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Evaluation of Welded Tensile Specimens in the Hopkinson Bar

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Abstract

The high strain rate behavior of a welded interface was evaluated using a split Hopkinson pressure bar (SHPB). The welds of interest are under-matched welds between identical aluminum alloys; the welds were processed using metal inert gas (MIG) welding. A direct tension bar setup was employed for the high strain rate testing. To accommodate both the weld and the heat affected zone in the gage length of the tensile specimen, it was necessary to use a longer specimen than is typically used for SHPB tensile testing. Limitations on specimen geometry and maintaining the weld bead intact were imposed to provide a specimen that was most representative of the material and application. Challenges associated with specimen design and testing in the pressure bar are discussed. Numerical simulations were employed to assist with specimen design and interpretation of the wave response. The experimental results obtained to date will be presented at the conference.

Background

Welded aluminum construction is utilized in high speed naval vessels for weight reduction. Understanding the behavior of these welded joints, especially at high strain rates, is critical for design of ship structures. Aluminum alloys used in marine applications (e.g., 5000 and 6000 series alloys) show significant strength decline when fusion welded [1,2]. The strength decline for under-matched welds in structures must be considered as plastic deformation will often localize at a weld during structural deformation [1,3]. Although the mechanical behavior of aluminum weld metals have been evaluated, testing has generally been conducted on coupons extracted from the weld (e.g., [4,5]). The effects of structural constraints on the weld are not usually considered in mechanical characterization studies of weldments. An objective of the present investigation is to evaluate the behavior of welded specimens (vs. weld metal only). The test specimens contained the weld bead and the heat affected zone (HAZ) on either side of the weld.

Materials

Two different welded aluminum alloys were evaluated: Al 5083-H116 and Al 6082-T651. Under-matched welds were processed between identical aluminum alloys using metal inert gas (MIG) welding and 5183 filler wire. For the Al 5083 alloy, 9.5-mm thick plates, machined down to 6.35 mm at the weld joint, were welded together. Thinner stock (approximately 3.8-mm) was used for the Al 6082 welds owing to differences in the material application. Both virgin and welded specimen blanks of each aluminum alloy were provided by the Naval Surface Warfare Center, Carderock Division, for testing. Although some high strain rate test data is available for the Al 5083 alloy [6], monolithic material from the same plate was tested to provide a baseline for comparison with the welded specimens. High strain rate test results for the less common Al 6082 alloy are not available in the literature.

Specimen Design

A standard tensile specimen could not be employed for the SHPB tension tests owing to the longer gage lengths (30-mm minimum) required to accommodate the weld, and HAZ material on either side of the weld, in the specimen gage section. An additional design requirement was the need to include the weld crown in the specimen to ensure that fracture occurs in a manner typical of a production weldment. Two different specimen designs were employed owing to the difference in thickness of the aluminum stock: 9.5-mm Al 5083 and 3.8-mm Al 6082. To allow direct comparison of the results, identical specimen designs were also used for tests on the corresponding virgin material.

The thickness of the Al 5083 plate was adequate for machining a threaded specimen for use in the direct tension bar setup. Several threaded cylindrical specimen designs were initially considered. The specimen design chosen

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is illustrated in Figure 1, and was selected based on numerical simulation results of the SHPB direct tension test, and initial testing trials. This flat specimen design was chosen to eliminate the need for machining near the weld. Numerical simulations were conducted to analyze the stress wave response for tensile specimens with different gage lengths.

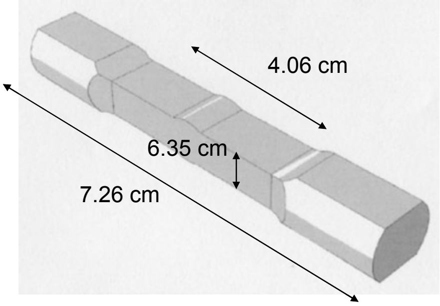

Figure 1. View of welded SHPB tensile specimen for Al 5083 prior to threading of the grip ends.

The simulation results confirmed that stress wave equilibrium is achieved in these tensile specimens with long gage lengths. This is illustrated in the force versus time plot in Figure 2. However, there was some concern whether specimen failure would occur on the first stress pulse due to the extra long specimen gage length (approximately 50-mm) needed to accommodate the weld. The numerical simulations were also used to estimate strain rates in the specimen as a function of the specimen length.

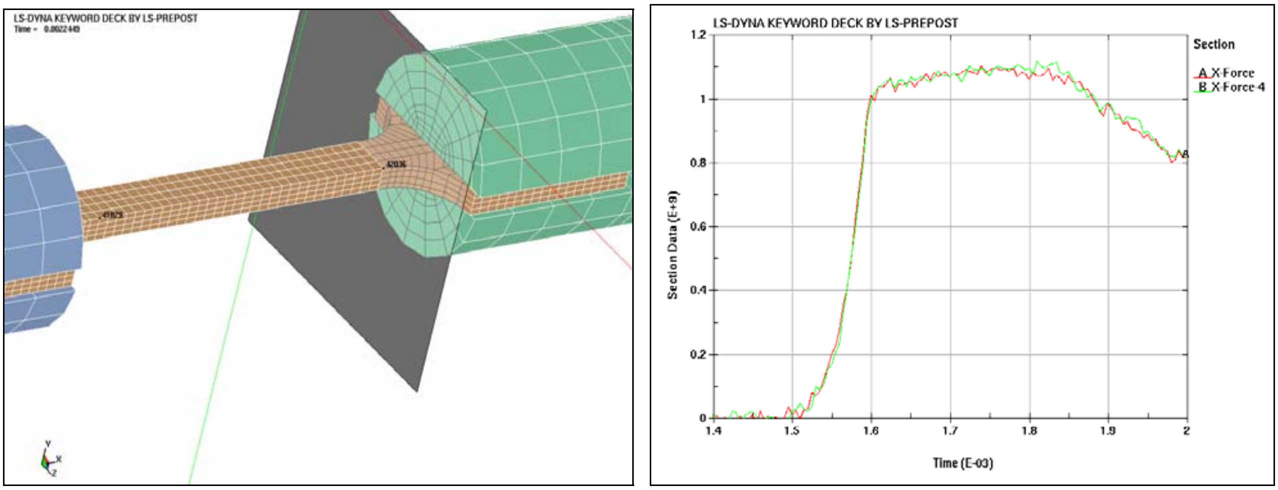

Figure 2. Numerical simulation of a SHPB direct tension test for a flat specimen design (with 50-mm long gage length). The results in the force vs. time plot show that stress equilibrium is maintained for this longer specimen. The two locations are those shown in the schematic on the left at opposite ends of the gage length.

For Al 6082, a flat specimen design was also used since the thickness of the available plate was only 2-3 mm. A specimen gage length exceeding 30-mm was also required for the Al-6082 specimens so that the weld and heat affected zone could be accommodated. A dog-bone geometry was utilized to ensure specimen failure in the gage section.

Experimental Procedure

High strain rate tension tests were conducted at SwRI using a Hopkinson bar system that allows direct tension loading of the specimen. The tensile load is applied directly to the specimen versus indirect tension systems, such as that developed by Lindholm [7]. Direct tension systems are preferred as specimen pre-damage can occur with indirect tension SHPB setups since the specimen is loaded in compression before pulling it in tension. The principle of the direct tension system is the same as for traditional SHPB systems. A projectile (30 or 60-cm long) travels down the barrel and impacts a reaction mass; the stress wave is reflected directly through the tensile specimen. The projectile, incident and transmitter bars are maraging steel; the bar diameter is 25-mm. Reduction of the data to obtain stress-strain curves is identical to the analysis for traditional SHPB systems.

The high strain rate (~10^2 s^{-1}) tests were conducted using the SwRI direct tension bar system; welded and virgin specimens were tested. The maximum strain rate achieved for the SHPB tests was approximately 800 s^{-1}, owing to the long specimen gage length. The Al 5083 specimens were threaded into the bars. A different grip was utilized for the Al 6082 specimens; the grip adapter was threaded into the bars. Low strain rate (~10^{-4} s^{-1}) tension tests were also conducted using an MTS servohydraulic machine. These tests were performed on specimens with similar geometries to allow a direct comparison with the higher strain rate test results.

To obtain an accurate strain measurement, failure of the tensile specimen must occur on the initial pulse. Estimates of the strain are possible; post-test measurements on the specimen can also provide strain estimates. Since first pass failure does not always occur, strain gages were applied to some specimens in the HAZ region on either side of the weld. This strain data was used to “calibrate” the numerical simulations used to aid in interpretation of the experiments.

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