

The Effect of Welding Dimensional Variability on the Fatigue Life of Gas Metal Arc Welded Joints

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ABSTRACT

Gas Metal Arc Welding (GMAW) is widely employed for joining relatively thick sheet steels in automotive body-in-white structures and frames. The GMAW process is very flexible for various joint geometries and has relatively high welding speed. However, fatigue failures can occur at welded joints subjected to various types of loads. Thus, vehicle design engineers need to understand the fatigue characteristics of welded joints produced by GMAW. Currently, automotive structures employ various advanced high strength steels (AHSS) such as dual-phase (DP) and transformation-induced plasticity (TRIP) steels to produce lighter vehicle structures with improved safety performance and fuel economy, and reduced harmful emissions. Relatively thick gages of AHSS are commonly joined to conventional high strength steels and/or mild steels using GMAW in current body-in-white structures and frames. Therefore, the Sheet Steel Fatigue Committee of Auto/Steel Partnership (A/S-P) has completed fatigue tests of GMAW joints for DP590 GA, SAE 1008, HSLA HR 420, DP600 HR, Boron, DQSK,

TRIP780 GI, and DP780 GI sheet steels. Dissimilar metal welded joints were tested for DP590GA and SAE1008, DP600 and SAE1008, TRIP780 and SAE1008, DP780 and SAE1008, and Boron and HSLA. The specimen configurations included single lap-shear, double lap-shear, butt weld, start-stop, and perch mount. The fatigue test results obtained from various sheet steels and specimen types showed that the strength of the base metal was not an important parameter to determine the GMAW fatigue life. For the same specimen type and sheet thickness, the test results for the different base materials collapsed nicely into a well defined curve when plotted in log-log scales. However, some specimen types showed greater scatter at long fatigue lives than others. This study investigated the sources of the scatter in terms of the dimensional variability of the weld geometry, such as weld toe radius, weld gap, horizontal weld leg length, and vertical weld leg length.

INTRODUCTION

Advanced High Strength Steels (AHSS) are now widely employed in the automotive industry for the weight reduction of vehicles because of their improved formability and higher strength. The application of AHSS means that the thickness of sheet steels can be reduced without losing structural performances of the vehicles. At the same time, it brings many challenges to automotive engineers.

Generally, vehicle structural integrity depends on the structural performance of welded joints. Thus, the Sheet Steel Fatigue Committee of the Auto/Steel Partnership (A/S-P) extensively studied the fatigue performance of welds of AHSS in the Phase-1 [1,2] and Phase-2 [3] programs, and these studies included Dual Phase (DP), martensitic grades (Boron), and TRansformation Induced Plasticity (TRIP) steels. Some previous studies reported fatigue properties of limited numbers of AHSS welded joints in [4,5,6,7,8,9].

The Sheet Steel Fatigue Committee of the A/S-P examined various specimen geometries and material combinations under cyclic loading. The specimen geometries included single lap-shear, double lap-shear, start-stop, butt-weld, and perch-mount specimens. AHSS were either welded to the same or different AHSS grades to characterize the fatigue performance of welded joints. Further, AHSS were also welded to low carbon and high strength low alloy steels (HSLA). The AHSS materials used in this study were DP600, DP590, DP780, TRIP780, and Boron while the conventional steels were SAE 1008 and HSLA 420. The only low carbon steel used was Draw Quality Specially Killed (DQSK). In this study, sheet thicknesses of 1.6mm and 3.4mm were used. Most specimens were fabricated with the same thickness, while a few specimen groups were welded between thickness of 1.6mm and 3.4mm.

The weld geometry was closely controlled as discussed in detail in references [1,2,3]. The critical dimensions of the welded specimens were measured including the vertical and horizontal weld leg lengths, the depth of penetration, and the convexity.

This paper discusses the fatigue test results of GMAW joints for Phase-2 that includes single lap-shear, double lap-shear, and start-stop specimen geometries. Most fatigue tests were conducted at the load ratio of $R=0.1$, but some iterations were also tested at a load ratio of $R=0.3$. This paper also discusses the effect of dimensional variability of weld geometry on fatigue life of the welded joints tested in Phase-1 and Phase-2. The dimensions evaluated are the horizontal and vertical weld leg lengths, sheet thicknesses, and weld gaps. Weld toe radii were also investigated for the single lap-shear and double lap-shear specimens.

EXPERIMENTAL PROCEDURE

FABRICATION OF SPECIMENS

The Committee made efforts to control the variability in the weld geometry dimensions that could affect to the fatigue life of the welded joints. To obtain more consistent welded specimens for single and double lap-shear specimens, a robotic welding machine was used to construct welds of long sheets with 70ksi (480MPa) filler wire. Then, the specimens were cut to final dimensions out of the long welded sheets with an abrasive water-jet cutter. While cutting the specimens from the long welded sheets, the portion of the welded sheets within 20mm of the weld stops and starts was excluded from specimens. The procedures and criteria of specimen fabrication are thoroughly described in references [1] and [2].

SPECIMEN TYPES AND GEOMETRIES FOR PHASE_1 AND PHASE_2

The weld configurations used in this study can be observed in automotive structures. The five specimen types included single lap-shear, double lap-shear, start-stop, butt weld, and perch mount were used in Phase-1. But only single lap-shear, double lap-shear, and start-stop specimens were used in Phase-2. Further information concerning the specimens used in Phases-1 and -2 is provided in references [1, 2]. The three specimen types used in Phase-2 have the same dimensions as those used in Phase-1. The specimen types employed in Phases-1 and 2 are shown in Figure A in APPENDIX.

Table 1 shows the information for materials, sheet thickness, and specimen configurations for Phase-1 and Phase-2. The specimens tested for Phase-1 were marked with “X” and for the one tested for Phase-2 were marked with “O”. Most fatigue tests were conducted at the load ratio of $R=0.1$, but some iterations (shaded in Table 1) were additionally tested at a load ratio of $R=0.3$. In each row of Table 1, if the same material is welded to itself, the specimen material is mentioned once. Both materials are mentioned if the joined materials were different.

MEASUREMENT OF WELD GEOMETRIC DIMENSIONS

Before conducting tensile and fatigue tests, only appropriate specimens were selected and critical geometrical dimensions were measured as shown in Figure B in APPENDIX. This information was used for identifying the sources of scatters in fatigue test results. Even though the Committee tightly controlled the dimensions of weld geometry, slight variations of these dimensions was inevitable. Some dimensions including weld toe radii were also measured after the testing was completed.

Table 1. Materials, gages and specimens types tested in Phase_1 and Phase_2.

Materials	Gauge (mm)	Single Lap-Shear	Double Lap-Shear	Start-Stop	Perch Mount
Boron	3.4	X	X		
Boron to HSLA	3.4	O	O	O	
DP590	1.6	X	X		
DP590 GI	1.6		O	O	
DP590 GI Stripped	1.6		O	O	
DP590 HR	3.4			O	
DP600	3.4	X	X	X	X
DP780	1.6	O	X		
DQSK	1.6		X		
HSLA	3.4	X	X	O	X
SAE1008	3.4	X	X		
TRIP780	1.6		X		
DP590 to SAE1008	1.6 to 3.4		X		
DP600 to SAE1008	3.4 to 3.4		X		
DP780 to SAE1008	1.6 to 3.4		X		
TRIP780 to SAE1008	1.6 to 3.4		X		

RESULTS AND DISCUSSION

TENSILE TESTS OF WELDED JOINTS

The ultimate strength (P_{max}) of the joints was obtained from tensile tests of the welded specimens. The tests were conducted at the loading rate of 2.54 mm/min. Tensile test results for Phase-1 were reported in reference [2], and the load versus displacement curves obtained from tensile tests for Phase-2 are shown in [Figure 1](#). As seen in the plots, the thick specimens (3.4mm) for single lap-shear (Boron-HSLA) and start-stop (Boron-HSLA, DP590 HR, HSLA) had higher ultimate strength than those of thin specimens (1.6mm). Also, double lap-shear specimens (DP590_GI and DP590_GI Stripped) showed superior ductility compared with that of start-stop specimens tested in Phase-2. The ductility of start-stop specimens was similar regardless of the sheet thicknesses. The ultimate strengths of single lap-shear and start-stop specimens were similar when the specimens were fabricated with the same sheet thickness and the same base metal combinations as shown for the Boron-HSLA specimens. The ultimate tensile strengths for the specimens tested in Phase_2 are shown in [Figure 2](#).

FATIGUE TEST RESULTS

All of the fatigue tests in Phase-2 were performed as those conducted in Phase-1. Further testing information can be found in Reference [2]. All of the fatigue tests conducted in Phase-2 were load controlled testing with load ratio (P_{min}/P_{max}) of $R=0.1$. The single lap-shear of DP780 (1.6mm) was additionally tested at $R=0.3$ to investigate the influence of mean stress on fatigue life of the welded joints. Fatigue tests

were conducted at a minimum of three (3) different load levels with at least three valid repetitions within each load level. The failure criterion was defined as the full separation of the specimen. Fatigue tests were commonly discontinued after a *runout* life of 5×10^6 cycles. However, if a specimen experienced greater than a 20% increase in compliance by the runout life, the test was continued until specimen failure.

Double Lap-Shear Test Results

The results for Phase-2 are shown in [Figure 3](#). Three specimen configurations were tested in Phase 2 with DP590_GI (1.6mm), DP590_GI Stripped (1.6mm), and Boron-HSLA (3.4mm). All the data points form a fairly narrow and consistent band. [Figure 4](#) shows the effect of sheet thickness on fatigue life of welded joints tested at Phase-1 and Phase-2. The effect of the sheet thickness on fatigue life of welded joints was not clear as observed in single lap-shear and start-stop specimens. The same trend was observed in Phase-1. Typically, cracking started at the middle of the specimens along the weld toe line and propagated in the sheet thickness direction. The direction of the fatigue crack propagation can be observed in [Figure 5](#). Thick specimens showed smooth failure surfaces and the cracks were developed along the weldline. On the other hand, the crack surfaces of the thin specimens showed more irregular shapes compared to those of the thick ones. [Figure 6](#) shows the load range versus fatigue life of the specimens obtained from Phase-1 and Phase-2. Runouts are marked with an ellipse.

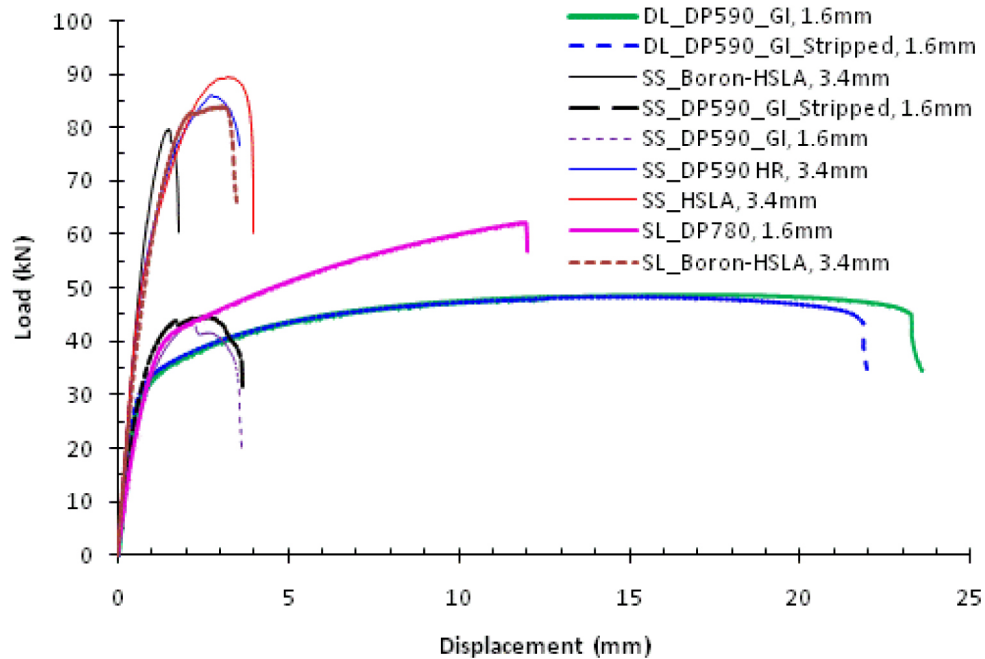


Figure 1. Load-displacement curves obtained front tensile tests of double lap (DL), single lap (SL), and start-stop (SS) specimens for Phase-2.

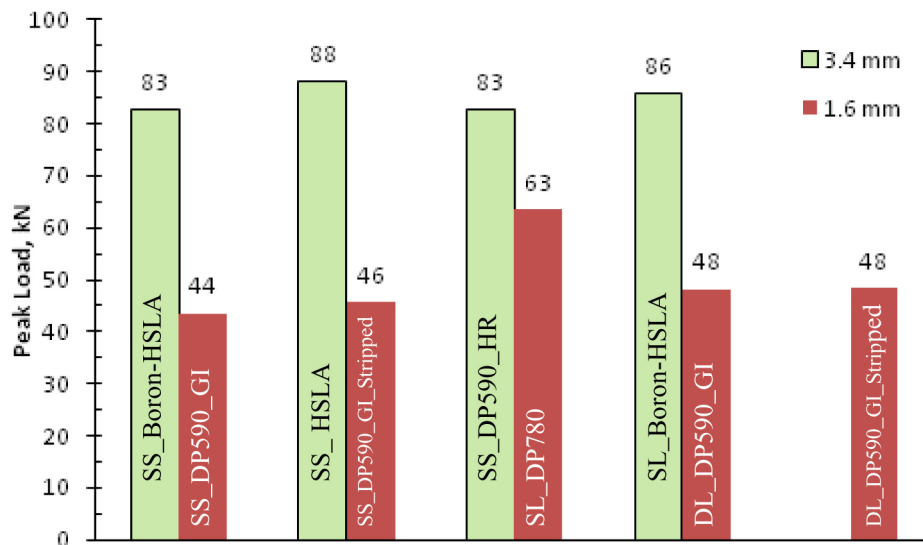


Figure 2. Tensile test results of double lap (DL), single lap (SL), and start-stop (SS) specimens for Phase-2.

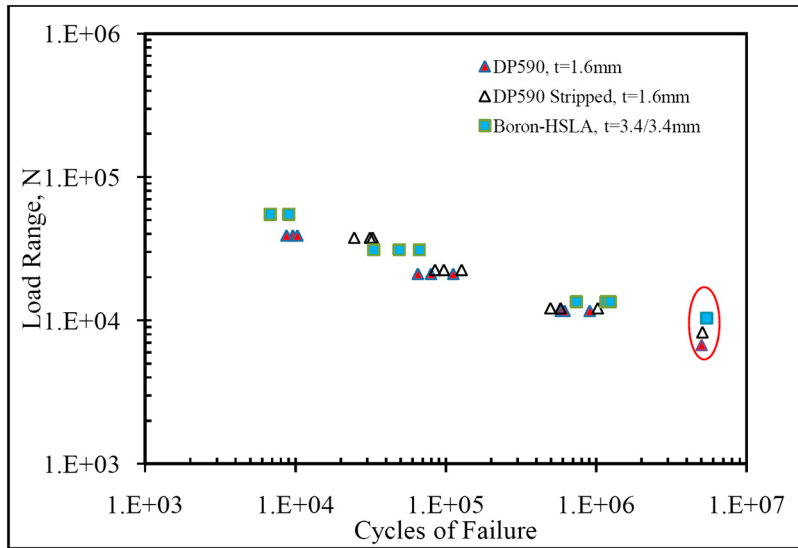


Figure 3. Test results for double lap-shear specimens front Phase-2.

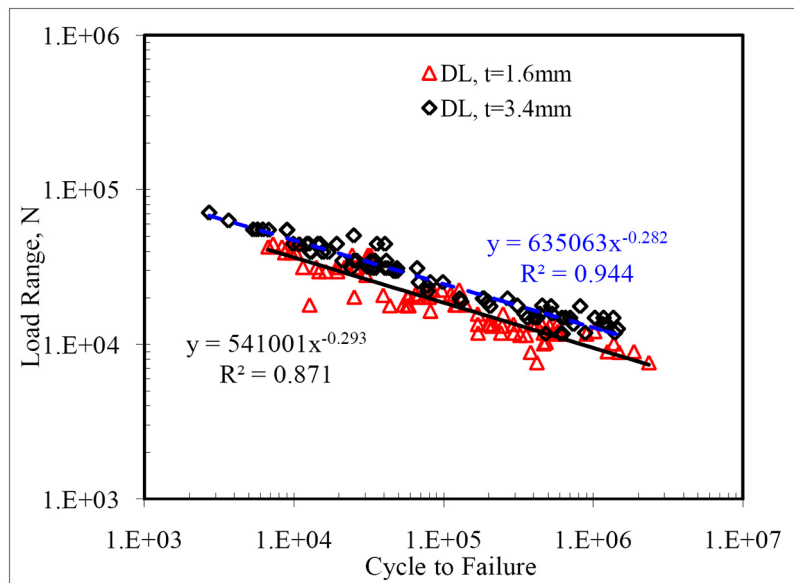


Figure 4. Sheet thickness effect on fatigue life of welded joints for double lap-shear specimens front Phase-1 and 2.