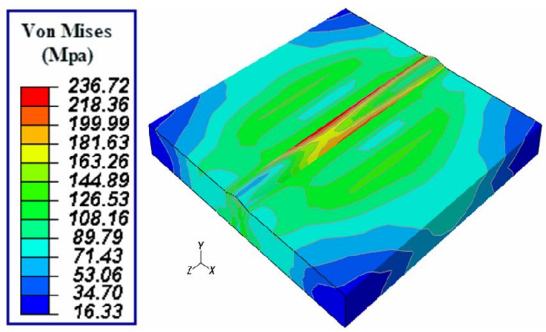

Fig. 6. Distribution of Von Mises stresses after cooling

By finishing the simulations, we now compare the results in each case. Two models where one of them was radiation and the other one did not consider convection heat transfer method are compared in Fig. 7 along weld line.

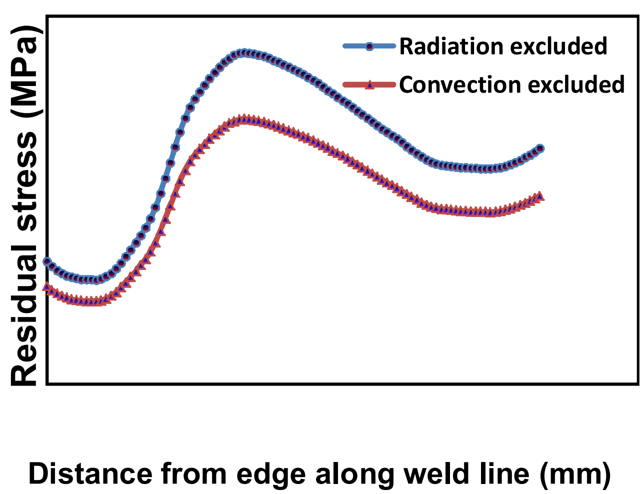

Fig. 7. Residual stresses obtained by original simulation of welding and superposition of convective and radiative effects in two separate simulation along weld line direction

As is shown in this figure, residual stresses that obtained by convectional heat transfer are more than those achieved by radiation method.

Other comparison that is very important in this research is associated with residual stresses measured by superposition of convection where radiation methods are more than obtained residual stresses by original simulation. Both of these methods of heat transfer are considered, simultaneously. This fact clearly is shown in Fig. 8. Effect of each heat transfer technique alone is less than its effect in addition to the other technique effects.

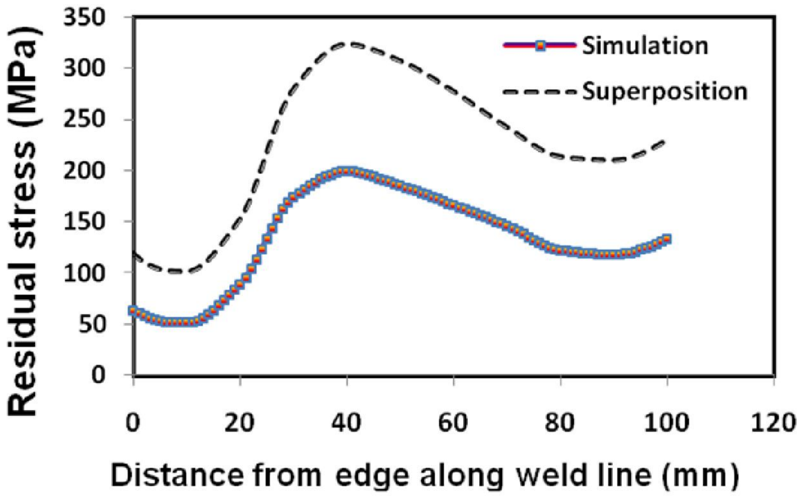

Fig. 8. Residual stresses obtained by original simulation of welding and superposition of convective and radiative effects in two separate simulation

All simulation results are shown in Fig. 9. In this figure, residual stresses obtained by each three cases are shown. These cases are: original simulation where all heat transfer methods were been considered, simultaneously, simulation without convection consideration and simulation with consideration of convection heat transfer alone. More, superposition of these recent cases is shown in this figure, too.

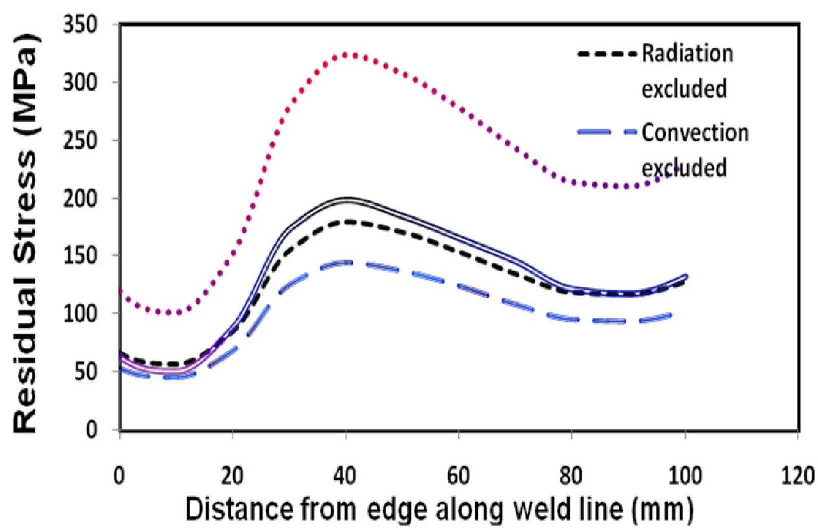

Fig. 9. Comparing four cases results

Three welded plates with different heat transfer states have been modeled. In each case, stress distribution has been achieved. Solution of these simulation were very time consuming and onerous, but it was worth the advantageous results. Results clearly show stress distribution in three cases has similar shape but they are in different range. On the other hand, it can be realized from the result that the effect of each method of heat transfer decreases. It maybe occurred because of opposite influence of these two methods along with two other factors, which reduces other factor effects. Both of heat transfer techniques have great influences in stress distribution (of course the effect of convection is more). In many papers, the radiation is not considered for simple simulation, this work increase the errors and simulation has less similarity to real conditions of welding process.

7. Conclusion

Results of this research can be summarized in following bullet points:

- Stress distribution in three cases (original simulation, convectional ignored and radiation ignored) have the same shape but are in different ranges.

- Convective heat transfer technique has more effect on the residual stresses where welding causes inside the specimen. However, radiation heat transfer effects are not negligible at all.

- Superposition of stresses which achieved by each method alone are more than residual stresses that obtain by all of them in original simulation of welding.

Acknowledgment

Authors would like to acknowledge the help from Mrs. S. Baghaee & Mrs. M.Pazouki to preparing this paper.

References

ABAQUS/Standard User's Manual (2010). ABAQUS Inc., Version 6.10.

Goldak, J., Chakravarti, A., & Bibby, M. (1984). A new finite element model for welding heat sources. *Metallurgical transactions B*, *15*(2), 299-305.

Lindgren, L. E. (2001). Finite element modeling and simulation of welding part 1: increased complexity. *Journal of thermal stresses*, 24(2), 141-192.

Mahmoudi, A. H., Hosseinzadeh, A. R., Jooya, M. (2012). Experimental Calibration of the Convection Heat Transfer Coefficient in Quenching Process for a Reliable Prediction of Residual Stresses. *The International Conference on Experimental Solid Mechanics and Dynamics* (*X-Mech*), Tehran, Iran, University of Science and Technology.

Mahmoudi, A. H., Hosseinzadeh, A. R., & Jooya, M. (2012). Experimental Measurement and Numerical prediction of Residual Stresses Using Contour Method in a Quenched Cylinder. *The International Conference on Experimental Solid Mechanics and Dynamics* (*X-Mech*), Tehran, Iran, University of Science and Technology.

Mahmoudi, A. H., Hossain, S., Truman, C. E., Smith, D. J., & Pavier, M. J. (2009). A new procedure to measure near yield residual stresses using the deep hole drilling technique. *Experimental mechanics*, *49*(4), 595-604.

Teng, T. L., Fung, C. P., Chang, P. H., & Yang, W. C. (2001). Analysis of residual stresses and distortions in T-joint fillet welds. *International Journal of Pressure Vessels and Piping*, *78*(8), 523-538.

Totten, G. (2005). *Handbook on residual stress*. vol. 1. SEM, Bethel, ISBN: 978-0871707291; p. 417.

Ueda, Y., Wang, J., Murakawa, H., & Yuan, M. G. (1993). Three Dimensional Numerical Simulation of Various Thermo-mechanical Processes by FEM (Report IV): Deformation Analysis of Pipe-Plate Joint with Holes by Multi-pass Welding (Mechanics, Strength & Structural Design). *Transactions of JWRI*, *22*(2), 289-294.

Ueda, Y., & Yamakawa, T. (1971). Analysis of thermal elastic-plastic stress and strain during

welding by finite element method. *Transactions of the Japan Welding Society*, *2*(2), 186-196.
Wang, J., Ueda, Y., Murakawa, H., Yang, H. Q., & Yuan, M. G. (1996). Improvement in numerical accuracy and stability of 3-D FEM analysis in welding. *Welding Journal*, *75*(4).
Withers, P. J., & Webster, P. J. (2001). Neutron and Synchrotron X-ray Strain Scanning. *Strain*, *37*(1), 19-33.