R. Sheet Steel Fatigue Characteristics Project (ASP 160[i])

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Objectives

- Compile the test data generated in the previous phases of the program into a user-friendly database that can be used in all phases of design and analysis of sheet-steel-vehicle bodies.
- Investigate the fatigue life of joints formed by spot welding, adhesive bonding and weld bonding (a combination of spot welding and adhesive bonding.
- Explore the fatigue responses of AHSSs after being subjected to metal inert gas (MIG) and laser-welded joining and compare this behavior with that of standard automotive steels.
- Assist the Joining Technology team in identifying the optimum welding parameters for laser- and MIG-welded joints, and develop a fatigue test program.

Approach

- Investigate the fatigue characteristics of resistance spot welding, a fusion process in which the metal pieces to be joined are melted and re-solidified via a brief, high-voltage electrical pulse, forming an alloy with a distinctly different microstructure than that of the parent metals. At the intersection of the weld nugget, or button, and the faying surfaces, a crack-like discontinuity is formed which is often the site of initial crack growth. In addition, the weld nugget itself may contain discontinuities (such as porosity), which can also become sites at which fatigue cracks form. The amount and type of discontinuities and thus the fatigue properties, can be affected to a considerable extent by the welding process. The microstructures of the joined metals are also changed in the area adjacent to the weld, which is known as the heat-affected zone (HAZ).

- Investigate the fatigue characteristics of adhesive bonding, which substitutes an entirely different material in place of the weld to act as the load-bearing connection. The adhesive must adhere to the metals being joined and resist interfacial fatigue failure at the adhesive/metal interface and within itself (cohesive failure).
- Investigate the fatigue characteristics of weld-bonding, which is a combination of adhesive bonding and spot welding..
- Investigate the previously unknown, or at best little known, factors that are expected either to improve or impact durability, and facilitate their modeling and simulation.
- Reduce the spot-welded adhesively-boned and weld-boned test data to a form that is useful to design engineers who perform vehicle structural analysis.
- Develop a test program to investigate the fatigue performance of gas metal arc welding (GMAW) – a fusion-welding process which results in continuous joints. However, under GMAW (or Metal Inert Gas/MIG) welding, a third "filler" metal is introduced under an arc and shielding gas, and, akin to spot-welding, alloys and microstructures are formed which are different from the metals being joined.
- Identify the parameters, including metal grades, metal thicknesses, coatings and joint configurations that impact the fatigue performance of GMAW welded joints.

Accomplishments

- Completed testing of spot-welds in mild steel and ultra-high-strength boron steel, and placed online, the knowledge base developed from the results.
- Developed a specification for fabricating MIG and laser-welded specimens, submitted a request for quotation, selected a contractor and awarded a construction contract.
- Completed fatigue testing of MIG welded specimens created by the Joining Technologies Team, ASP070.

Future Direction

- During the next fiscal year, the project team will complete fabrication of test samples and conduct the first phase of its own program of fatigue testing of metal inert gas (MIG) welds.

Introduction

Future and near-future vehicle designs are faced with several stringent requirements that impose conflicting demands on the vehicle designers. Safety, particularly crash energy management, must be improved while vehicle mass and cost are contained. Advanced high-strength steels, judiciously selected and applied, are currently the best candidates to achieve low-cost (compared with aluminum, magnesium and plastics), reliable materials for meeting these mandates. As structural components are optimized and thinner-gauge, higher-strength materials are assessed, the fatigue life of the areas where loads are transferred become increasingly important considerations. To assess the performance of a component in the design phase, the fatigue characteristics of not only the base material but the joints, where loads are transferred, must be known. This project has essentially completed testing various grades of steel and steel coupons that have been spot welded, adhesively bonded and weld bonded. Testing of gas metal arc welded (GMAW)- and laser-welded joints is under way.

Discussion

The effort to evaluate the fatigue characteristics of spot welds began in the 2002 fiscal year with presentations by key researchers on the current state of the work at DaimlerChrysler Corporation, Ford Motor Company, and General Motors Corporation. Based on these presentations, the Sheet Steel Fatigue Project Team has produced results beneficial to all three companies. Early in the planning, the Auto/Steel Partnership (A/SP) Joining Technologies

Team was consulted, and that team prepared the samples that were tested. This interaction ensured that the samples were joined using consistent procedures that were properly controlled and in adherence to the best current practices in sheet-metal joining in the automotive industry.

The following fatigue test parameters were agreed upon and carried out:

- Two modes of testing: tensile shear (Figure 1) and coach peel (Figure 2).
- A single thickness (1.6 mm) was selected to ensure that results were comparable between steel grades. A small, second, thinner gage (0.8 mm) was selected for a small satellite study (one AHSS & one HSLA) on the effects of gage thickness on fatigue.
- Because no such data were available for advanced high-strength steels, several grades in this class were tested.
- Testing was done at two R ratios: 0.1 and 0.3. The stress ratio, R, is defined as the ratio of the minimum stress to the maximum stress in the test cycle. Maximum and minimum values are algebraic, with tension designated as positive and compression negative.

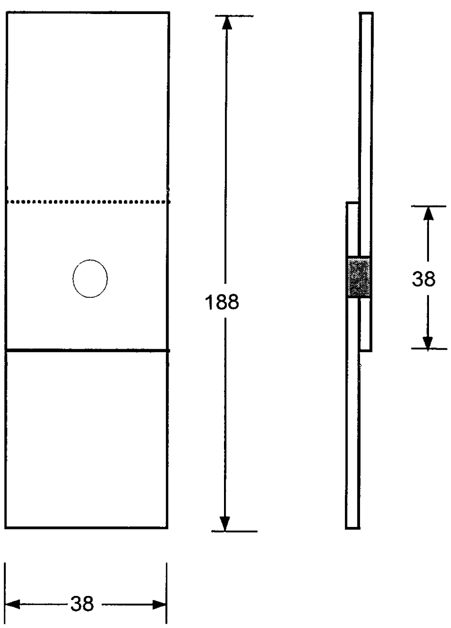

Figure 1. Spot-welded lap shear test specimen.

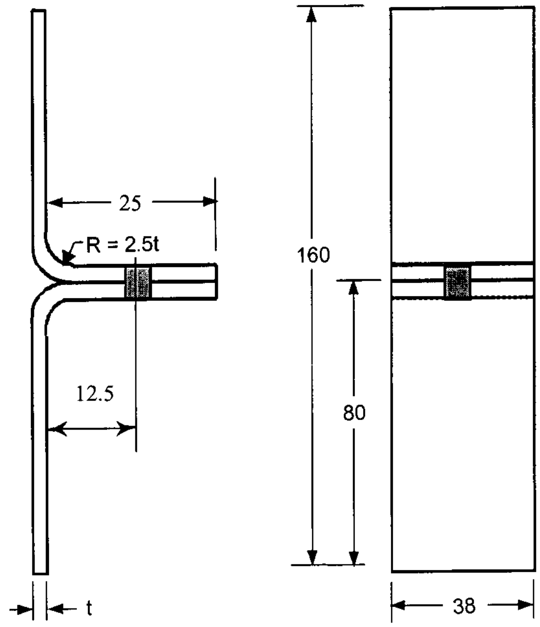

Figure 2. Coach peel test specimen.

- Eleven steel grades were tested.
- While the majority of testing was performed on spot-welded joints, the fatigue performance of adhesively-bonded and weld-bonded joints was explored in several tests series.

Two testing sources, of the nine invited to submit testing proposals, were selected to perform the fatigue experiments: The University of Missouri at Columbia, Missouri, and Westmoreland Mechanical Testing and Research, Inc. in Youngstown, Pennsylvania.

As the testing progressed and results were analyzed, the following tests were added for comparison purposes:

1. Testing at specified R ratios means that the maximum and minimum loads are constant throughout a given test. However, as the maximum load is increased to generate fatigue-curve data, the minimum loads also increase. This process is valuable for establishing baseline data. However, in the real world, load amplitudes can be expected to be variable. For this reason automotive-spectrum load tests, set to two different predetermined scaling, were run.

2. To investigate the effect of button size, fatigue studies were performed on specimens with a welding schedule that produced a smaller weld button.
3. At the request of the Joining Technologies Team, three test series were run using wide samples (125 mm vs. the standard 38 mm). The wider samples minimize rotation of the weld under load and allow negative R-ratios to be explored.

Gas Metal Arc Welded (GMAW) Joints

GMAW welding is the second most common welding process used on vehicle structures, with the rate of applications increasing yearly. GMAW or MIG welds are used not only on body members and sub-frames in passenger cars but also in frames for larger passenger vehicles, light trucks and sport-utility vehicles (SUVs). Therefore, the test samples will be made from two thickness ranges: 1.6 mm for body applications and 3.4 mm for frame applications. These target thicknesses, primarily based on material availability, represent typical as-welded material thicknesses found in body and frame applications respectively.

Frame members do not generally require as much formability as do body members, and they offer excellent opportunities for mass reduction through downgrading. Therefore, tests on frame joints will ultimately employ higher-strength materials than those specific to body members, but often result in similar numbers of welds and amount of weld area.

The Team agreed to four types of testing coupons. Each explores a different loading mode and reveals different information about the material performance: butt weld (Figure 3), single lap-shear (Figure 4), double lap-shear (Figure 5), and perch mount (Figure 6).

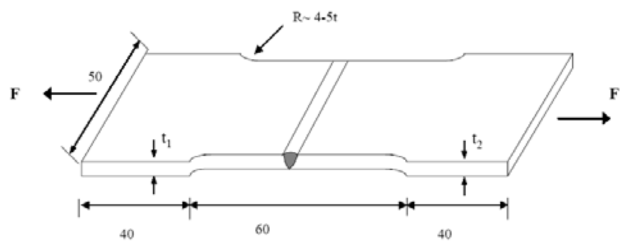

Figure 3. MIG butt-welded specimen.

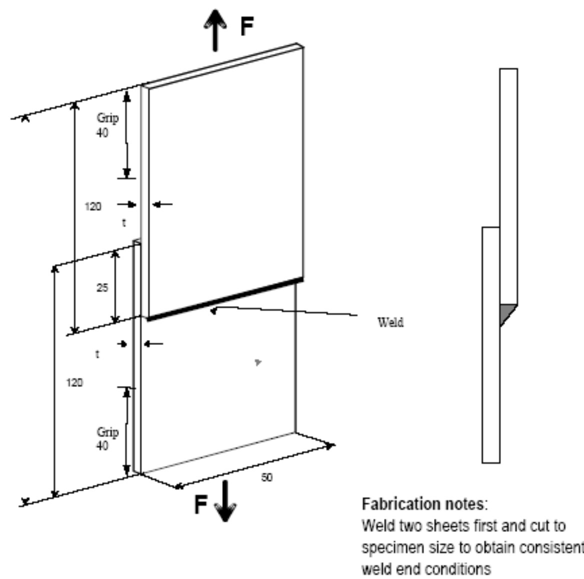

Figure 4. MIG welded single-lap shear specimen.

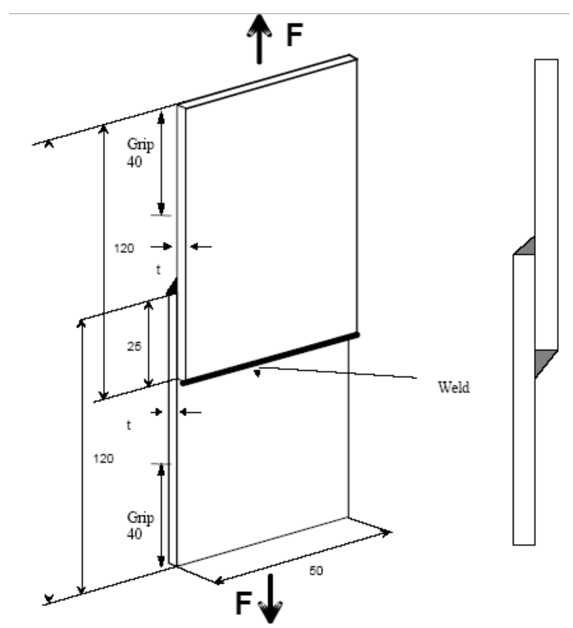

Figure 5. MIG welded double-lap shear specimen.

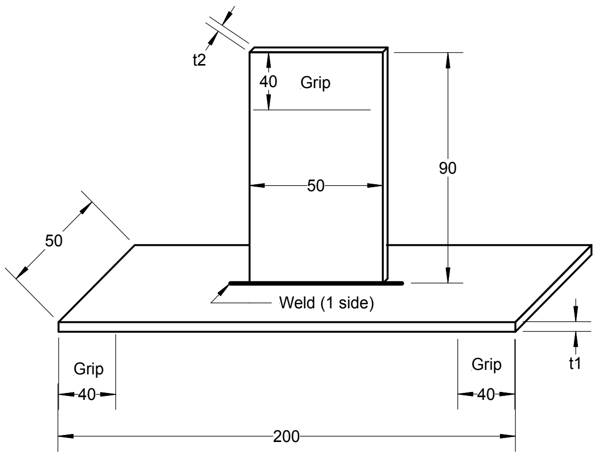

Figure 6. MIG welded perch mount specimen.

Results – Spot welds

Plotted in Figure 7 are all the tensile shear and coach-peel fatigue results for all nominal 1.6 mm gage materials with 7 mm-diameter spot weld, conventional steels and AHSS included. Data labels ending in R0.1 indicate R=0.1 loading and data labels ending R0.3 indicate R=0.3 loading. Run outs are plotted but not otherwise indicated in this figure.

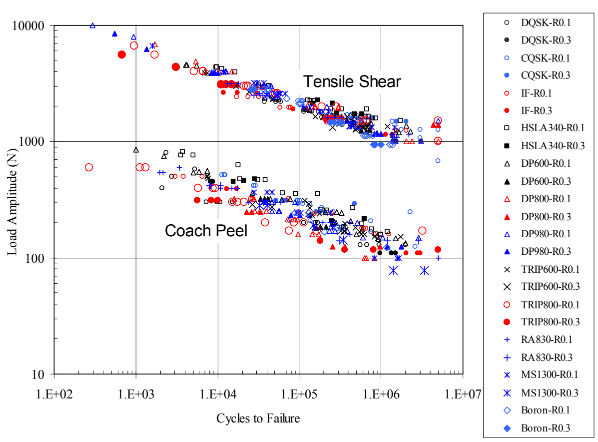

Figure 7. Fatigue results for all 1.6-mm-thick, 7 mm diameter nugget spot-welded materials.

Two thicknesses of HSLA340 (1.0 mm and 1.78 mm) and two thicknesses of DP600 (1.53 mm and 0.83 mm) are compared in Figure 8. The nominal button size for all specimens was 7.0 mm, and the welding parameters were held as similar as possible between the gages/grades without compromising strength. It was expected that the thinner gages would show shorter life because of the intrinsically higher stresses in the joint, and this result was indeed found in both materials.

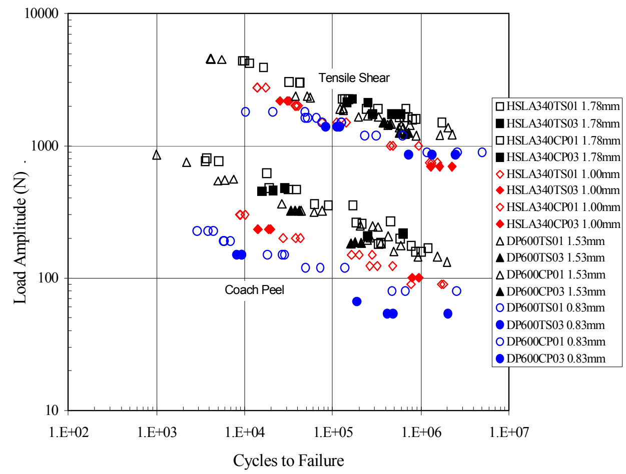

Figure 8. Effect of thickness on fatigue performance.

Results – Fusion Welds

Fatigue testing of specimens containing the fusion weld-line within the width of the specimen was conducted to assist the Joining Technology team in identifying the optimum welding parameters for laser- and MIG-welded joints. The dimensions of the specimens are shown in Figure 9. The weld location was centered between the edges of the sample and the robot travel was 25 mm total. This produced a weld with a start and a stop within the gage section of each specimen. GMAW welding of the DP780 AHSS was performed with 70 ski and 90 ski filler wires while GMAW welding of the DP600 AHSS was performed with only 70 ski filler wire. No filler was used with the laser welds.

The DP600 results of the fatigue, shown in Figure 10A, indicate no significant difference in performance between the AC, DC or laser-assisted GMAW welding processes. Similarly, the performance of the DP780 GMAW welds (Figure 10C) was not influenced by either the process type or the strength of the filler material used. Similar observations may be made concerning the laser processing presented in Figures 10B and 10D. The mean stress appears to be an insignificant factor in the fatigue performance of fusion-welded joints. This behavior can be seen in all the graphs in Figure 10.

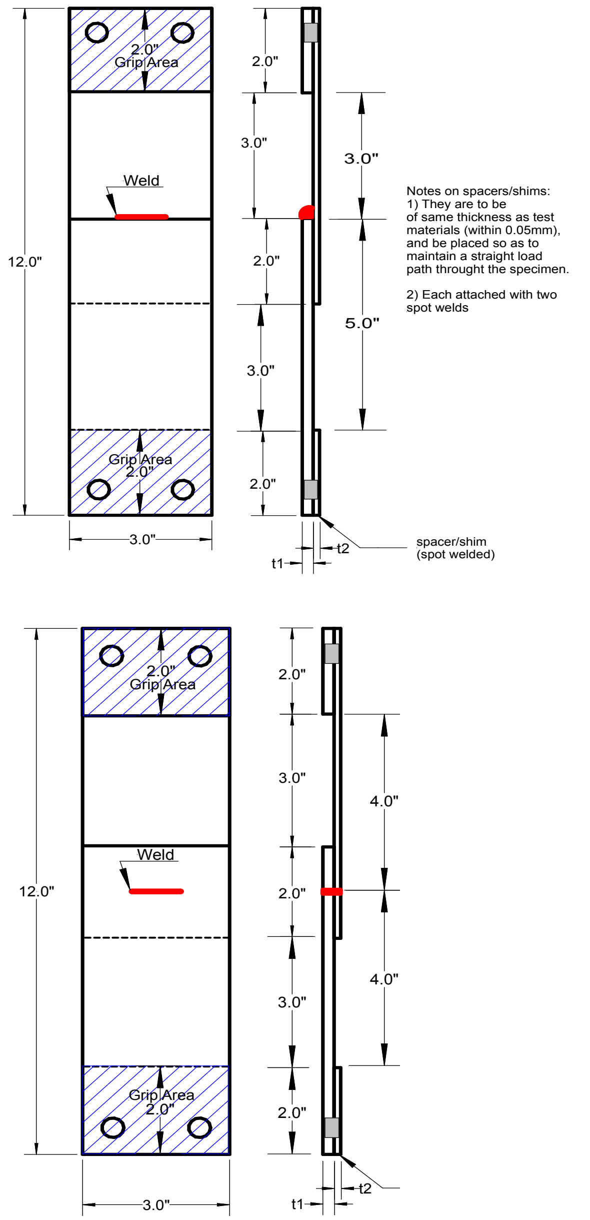

Figure 9. Schematic of specimens for a) GMAW and b) Laser weld fatigue tests. Dimensions in mm.

Conclusions

Analysis of test results indicates that the fatigue performance of a spot weld is independent of the materials being welded. This finding supports the initial understanding that the melting and resolidifying processes associated with spot welding form new alloys and make the properties and coating of the material(s) being joined, and the welding parameters, insignificant contributors to fatigue performance.

Similarly, the results clearly indicate that, within either the GMAW or laser-weld groups, the type of weld does not seem to influence (e.g., for GMAW it does not matter if the weld is AC, DC, or laser-assisted) the fatigue performance.

Presentations and Publications

1. "Sheet Steel Fatigue Group", Auto/Steel Partnership Program Review, Department of Energy, September 21, 2005.

2. "A/SP Sheet Steel Fatigue Committee," Joint Policy Board, Feb. 1, 2006.

3. J.J.F. Bonnen, Hari Agrawal, Mark A. Amaya, Raj Mohan Iyengar, HongTae Kang, A. K. Khosrovaneh, Todd M. Link, Hua Chu Shih, Matt Walp, Benda Yan, "Fatigue of Advanced High Strength Steel Spot Welds," 2006, Society of Automotive Engineers, SAE-2006-01-0978, pp. 19. *Republished in 2006 SAE Transactions.*

4. Kang, HongTae, "Evaluation of Spot Weld Fatigue Damage Parameters" 2006, Society of Automotive Engineers, SAE-2006-01-0978, pp. 19. *Republished in 2006 SAE Transactions.*

5. "Spot Welds, MIG Welds and their effect on the fatigue of AHSS steels," Mar. 10, 2006 (A/SP Frame group).

6. "Sheet Steel Fatigue Committee," A-S/P SPARC financial planning review, July 18, 2006.

7. "Spot Welds, MIG Welds and their effect on the fatigue of AHSS steels," Mar. 10, 2006 (Joining group)

8. "Fatigue of MIG Welds" AISI Wheel Task force meeting, Nov 18, 2005.

9. ASP Team Review, Dec. 15, 2005.

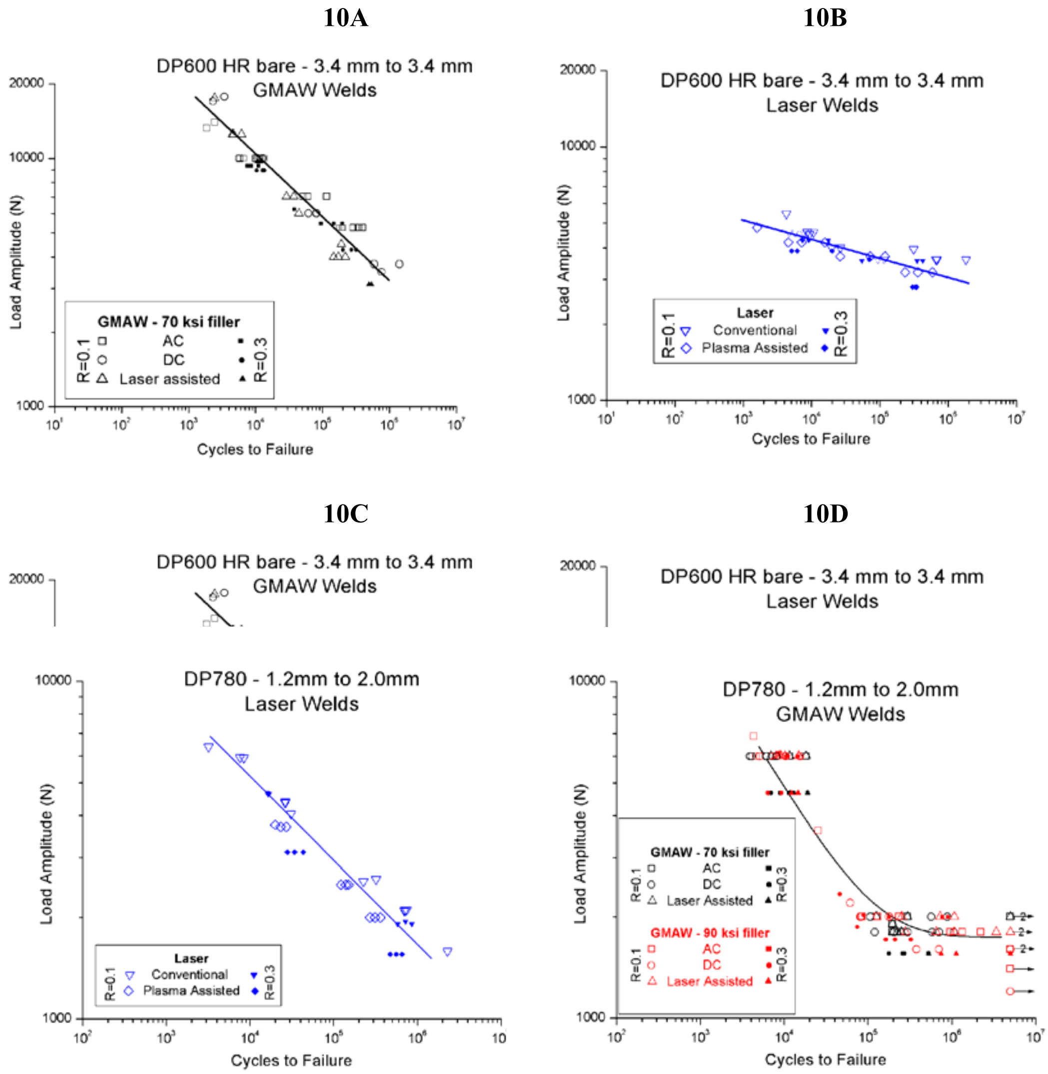

Figure 10. Fatigue performance evaluation of GMAW and laser welds in two advanced high-strength steels, DP600 hot-rolled, bare, and DP780 coated. Specimens for DP600 are 3.4 mm to 3.4 mm while the specimens for DP780 are 1.2 mm to 2.0 mm.

10. "Fatigue of AHSS SpotWelds," 2nd Annual Ford AHSS Conference, Oct. 18, 2005.

11. J.J.F. Bonnen and R. Mohan-Iyengar, "Fatigue of Spot Welds in Low-Carbon, High-Strength Low-Alloy, and Advanced High-Strength Steels and Fatigue of Fusion Welds in Advanced High-Strength Steels," 2006 Proceedings of the International Automotive Body Congress (IABC 2006), pp 12, 2006.

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[i] Denotes project 160 of the Auto/Steel Partnership (A/SP), the automotive-focus arm of the American Iron and Steel Institute. See www.a-sp.org. The A/SP co-funds projects with DOE through a Cooperative Agreement between DOE and the United Sates Automotive Materials Partnership (USAMP), one of the formal consortia of the United States Council for Automotive Research (USCAR), set up by the "Big Three" traditionally USA-based automakers to conduct joint pre-competitive research and development. See www.uscar.org.