Accurate Spot Weld Testing
for Automotive Applications

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Typical vehicles contain more than 3000 spot welds—whose failure must be accurately predicted in crash simulations. A new test method is proving useful for accurately defining spot weld failure parameters.

Resistance spot welding (RSW) remains the most common joining method in the automobile industry, where it is used to weld sheet metal to form vehicle bodies and other parts. The main advantages of RSW include high speed and low cost, the ability to weld a wide range of joint configurations with the same gun, lack of weld consumables, and ease of high volume automation. RSW is used to join many ferrous and non-ferrous alloys such as carbon steels, high strength low-alloy steels, stainless steels, aluminum and light alloys, nickel alloys, and galvanized sheets.

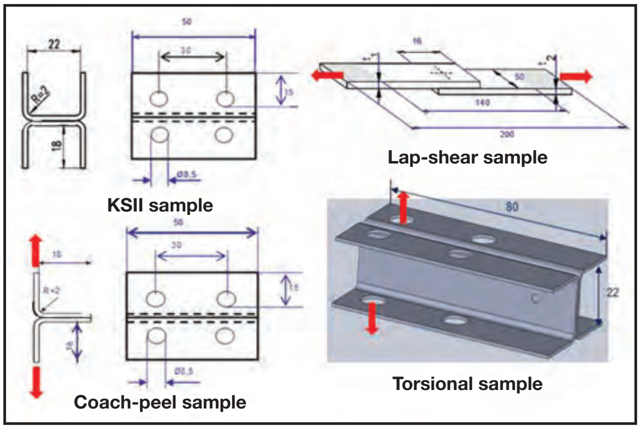

Fig. 1 — *Small sample types used to develop spot weld failure parameters.*

Because a typical vehicle contains approximately 3000 spot welds, their joint strength is important to the overall structural integrity and safety. To reduce weight and improve vehicle safety, higher strength materials are continuously implemented with each new generation of vehicles. Spot weld failure during automotive crash testing is a critical issue due to the high hardness and brittleness of these welds for high and ultra-high strength steels. To achieve optimal vehicle design, spot weld failure must be accurately predicted in crash simulations. Over the past few decades, several failure models have been developed and implemented in the widely used LS-DYNA software to predict crash performance. Equation 1 shows one of the spot weld failure models[1,2]:

$$f=\left(\frac{\sigma_N}{S_N\left(\dot{\varepsilon}_{eff}\right)}\right)^{n_N}+\left(\frac{\sigma_B}{S_B\left(\dot{\varepsilon}_{eff}\right)}\right)^{n_B}+\left(\frac{\tau}{S_S\left(\dot{\varepsilon}_{eff}\right)}\right)^{n_S}\geq 1 \quad (1)$$

where σ_N, σ_B, and τ are axial, bending, and shear stress, respectively, $\dot{\varepsilon}_{eff}$ is effective strain rate, and $S_N(\dot{\varepsilon}_{eff})$, $S_B(\dot{\varepsilon}_{eff})$, and $S_S(\dot{\varepsilon}_{eff})$ are strain-rate dependent axial, bending, and shear strength. The model includes six empirical failure parameters (S_N, S_B, S_S, n_N, n_B, and n_S). By providing a set of failure parameters, a failure surface can be defined by Equation 1. If a stress state is outside the surface ($f>1$), the spot weld will fail.

These failure parameters are specific to each weld size and material stack-up. Until now, there was not a standard testing method for developing these parameters and few research programs have tried to create one[1-4]. A testing protocol developed at EWI for the purpose of creating spot weld failure parameters has been used since 2010 to establish these parameters for automotive manufacturers for a range of steel and aluminum stack-ups. Crash simulations in full-vehicle models show that the failure parameters created by this method are accurate for predicting the initiation of spot weld failure by comparing results with experimental data.

Test sample design

Small samples including one spot weld were designed based on past experience as shown in Fig. 1[2,4]. Sample designs can be classified into four basic types—KSII, lap-shear, coach-peel, and torsional. The *KSII sample* is designed to test spot weld axial strength when a load is applied in a 90° direction (normal to the spot weld interface), and the spot weld shear strength when a load is applied in a 0° direction (parallel to the spot weld interface). The KSII sample can also be used to evaluate joint strength for a combination of axial, shear, and bending load by testing in a 30° and 60° direction. The *lap-shear sample* is designed to evaluate both tensile and shear joint strength, as the joint rotates during loading due to the sheet metal's low stiffness. *Coach-peel* and *torsional samples* are designed to evaluate spot weld bending strength and shear strength (for a torque load), respectively.

The *T-section sample* as shown in Fig. 2 is designed to test spot weld failure at the component level by applying a transverse load and

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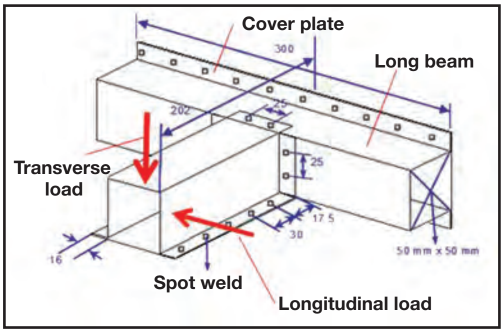
Fig. 2 — *A component sample used to validate spot weld failure parameters.*



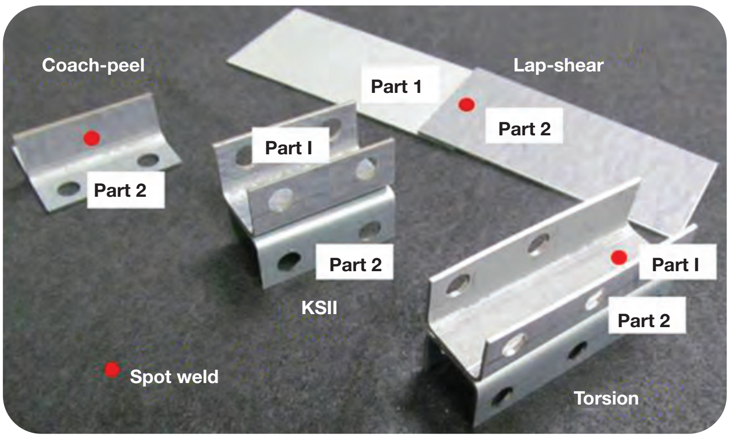


Fig. 3 — *Welded versions of small samples.*

longitudinal load, respectively[5]. Testing was modeled using finite element analysis (FEA) to predict spot weld failures by inputting the failure parameters developed from the small samples, and then comparing these with testing results to validate the spot weld failure parameters.

Sample fabrication

Sheet metal was cut and formed into the C-channel shape according to the dimensions shown in Fig. 1. Weld fixtures were designed to prepare the samples and welding procedures were supplied by the automotive manufacturer. Figure 3 shows the welded KSII, coach-peel, lap-shear, and torsional samples with one spot weld. Weld size could be either the minimum size (normally $4\sqrt{t}$, where t is the sheet thickness in mm) or the actual weld size used in the vehicle. If the minimum size is selected, the developed failure parameters will be conservative, which is preferred for automotive structure design.

Holes were drilled in samples prior to welding, for bolting samples to fixtures and eliminating slippage during testing. Holes were also added to the cover plate on the long beam of the T-section sample, to attach the plate to the fixture.

Small sample testing

Sample testing must be conducted with different strain rates because a spot weld's axial strength, shear strength, and bending strength is a function of strain rate as shown in Equation 1. Typically, three strain rate tests are conducted including static testing for low strain rate, intermediate speed testing for medium strain rate, and high-speed testing for high strain rate. Note that high-speed testing is more important than static testing because most crash impact testing is conducted at high speeds, such as 50 mph or higher.

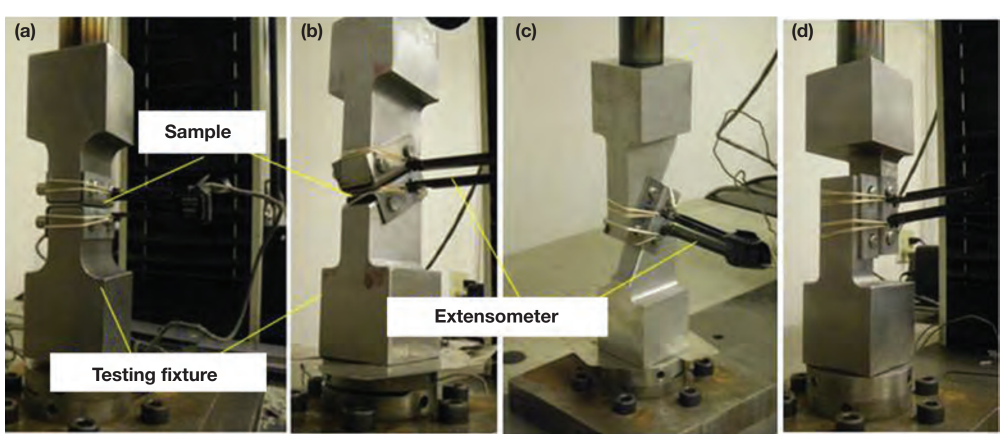
Testing fixtures are designed to simulate the rigid conditions in automotive spot welded structures for small sample testing. Figures 4 and 5 show the testing fixture used for KSII-90°, KSII-60°, KSII-30°, KSII-0°, lap-shear, coach-peel, and torsional samples. The same testing fixtures are used for static, intermediate, and high-speed testing.

Both static and intermediate speed tests are performed with an electromechanical test system at a 50 mm/min and 50 mm/second crosshead speed, respectively. Sample displacement is measured using both an extensometer, as shown in Figs. 4 and 5, and the crosshead positioning system. Load is recorded by a load cell.

Figure 6 shows a typical *load vs. time* and *displacement vs. time* graph for a spot weld static test. Five tests were conducted for the same conditions to check data repeatability. Small variations resulting from weld size differences were found, and the peak load was used to determine spot weld joint strength for developing failure parameters. Load curve after peak load was used to determine damage parameters. Figure 7 shows broken samples for KSII, coach-peel, and lap-shear testing. KSII and coach-peel samples exhibit pullout-button failure, while the lap-shear sample shows interfacial failure.

High-speed tests were performed on a modified Dynatup Model 8250 (General Research Corp.) instrumented drop weight tower, shown in Fig. 8. Consistent with static tests, the same upper and lower sample holders using bolts

Fig. 4 — *KSII sample testing: (a) 90° loading, (b) 60° loading, (c) 30° loading, and (d) 0° loading.*



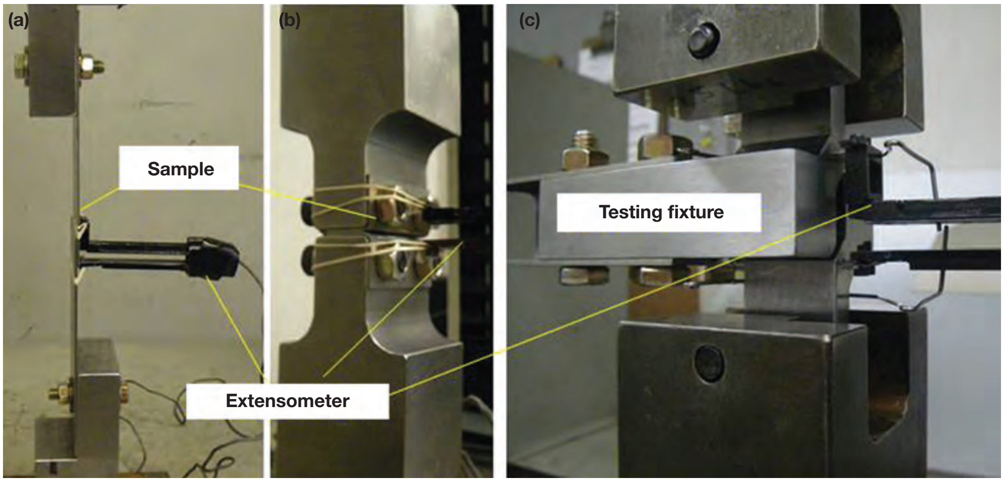


Fig. 5 — *Testing of (a) lap-shear, (b) coach-peel, and (c) torsional samples.*

or pin connections were used for high-speed testing. Impact load was measured at the reaction point during the impact event using a strain gauge-type load cell attached below the rigid table structure. The load cell was connected to the welded coupon through the upper sample holder. The moving head was dropped from a free-fall height of 2.59 m (8.5 ft). The moving mass contacted an impact bar extending through the structure and connected to the lower sample holder. Load was transmitted directly to the bottom attachment point of the test coupon. Sample displacement was measured using a linear voltage displacement transducer (LVDT) placed between sample attachment points.

T-section sample testing

Longitudinal and transverse loading were applied during T-section sample testing, as illustrated in Fig. 2. T-section static testing was conducted with an electromechanical test system and a fixture was designed to rigidly secure the T-section sample during testing. The fixture includes a 45 × 45-mm backing bar inside the long beam to bolt the sample to the fixture base through the holes in the cover plate (Fig. 2).

High-speed testing was conducted using an MTS drop tower, instrumented with an LVDT and load cells. The same rigid test fixture used for the static tests was used in the high-speed testing. Figure 9 shows broken T-samples for transverse and longitudinal loading. For transverse loading, spot welds were broken at the cover plate joined to the long beam. For longitudinal loading, spot welds were broken at the long beam to short beam intersection. FEA was conducted using the failure parameters developed from the small samples to predict spot weld failure and validate the final failure parameters.

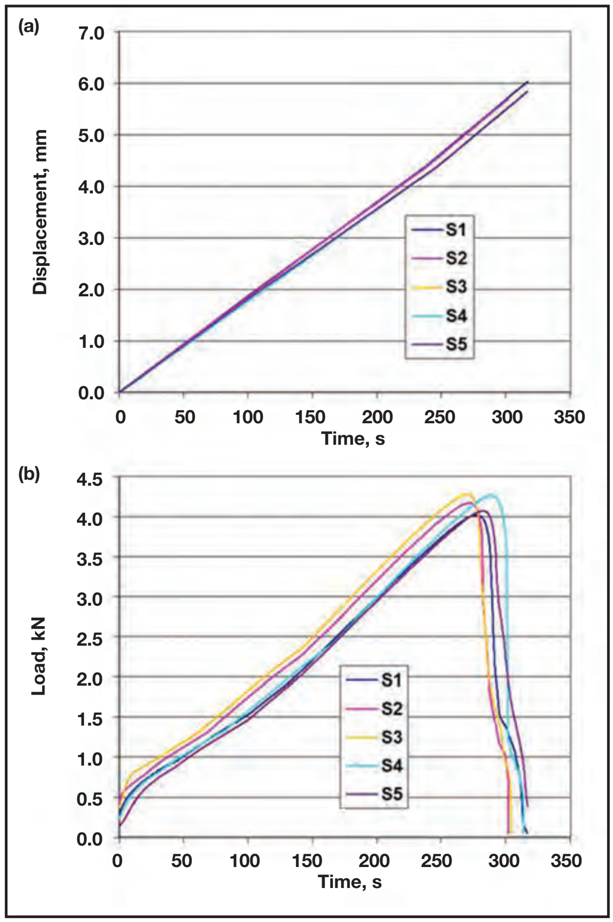


Fig. 6 — *Typical static testing results for KSII 90° samples: (a) Displacement and (b) load curve for a spot weld.*

Summary

A test method was developed to create spot weld failure parameters (joint strength at axial, shear, torsional, and combined loading) for crash simulation during automotive structure design. The method includes testing small samples and T-section samples. Small samples consisting of KSII, lap-shear, coach-peel, and torsional configurations were designed to evaluate the axial, shear, and bending strength of spot welds, as well as the strength during combined axial, shear, and bending loads. T-section samples were de-

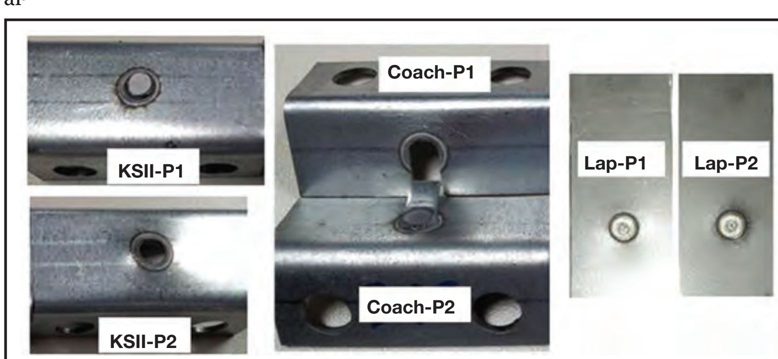


Fig. 7 — *Typical broken samples for KSII, coach-peel, and lap-shear testing.*

Fig. 8 — *Drop tower for high speed sample testing.*

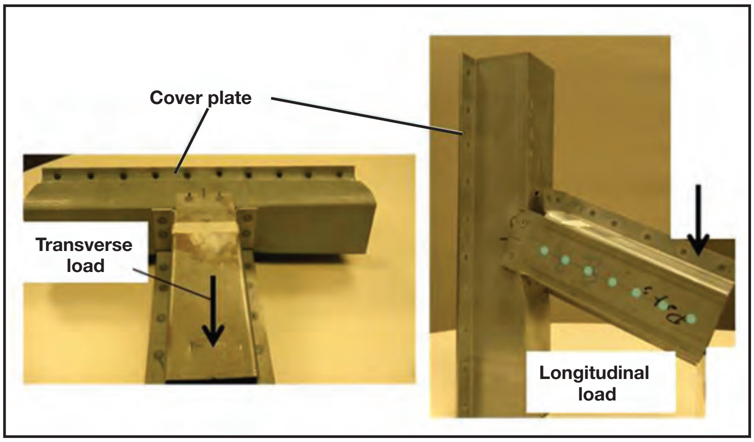


Fig. 9 — *Broken T-Section samples.*

signed and tested to validate failure parameters at the component level. ❍

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