BY ERIC PAKALNINS

Q: Our company is in the process of quoting the resistance spot welding of several small automotive assemblies. We must provide the customer with metallographic results using AWS D8.1M:2007, *Specification for Automotive Weld Quality — Resistance Spot Welding of Steel*. This standard contains a large amount of information. Could you review and discuss the metallographic information I need to know to satisfy my customer's request?

A: Before discussing the metallographic requirements of AWS D8.1M:2007 (Ref. 1), it is important to understand the specification's scope. This specification applies to resistance spot welds in automotive steels and is intended to define their desired weld quality. It does this by addressing the needs of both the production floor and the laboratory. Welding experts from various automotive and steel companies, and consulting/testing organizations agreed to the quality characteristics and metrics pertaining to these resistance spot welds. The evaluation methods and inspection criteria specified in this standard include both nondestructive and destructive elements and can be used to 1) evaluate welding equipment capability and procedures (such as weld schedules), and 2) characterize the weldability of a particular steel. Further, Section 5 (Spot Weld Acceptance Criteria) states that not all inspection methods have to be applied to determine weld quality. In other words, it is up to the customer to determine what test methods are appropriate to define weld quality for a particular application.

Before discussing the metallographic information your customer has requested, it is important to note that D8.1M:2007 classifies steels used in resistance spot welding by their minimum ultimate tensile strength (UTS). Table 1 in the specification has steels grouped into four categories: Low Strength (<350 MPa), Intermediate Strength (350 to 500 MPa), High Strength (>500 MPa up to and including 800 MPa), and Ultra High Strength (>800 MPa). The specification does not require knowledge of what group the steels are from when metallographically inspecting the resistance spot weld(s). However, it is recommended to have this information. Please note that it is necessary to know the steel classification when performing nondestructive surface inspections and other destructive inspections such as peel/chisel tests and shear/cross-tension load tests.

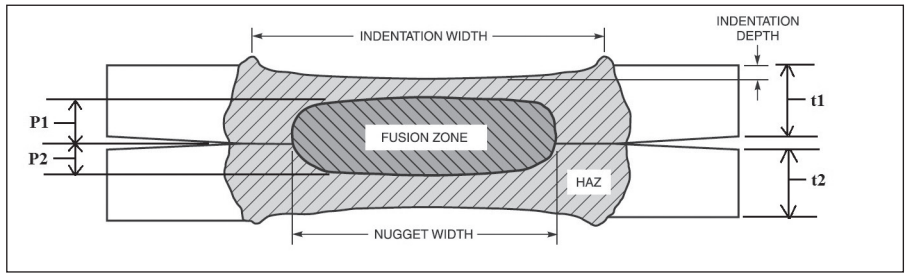

Fig. 1 — Fusion zone, nugget width, HAZ, penetration, and indentation (Ref. 1).

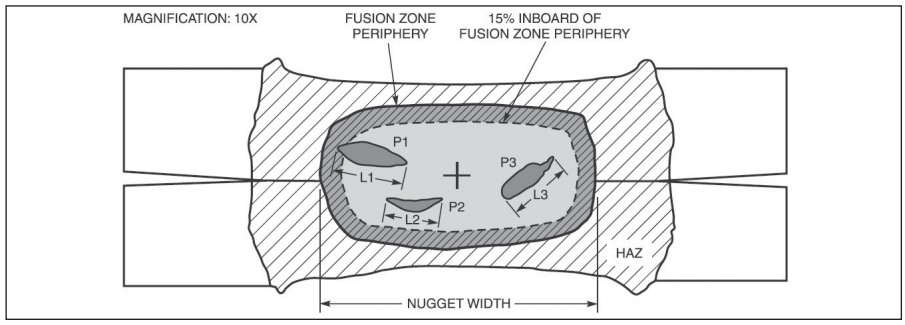

Fig. 2 — Example of discrepant pores and cavities (Ref. 1).

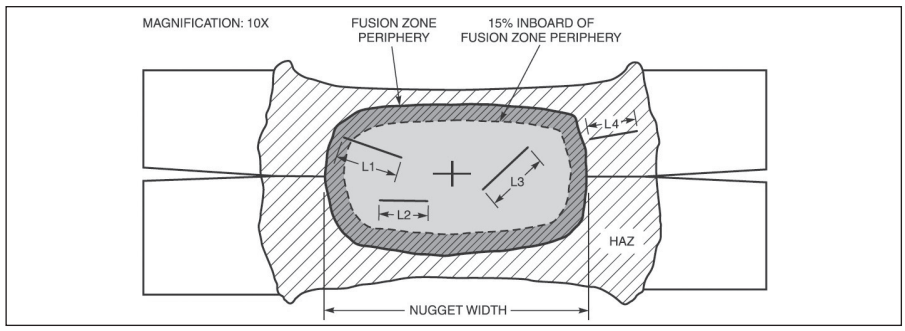

Fig. 3 — Example of discrepant internal cracks (Ref. 1).

Destructive Inspection and Metallographic Criteria (Section 5.2)

Sample Preparation

The welds to be evaluated should be cross-sectioned slightly off-center so that after mounting (if necessary) and sanding/polishing, the centerline plane going through both sheets will be available for examination. You should check with the customer to determine the desired cross-section orientation as weld(s) can be cross-sectioned in any direction, including parallel (longitudinal cross section) or perpendicular (transverse cross section) to the edge of the sample. After obtaining the necessary surface finish, the customer may want photomacrographs (typically 10 to 20×) prior to etching. These can be examined for the presence of cracks and porosity. Next, the weld is exposed to a suitable etchant to bring out the weld features (weld nugget, heat-affected zone) and base metal.

Nugget Width (Section 5.2.1)

Weld nugget width is one of the main parameters to be determined from metallographic examination. As shown in Fig. 1, the nugget width is the width of the fusion zone. The fusion zone is the volume of solidified metal resulting from the welding process. It does not include the heat-affected zone (HAZ). The HAZ is the portion of base metal next to the nugget whose mechanical properties or microstructure have been altered by heat input from the welding process.

The term "nugget" is often incorrectly used interchangeably with the term "button." A button is the part of a spot weld that tears out during destructive testing of welded steel. It may include all or part of a nugget, the HAZ, and base metal. Typically, a hole is left in the mating sheet(s).

An acceptable weld has a nugget width equal to or greater than the weld size listed in Table 2 of the specification, unless the customer specifies otherwise. This weld size is also called the minimum weld size (MWS). The MWS is approximately related to $4 \times \sqrt{t}$, where t is the governing metal thickness (GMT). Table 2 has a range of GMTs called out for each listed weld size.

The GMT for a two-sheet (2T) stack-up is the thinner metal thickness of the two sheets. For a three-sheet (3T) stack-up, the GMT is generally the metal thickness of the second-thickest sheet. However, another approach for a 3T stack-up is to consider each of the two faying surfaces as a separate 2T thickness where the GMT would be the thinner metal thickness of the two sheets making up the faying surface. Consult your customer to determine their weld size requirement for a 3T stack-up.

Table 2, note b, states that the weld size applies to both the nugget width obtained metallographically or to the size of the fracture mode (for example, a button) that is obtained from destructive testing. It is possible that a customer may specify one weld size requirement for a nugget and a different weld size requirement for a fracture mode result obtained from destructive testing of the same weld.

When measuring the nugget width in Fig. 1, the customer may require that any unfused lengths within the nugget where the faying surface or interface between the two sheets originally existed, are subtracted from the nugget width to come up with an effective nugget width. Check with your customer to determine their requirement for this situation.

Penetration (Section 5.2.2)

Penetration is the ratio of the nugget's maximum depth of fusion to the prewelded sheet thickness, expressed as a percentage [(P1/t1) × 100 and (P2/t2) × 100]. See Fig. 1 for 2T welding. It should exceed 20% of the prewelded sheet thickness into each sheet of the stack-up for both 2T and 3T welding. One hundred percent penetration into the outer sheets is undesirable, and in that case, it may result in discrepancies such as surface cracking.

Indentation

D8.1M:2007 discusses indentation in Section 5.1.4 (Surface Inspection Criteria). Indentation is the ratio of the amount of weld depression to the prewelded sheet thickness, expressed as a percentage. Indentation should be less than 30% of the thickness of each outside sheet of the welded joint unless specified otherwise by your customer.

Although indentation is not addressed in Section 5.2 (Destructive Inspection-Metallographic Criteria), it is possible to measure indentation depth as shown in Fig. 1. For 2T welding, the percentage indentation into each sheet t1 and t2 can then be calculated. If the indentation depth varies over the length of indentation width, it is usually measured at its deepest location. Verify this with your customer. 3T weld surface indentations are calculated the same way as the 2T weld surface indentations by considering the outer two sheet thicknesses to be t1 and t2. A final note of caution: ensure that sheet metal deformation is not included in the measurement of indentation.

Porosity (Section 5.2.3)

Welds are discrepant if the pores, cavities, or voids observed in a cross section examined at 10× meet any one of the criteria listed below:

Calculate the area and length for each pore, cavity, and/or void (see example in Fig. 2).

1. If the sum of all the areas (P1 + P2 + P3) is equal to or greater than 15% of the nugget area, then the weld is discrepant.

2. If the sum of all the lengths (L1 + L2+ L3) is equal to or greater than 25% of the nugget width, then the weld is discrepant.

Calculate 15% of the linear distance between the fusion zone periphery and its center. Measure this distance inboard of the fusion zone periphery to establish a 15% inboard of fusion zone periphery as shown by the dotted line in Fig. 2.

3. If any pore, cavity, and/or void or portion thereof extends into this outer zone between the fusion zone periphery and the 15% inboard of fusion zone periphery, then the weld is discrepant. For example, the pore defined by area P1 makes the weld in Fig. 2 discrepant.

Internal Cracks (Section 5.2.4)

Welds are discrepant if the cracks observed in the nugget or HAZ at 10× meet any one of the criteria listed below:

Calculate the length of each crack in the fusion zone only (see Fig. 3).

1. If the sum of all the lengths (L1 + L2 + L3) is equal to or greater than 25% of the nugget width, then the weld is discrepant.

Calculate 15% of the linear distance between the fusion zone periphery and its center. Measure this distance inboard of the fusion zone periphery to establish a 15% inboard of fusion zone periphery as shown by the dotted line in Fig. 3.

2. If any crack or portion thereof (for example, the crack defined by L1) extends into this outer zone between the fusion zone periphery and the 15% inboard of fusion zone periphery, then the weld is discrepant. Also, if there are any cracks in the HAZ (for example, the crack defined by L4), the weld is discrepant. An exception to this would be cracks deemed acceptable by surface inspection (refer to Section 5.1.2), but do not extend into the fusion zone.

In summary, AWS D8.1M:2007 has detailed acceptance criteria relating to weld size, penetration, indentation, porosity, and internal cracks as they pertain to metallographic analysis. However, check with your customer to determine whether they have modifications to these requirements.◆

Reference

1. AWS D8.1M:2007, *Specification for Automotive Weld Quality — Resistance Spot Welding of Steel*. Doral, Fla.: American Welding Society.

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