Determination of the Constitutive Properties of Laser Welds in 304L Stainless Steel

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Introduction

The mechanical performance of weldments is controlled by the properties of the fusion zone, heat-affected zone, and base metal. Performance assessments require an accurate description of the constitutive stress-strain response of these regions. However, the properties in the fusion and heat-affected zone are not always easy to determine. For large welds, tensile samples can be extracted directly from the weld for subsequent tensile testing. This provides the most direct method for measuring the mechanical properties of weld zones, but is extremely difficult in laser welds. Instead, for these small-scale welds, we evaluated a strain-mapping technique to assess local properties.

Technical Approach

The digital image correlation (DIC) method was used to determine the constitutive tensile stress-strain response in partial-penetration laser welds in 304L austenitic stainless steel sheet. Both continuous-wave (CW) and pulsed (PW) laser welds were examined. Testing was conducted in the transverse (cross-weld) orientation and samples were ground smooth to eliminate geometric effects (weld root notch) and to facilitate comparison with the base metal. The DIC method provides quantitative 2-dimensional strain maps of the deformation field across transverse weld samples throughout tensile testing. Local stress-strain response was extracted from regions within the fusion zone, and compared to basemetal response.

Results/Discussion

DIC was found to be a suitable method to map the localized mechanical properties of the small (<1 mm) laser welds. The use of bead blasting to create necessary speckled image contrast was advantageous over painting methods, due to its applicability over an unlimited strain range and the fine spatial scale of contrast. For the conditions examined, the strain resolution was found to be better than 0.001 mm/mm.

The DIC method provided maps of the spatial variation of strain across the transverse weldments, showing steep gradients in the vicinity of the welds, and relatively uniform far-field strains. These maps are useful for verifying analytical predictions and/or for extracting strain response from local regions. The local stress-strain response far from the weldment showed good agreement with a conventional unwelded basemetal tensile test.

The center of the fusion zone in both CW and PW weldments exhibited a higher yield strength than the parent material. The 0.2% offset yield strength was 337 MPa and 367 MPa at the center of the fusion zones in CW and PW conditions respectively, compared to a value of 295 MPa in the basemetal. This resulted in a localized strain deficit in the weldment during early deformation and a strain gradient from the low-strain weldment to the parent material.

The metallurgical origin for the fusion zone strengthening was largely attributed to Hall-Petch and ferrite content effects. While failures localized in the fusion zone with little appreciable necking, the fusion zone retained considerable local ductility: more than 45% strain at failure. Under the test conditions, the significant weld root porosity found in the PW condition and absent in the CW condition appeared to have no deleterious effect on the mechanical performance in this very ductile flaw-tolerant material.

Conclusions

Digital image correlation has been shown to be a powerful technique for assessing the mechanical behavior of laser welds in 304L stainless steel. The technique provided sufficient resolution to differentiate the subtle differences in constitutive properties of the various weld zones which were related to differences in microstructural features. The technique is also suitable for examining the mechanical response near weld defects, such as isolated pores, and is applicable to alloy systems which display a greater disparity in properties across the weld zones. Examples of these will be discussed.

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