

Friction Stir Spot Welding (FSSW) of Advanced High Strength Steel (AHSS)

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ABSTRACT

Friction stir spot welding (FSSW) is applied to join advanced high strength steels (AHSS): galvanized dual phase 780 MPa steel (DP780GA), transformation induced plasticity 780 MPa steel (TRIP780), and hot-stamped boron steel (HSBS). A low-cost Si_3N_4 ceramic tool was developed and used for making welds in this study instead of polycrystalline cubic boron nitride (PCBN) material used in earlier studies. FSSW has the advantages of solid-state, low-temperature process, and the ability of joining dissimilar grade of steels and thicknesses. Two different tool shoulder geometries, concave with smooth surface and convex with spiral pattern, were used in the study. Welds were made by a 2-step displacement control process with weld time of 4, 6, and 10 seconds. Static tensile lap-shear strength achieved 16.4 kN for DP780GA-HSBS and 13.2kN for TRIP780-HSBS, above the spot weld strength requirements by AWS. Nugget pull-out was the failure mode of the joint. The joining mechanism was illustrated from the cross-section micrographs. Microhardness measurement showed hardening in the upper sheet steel (DP780GA or TRIP780) in the weld, but softening of HSBS in the heat-affected zone (HAZ). The study demonstrated the feasibility of making high-strength AHSS spot welds with low-cost tools.

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INTRODUCTION

Advanced high strength steels (AHSS) provide benefits to the automotive body structure. They offer opportunities in reducing the weight, or increasing the strength and improving safety without adding weight [1]. AHSS are multi-phase steels, which contain martensite, bainite, and/or retained austenite in quantities sufficient to produce unique mechanical properties. Compared to conventional high-strength steels of comparable strength, AHSS exhibit higher levels of ductility. Within the AHSS category are two distinct families of steel types: one, including dual phase (DP) and transformation induced plasticity (TRIP) steels, is the high strength steels with increased formability for more complex part designs. The second family has increased tensile strength while maintaining good crush resistance and energy absorption. These are complex phase (CP) and martensitic (MS), and hot-stamped boron (HSBS) steels [2].

One of the major technical challenges of AHSS manufacturing is joining. Resistance spot welding (RSW) is the most popular joining method for automotive body construction. While the RSW is capable of welding of DP and TRIP steels up to a strength of 590 MPa, the weldability of some of the higher strength steels is still being worked on [2]. Due to the nature of fusion welding in RSW, issues such as heat-affected zone (HAZ) and weld metal hardening or softening, weld cracking and propensity for generating weld defects are the concerns for RSW. Addition of elements such as C, Al, Si, Mn pose a challenge for weldability [1,3]. When welding different thickness and dissimilar AHSS, material resistivity, dilution and hardenability must be considered [1].

With the limitation of RSW, friction stir spot welding (FSSW), a solid state joining process, has been demonstrated to be successful in joining AHSS such as DP600, martensitic steel [4], uncoated and galvanized DP780 [5], and hot-stamped boron steel (HSBS) [6]. The joint strengths have

achieved the spot weld requirements by American Welding Society [7].

Polycrystalline cubic boron nitride (PCBN) has been the material of choice for FSSW tools for steels and AHSS in the previous studies. The high cost of the tool was one of the major obstacles in implementing the process economically [5]. The other issue is the high load imposed on tool during welding, often reaching 30 kN [5] which adds additional burden in designing suitable (e.g. robotic) FSSW equipment for mass production.

The objectives of this study are two-fold: (1) to test the feasibility of a low-cost tool material, and (2) to study the effect of tool geometry on the load imposed on the tool. Silicon nitride (Si_3N_4) tools made by a direct injection molding process were chosen as a low-cost alternative to PCBN. Two different geometries of the tool shoulder were chosen: concave and convex shapes. AHSS materials chosen to be welded were one with relative difficulties for RSW: DP780GA (galvannealed dual phase steel with tensile strength of 780 MPa), TRIP780 (TRIP steel with tensile strength of 780 MPa), and HSBS. Mixed-grade steels were welded: DP780GA to HSBS and TRIP780 to HSBS.

EXPERIMENTS

Three steel materials were used in this study: 1.5 mm thick galvannealed dual phase steel DP780GA, 1.4 mm thick bare transformation induced plasticity steel TRIP780, and 1.5 mm thick bare HSBS. Each was cut to strips of 100 mm in length and 30 mm in width. Two material combinations were chosen for FSSW: DP780GA-HSBS (DP780GA facing the tool tip and HSBS facing the anvil), and TRIP780-HSBS (TRIP780 facing the tool tip and HSBS facing the anvil). The strips were placed in lap joint configuration with an overlap of 35 mm. FSSW was made at the center of the overlapping section.

FSSW tools were made of EKasin® silicon nitride (Si_3N_4) from Ceradyne, Inc. The tools were made by direct injection molding of Si_3N_4 , which can be very economical. The tools had shoulder diameters of 10 mm. The tips are 5 mm in diameter and 2 mm in length. Three equally spaced flat features were cut on the end of the pins to aid with stirring action. Two different shapes of shoulders were used. One is labeled as DIM97, which has a 7° concavity and smooth shoulder, as shown in Figure 1. The second one, labeled as SN11, has 6° convex spiral shoulder, as shown in Figure 2. The designs follow the similar geometries of PCBN tools of BN97 and BN46 used in previous study [5].

The FSSW process was performed on a MTS-ISTIR system in displacement control with 2 steps. The first step was to plunge the tool to a depth 0.3 mm shallower than the total thickness of two-sheet stack-ups, and the second step was to plunge further 0.2 mm so that the remaining thickness was 0.1 mm from the tip to the anvil. In the case of FSSW of DP780GA-HSBS with total sheet thickness of 2.9 mm, the first step plunges 2.6 mm, and the second step plunges the

tool for additional 0.2 mm to a final depth of 2.8 mm. In the case of FSSW of TRIP 780-HSBS with total thickness of 2.8 mm, the first step plunges 2.5 mm, and the second step plunges the tool to a final depth of 2.7 mm. Three plunge speeds were chosen for the duration of the first step 2, 4, and 8 second. The duration of second step was always 2 second. This gives the total duration of the process to be 4, 6 or 10 second. The rotational speed of the tool was chosen at 800 rpm.

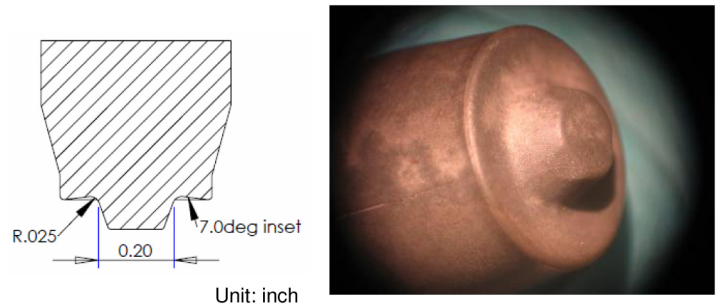


Figure 1. FSSW tool geometry of DIM97.

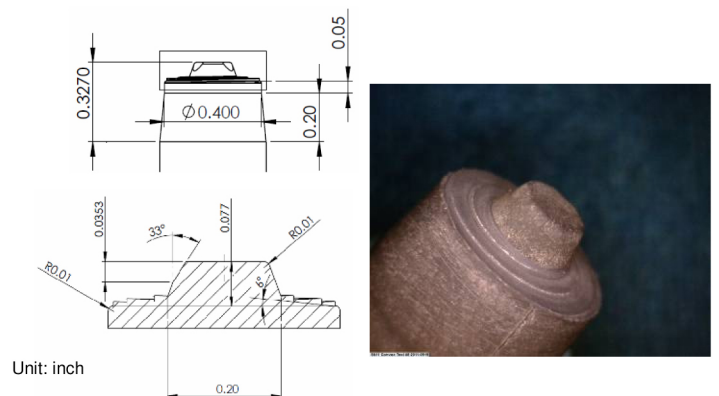


Figure 2. FSSW tool geometry of SN11.

Temperature during the welding is recorded by a thermocouple located in the anvil, just below the contact surface.

Four repetitive welds were made for each combination of material, tool, and welding parameters. Three were tested to get an averaged value of joint strength. The fourth weld was reserved for cross-section metallography and microhardness mapping. The lap-shear tests were conducted on an Instron machine at a crosshead speed of 10 mm/min without added spacer to offset the centerline. Selected samples were cross-sectioned and examined by optical microscope. Vickers microhardness map was obtained on cross-section samples with a LECO Automatic Hardness Testing System with 300 gm load and indentation spacing of 150 μm .

RESULTS AND DISCUSSIONS

Figure 3 and 4 show the failure load from lap-shear tests of DP780GA-HSBS and TRIP780-HSBS combinations.