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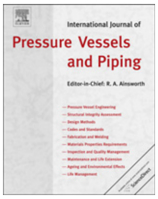

Temperature and residual stress simulations of the NeT single-bead-on-plate specimen using SYSWELD

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ABSTRACT

This study contributes to the NeT European Network formed in 2002. A series of “Phase 1” finite element simulations have been performed by the Task Group 1 of NeT to estimate temperature distributions and welding residual stresses. After discussion, the second round robin (Phase 2) was suggested to perform for improving the simulated results. Two significant changes are used in Phase 2 round robin. The welding efficiency, η, is fixed at 75%; and the weld bead fusion boundary profiles are based upon macrographs taken from the welded specimens, which has been destructively examined, rather than from test beads.

In this study, an uncoupled 3D thermal and mechanical analysis was carried out using the software code SYSWELD. A two-offset-double-ellipsoid heat source model was developed and fitted using the Heat Source Fitting tool. Power intensity was applied to simulate 1 s dwelling time at the weld start end. Simultaneously, the offset distances between two double ellipsoids were adjusted to obtain the weld bead fusion boundary profiles. The predicted temperatures were compared with the measured by thermocouples. In the mechanical analysis, the effects of three different hardening models (isotropic hardening model, kinematic hardening model and mixed isotropic-kinematic hardening model) on the welding residual stresses were studied and the optimum hardening model was confirmed. Moreover, the effect of clamping restraint on the residual stresses was also studied.

The results show that the predicted weld bead fusion boundaries profiles are in good agreement with the measured. The simulated temperatures are much similar to the measured data. The predicted welding residual stresses based on the mixed isotropic-kinematic hardening model show the best agreement with the measured. The clamping restraint has little effect on the residual stresses.

1. Introduction

Welding is one of the most important material-joining processes widely used in many industries. However, this process involves the deposition of molten filler metal and the localized input of intense heating. Consequently, the surrounding parent material undergoes complex thermo-mechanical cycles involving elastic, plastic and viscoplastic deformation. This processing history results in large residual stress gradients around the weld bead, which can be particularly detrimental to the structural integrity of components. Therefore, in order to analyze the integrity of welded structure, accurate quantitative estimation of the welding residual stress in welded fabrications is of significant interest.

At present, there are two approaches to estimate the welding residual stresses, the measurement and the numerical simulation. In many welded structures, especially for those in active service, it is difficult to measure accurately the welding residual stresses. Moreover, the measurement cannot be carried out in some special fields. With the development of strong computing power, the numerical simulation by the finite element method (FEM) becomes a particularly interesting tool to predict the residual stresses resulting from a welding process. Nevertheless, it is very difficult to obtain reliable predicted results due to many complex phenomena in the heat affected zone (HAZ). In order to carry out the numerical simulations with industrial computer FE codes, it is consequently current practice to neglect certain physical phenomena, to simplify the geometry or reduce the dimension of the problem. Moreover, materials characteristic data and their temperature dependencies are not straightforward to obtain, especially for high temperatures. As a result, it is difficult to control the accuracy level of the

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numerical solution, when performing simulation of a complete welding operation [1].

The European Network on Neutron Techniques (NeT) Standardization for Structural Integrity was established in 2002. Several benchmark studies were carried out by NeT. Task Group 1 (TG1) was established from the beginning of NeT in 2002 to examine the benchmark problem of a single weld bead laid down on the top surface of an austenitic stainless steel plate. This weld geometry produces a strongly three-dimensional residual stress distribution, with similar characteristics to a weld repair, in a compact, portable specimen, which is amenable to residual stress measurement using diverse methods. Moreover, the single weld pass is relatively straightforward to model using the finite element method, and allows full moving heat source residual stress simulations to be performed in practical time scales. TG1 has organized and performed two parallel round robins centered around the single-bead-on-plate specimen, covering the residual stress measurement and prediction [2]. In the Phase 1 simulation round robin, the participants were allowed independently to predict the transient welding temperature history and welding residual stresses in advance of measurements being available. Detailed reviews of both the measurements and the simulations identified a number of areas for improvement, particularly in the simulations [3]. In order to improve the simulation results and validate the numerical simulation of welding, the Phase 2 round robin was suggested to be perform. In the thermal simulation, two significant changes will be used. The welding efficiency, η, is fixed at 75%; and the weld bead fusion boundary profiles are based upon macrographs, which have been destructively examined, rather than from the test beads.

In this study, an uncoupled 3D thermal and mechanical analysis has been carried out using the software code SYSWELD. In order to predict accurately the weld bead fusion boundary profiles, a two-offset-double-ellipsoid heat source model was developed and fitted using the Heat Source Fitting (HSF) tool. Power intensity was applied to simulate 1 s dwelling time at the weld start end. At the same time, the offset distances between two double ellipsoids were adjusted to obtain the weld bead fusion boundary profiles. The simulated temperatures were compared with the measured by thermocouples. For welding residual stress simulation, the effects of three different hardening models (isotropic hardening model, kinematic hardening model and mixed isotropic-kinematic hardening model) on the welding residual stresses were studied. Compared with the welding residual stresses measured, the optimum material hardening model was confirmed. Moreover, the effect of clamping restraint on the residual stresses was also studied.

2. Experimental procedure

2.1. Welding process

AISI Type 316L stainless steel, which is an austenitic stainless steel, was chosen for this study. It is widely used in the nuclear industry for its good resistance to high-temperature creep and corrosion. Moreover, it has a stable austenitic matrix from the ambient temperature to melting point. During the welding process, thus, structural transformations do not take place in the HAZ, which will simplify welding process simulation. The chemical composition of the 316L plate is given in Table 1. Four nominally identical plate specimens were manufactured from a single piece of solution heat treated AISI Type 316L stainless steel plate. The four specimens identified as plates A11, A12, A21 and A22. The specimen dimensions were 120 mm × 180 mm × 17 mm.

Table 1
Chemical composition of the 316L plate in percent by weight.

C	Si	Mn	P	S	Cr	Ni	Mo	N
0.018	0.402	1.87	0.032	0.021	17.02	10.66	2.52	0.017

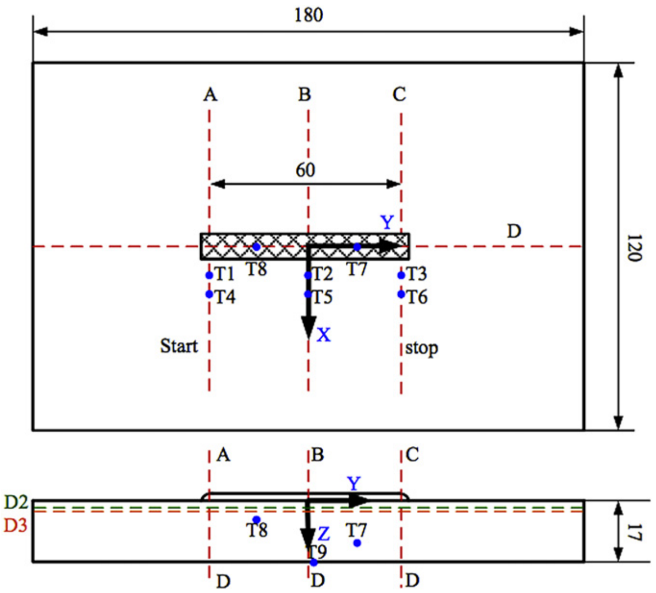

Fig. 1. Schematic of the bead-on-plate specimen.

A single weld bead on AISI 316L austenitic stainless steel was deposited along the centre-line using automated Tungsten Inert Gas Welding (TIG). The filler wire was 0.8 mm 316S96 Mini Mig with specification A5.9.93 (ASME) and ER316H specification. A schematic of the bead-on-plate specimen is shown in Fig. 1. The weld torch traverse distance between line A and line C is 60 mm and no weave was employed. The plate was restrained during welding by a vice with jaws 100 mm long. The jaws were positioned midway along the long sides of the specimen as shown in Fig. 2. It was judged to provide no restriction to rotation along the long edges of the plate, but provided some resistance to transverse expansion during welding and no resistance to transverse contraction during cooling. This weld geometry produces a strongly three-dimensional residual stress distribution, with similar characteristics to a weld repair.

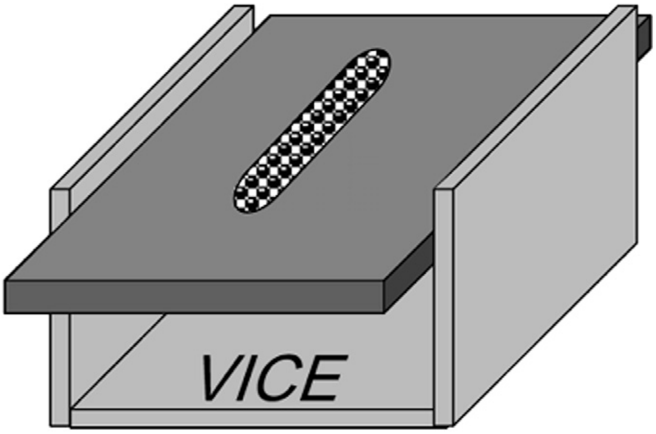

Fig. 2. Experimental device.