

A. Distortion Control in Welding Aluminum GIS Vessel

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Introduction

5083-O aluminum alloy was chosen as an alternative material to the original steel design for the GIS vessels to reduce weight. GMAW with argon shielding was used for fabrication. As a part of the procedure development efforts, welding-induced distortion was studied using an integrated approach involving both process modeling and experimental welding tests. The process design parameters, including joint detail, fixture constraint, and forced cooling, were investigated. The optimum cooling condition for a practical joint detail and jiggling constraints was determined from the FEA study using a plate model. This optimum cooling condition was verified by the welding experiment. A practical welding procedure and assembly sequence were developed, which also incorporated the distortion mitigation method developed from the plate model study. An aluminum GIS vessel was successfully produced demonstrating the effectiveness of distortion control using the forced cooling method.

Technical Approach

To determine the optimum joint details and to study the effect of constraint and forced cooling on angular distortion, the welding procedure qualification tests used CJP butt-groove, plate joints. Three types of joint details with different weld requirements, forced cooling, and jiggling restraining were experimentally investigated. To interpret the experimental results and to establish the theoretical foundation of the resulting distortion control methods, numerical modeling and analysis of the welding process and procedure was conducted using the finite element analysis (FEA) method. The modeling details incorporated temperature dependent material properties, moving heat source with double-ellipsoidal heating functions, applying and removing edge constraints, contact surfaces between the bottom of the joint and the supporting steel plate, and weld sequence. The forced cooling condition was simulated by increasing the heat loss coefficient, though values were rather intuitive.

Results and Discussion

5083-O aluminum alloy was chosen because of its good corrosion resistance and good weldability, as well as adequate strength as required for the current GIS design. The GIS vessel assembly consists of a main body and branch members of different sizes welded to the main body. The main body is rolled into a cylindrical form from two-pieces of 5083-O aluminum plate (16mm thick), which are joined together using two longitudinal, complete-joint-penetration (CJP) seam welds. A flange plate is joined to both ends of the vessel using the circumferential, CJP groove welds. The branch members are seamless pipes of the same material as the main vessel, with one end flange welded to the branch member using circumferential, CJP groove welds and the other end welded to the wall of the main vessel.

For distortion study, three joint details with increasing weld area, each consisted of three or four weld passes were investigated. All joints had a 60 deg (type 1), 45 deg (type 2), or 30 deg (type 3) included angle. The respective net groove areas were 119.75, 109.28 and 99.93 square mm. The heat inputs in all FEA analyses were calibrated based on the experimental data. The energies were assumed distributing in

the weld nugget area of each pass in the FEA analyses. High shrinkage strains were calculated in the last two-pass welds in type 1 joint and in the last-pass weld in types 2 and 3 joints. These last weld pass(es) causing most of the final weld distortion was also observed in the experimental tests. It was seen that reducing the weld requirement by decreasing the groove area reduced the total amount of shrinkage resulting in less distortion. Some tensile plastic strains were shown in the material's softening-temperature zone beside the lastly laid weld bead. These tensile plastic strains were shown at the geometric stress concentration sites. The built-up high joint stiffness from the previous two weld passes resulted in high residual stresses at these stress concentration sites where it showed the reverse tensile yielding. The magnitude of these tensile plastic strain zones was much smaller than the weld shrinkage strains.

In order to further reduce the angular distortion forced cooling was investigated. This concept was demonstrated to be very effective in the experimental investigation. Water spray was applied directly on the root face of the joint during the third (and forth for type 1 joint) weld pass. More than 70% reduction in angular distortion was observed. The FEA investigation was conducted to determine the effect of cooling and the optimum cooling condition for type 3 joint with fixed jiggling constraint. It showed reverse distortion that might occur if too much cooling was applied beneath the joint root. The steel heat sinking effect was insignificant because the heat sink locations were too far from the heated area. Water cooling practically removed most of the heat from the joint root surface without letting the heat diffusing to the side material. When water was applied directly to the joint root surface, this not only removed heat preventing temperature increase in the base metal, but also created shrinkage plastic strains in the joint root area. This would counter-balance the wrapping-up shrinkages caused by the cap weld passes. Too strong cooling would result in excessive yielding causing rather large reverse distortion. From the experimental experience it appeared that using garden spray nozzle to spray water to cool the joint was a very effective method to reduce angular distortion.

Conclusions

Water spray under the joint root surface, together with appropriate joint detail (type 3) and jiggling constraints, reduced angular distortion by more than 90% when compared with the baseline joint detail (type 1 joint) without forced cooling or constraint. This procedure was actually implemented in the final fabrication of the aluminum GIS vessel, which was successfully passed the proof pressure test. The dimensions of the finished vessel met the design tolerance requirement.