P. Sheet Steel Fatigue Characteristics Project

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Contractor: U.S. Automotive Materials Partnership
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Objective

- 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 structural analysis of sheet steel vehicle bodies.
- Investigate the fatigue life of joints formed by spot welding, adhesive bonding and weld bonding (a combination of welding and adhesive bonding).
- Explore the fatigue response of advanced high strength steels (AHSS) after being subjected to metal inert gas (MIG) and laser-welded joining and compare this behavior with that of standard automotive steels.
- Help Joining Technologies team (See report 2.N) identify 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 metals that are joined. In addition, the weld nugget, or button, may contain discontinuities, which can become sites at which fatigue cracks form. The amount and type of discontinuities, and thus the fatigue properties, are 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 fatigue failure at the adhesive/metal interface and within itself.
- Investigate the fatigue characteristics of weld bonding.

- Investigate the previously unknown, or at best little known, factors that are expected either to improve or impact durability, and facilitate modeling and simulation.
- Reduce the spot-welded, adhesive-bonded and weld-bonded test data to a form that is useful to design engineers who perform vehicle structural analysis.
- Develop a test program to investigate the fatigue characteristics of MIG welding, a fusion process akin to spot welding that introduces a third "filler" metal, forms alloy microstructures different from the metals being joined, but also results in continuous joints.
- Identify the parameters of MIG-welded joints including metal grades, metal thicknesses, coatings and joint configurations that impact fatigue.

Accomplishments

- Defined the parameters of the sheet steel fatigue database and engaged a contractor to perform the work. The database has been constructed and has undergone several evaluations by team members. Work is expected to be complete by the end of 2005.
- Selected 27 combinations of steel grades and coatings for discontinuous-joint fatigue testing. Of the combinations, 22 were spot welded, and all are completed. Two of the combinations were weld bonded, and both have been completed. Three of the combinations were adhesive bonded, and have been completed.
- Re-inserted several tests that had previously been dropped, and have begun tests on spot-welded DQSK and Boron steels.
- Performed data reduction on spot-weld tests and issued a report.
- Contacted several consultants, invited them to present proposals for fatigue testing MIG welds, and selected one to develop a test program. The project team has approved the program and materials have been procured.
- Began a program to test MIG and laser welds in support of the Joining Technologies Project ASP070. Two test laboratories have been selected, and a contractor has been selected to perform the welding.

Future Direction

During the next fiscal year, the project team will do additional testing of spot-welded samples of mild steel and ultra high-strength boron steel. Upon completion, the information will be made available on the A/SP website and in published form through SAE. The project team will also begin its own program of fatigue testing MIG welds.

Introduction

Future and near-future vehicle designs are faced with several stringent requirements that impose conflicting demands on the vehicle designers. Safety must be improved while weight and cost are contained. Advanced high-strength steels, judiciously selected and applied, are currently the best candidates offering 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, fatigue life of the component and 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 the base material and the joints, where loads are transferred, must be known. This project has essentially completed testing various grades of steel that have been spot-welded, adhesively-bonded and weld-bonded, and is currently initiating tests on DQ and boron steel. Testing of MIG- and laser-welded joints is under way.

Discussion

Spot-Weld, Adhesive-Bonding and Weld-Bond Testing

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 (See report 2.P) 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 to be tested. This interaction ensured that the samples were joined using procedures that were properly controlled and in adherence to the best current practices in sheet metal joining.

The following test parameters were agreed upon and carried out:

Two modes of testing: tensile shear (Figure 1) and coach peel (Figure 2).

Since weld fatigue performance is independent of metal thickness for mild steels, high-strength low-alloy (HSLA) grades and advanced high-strength steels (AHSS), tests on these grades utilized only one metal thickness (1.6 mm).

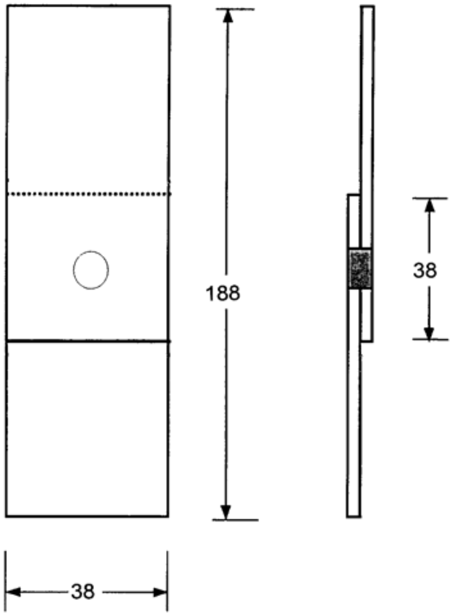


Figure 1. Spot-Welded Lap Shear Test Specimen

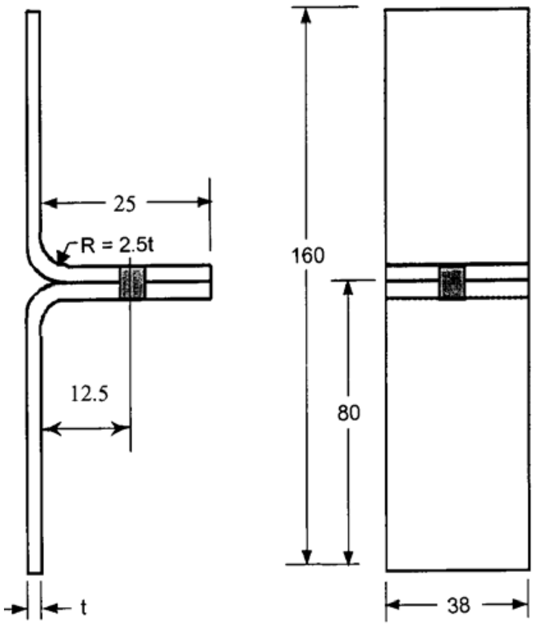


Figure 2. Coach Peel Test Specimen

Because no such data were available for AHSS, several grades in this class were tested at two thicknesses (1.6 mm and 0.7 mm).

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.

Eleven steel grades were tested. Most of the testing was performed on spot-welded joints. Several tests were also performed on adhesive-bonded and weld-bonded joints.

Two sources, of the nine invited to submit testing proposals, were selected to perform the work: The University of Missouri in 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, loads can be expected to vary. For this reason, two sets of automotive spectrum load tests, set to different predetermined load scalings, were run.
2. Two studies were performed on samples with a different welding schedule that produced a smaller weld button.
3. At the request of the Joining Technologies Team, three tests were run using wide samples (125 mm vs. the standard 38 mm). The wider samples minimize rotation of the weld under load.

Metal Inert Gas (MIG)-Welded Joints

MIG welding is the second most common welding process used on vehicle structures, and applications are expected to increase. MIG welds are used not only on body members and sub-frames, but also in frames for larger passenger vehicles, light trucks and sport-utility vehicles (SUV). Therefore, the test samples will be made from two thickness ranges: 1.6 mm for body applications and 3.4 mm for frame applications (boron steel will be tested at 1.8 mm thickness). These are target thicknesses based on material availability, and variations will be made where necessary on approval of the team.

Frame members do not generally require as much formability as body members, and they offer excellent opportunities for mass reduction through downgaging. Therefore, tests on frame joints will ultimately employ higher strength materials than those specific to body members.

The Team agreed to four modes of testing: butt weld (Figure 3), single-lap shear (Figure 4), double-lap shear (Figure 5), and perch mount (Figure 6).

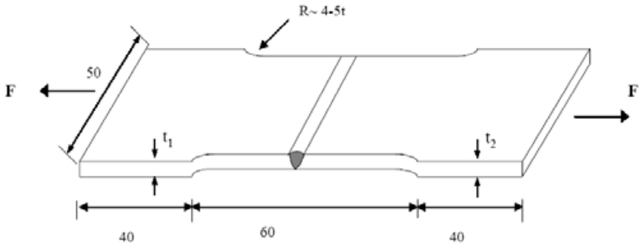
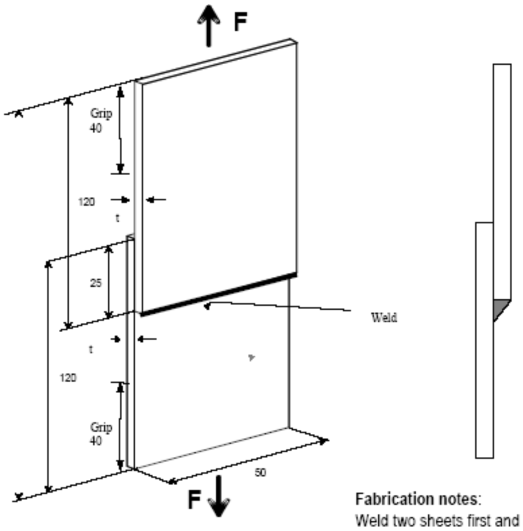


Figure 3. MIG-Butt-Welded Specimen



Fabrication notes:
Weld two sheets first and cut to specimen size to obtain consistent weld end conditions

Figure 4. MIG Welded Single-Lap Shear Specimen

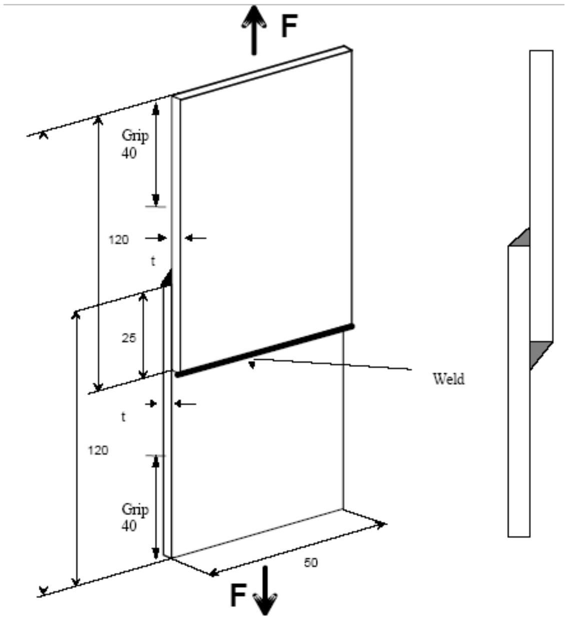


Figure 5. MIG Welded Double-Lap Shear Specimen

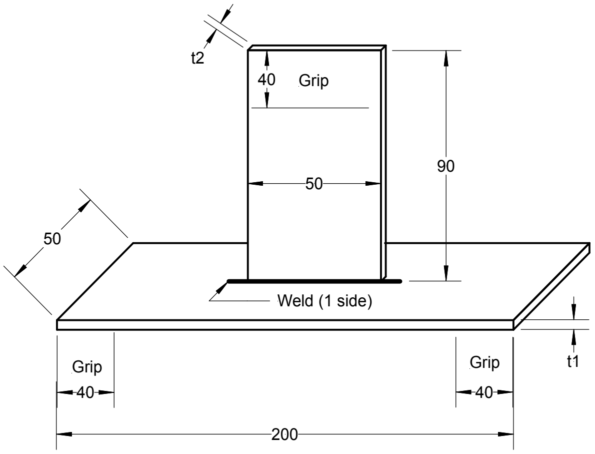


Figure 6. MIG-Welded Perch Mount Specimen

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.