BY TYLER ALEXANDER

Q: Our automotive end user has asked us to prove our resistance fastener welding process is capable because our push-out values are fairly inconsistent. What factors influence capability in resistance projection welding?

A: A number of factors influence the final result beyond the primary adjustable variables. Fundamentally, resistance welding relies on precise control of current, force, and time; however, by definition, resistive heating is the reason for the formation of the resistance weld. Many of the factors that need to be considered when discussing capability in resistance projection welding directly influence resistance in the welding loop, and it is imperative that variabilities in these factors are properly identified and evaluated.

This response is not meant to address all possible quality aspects that may deem a fastener welding process inconsistent. In discussing weld quality, there are more factors to consider than only a fastener's ability to withstand an applied load. Visual discontinuities, positional accuracy, fastener set down, thread function, and the presence or absence of weld buttons all may factor into the final quality assessment. Here we consider only the push-out test. Furthermore, inconsistent push-out values might result from an inconsistent welding or inspection process, but we will assume the inspection process is capable and will only discuss inconsistencies in the welding process.

While the AWS does not currently publish a document that specifically addresses resistance projection welding quality, AWS C1.4M/C1.4:2009, *Specification for Resistance Welding of Carbon and Low-Alloy Steels*, establishes welding equipment requirements and welding procedures used to produce resistance welds of acceptable quality in coated and uncoated carbon and low-alloy steels. Section 6.1 discusses validation of welding equipment and procedures, and includes the minimum parameters (essential variables) that must be specified on the Welding Procedure Specification as follows:

- Metal composition and coating
- Thickness range of metals
- Total weld schedule
- Metal cleaning and surface preparation
- Electrode force range
- Weld (travel) speed (primarily in roll spot/roll seam welding)
- Equipment and tooling
- Weld location and quantity.

While this is a generic list meant to apply to resistance welding in the broad form, it highlights the fact that a number of factors beyond the primary adjustable variables exist and influence a resistance weld. These factors need to be considered and properly controlled to ensure process capability. In dealing specifically with resistance projection welding, the list of essential variables from AWS C1.4 is too generic and should be modified to include material condition and fastener properties.

Metal Composition and Coating

In the automotive industry, many of the original equipment manufacturer's specifications outline chemical requirements for a given grade of material. A percentage range is often provided for the chemical composition and, if the chemical properties of the material fall within that range, the material is considered ac-

ceptable. Falling within a range for chemical compositions does not necessarily guarantee consistency, only that the material is held to a given designation.

Both workpiece material and fasteners are manufactured in lots. Any variation in chemical consistency, heat treat, quench, or forming can potentially cause a difference in material properties. A difference in process should be of special concern when changing material suppliers. A supplier may introduce a process that improves manufacturing efficiency with little consideration for its impact on weldability. Resistive heating is generally influenced by bulk material resistance, which is affected by the material's electrical and thermal conductivity. Any change in process or chemical composition that influences these properties may impact the heat developed in the weld.

Material coatings fall subject to much of the same variability. Several different methods can be used to apply coatings to the base material and fastener. These may introduce variability depending on the coating material and application method (e.g., hot dipped vs. electrogalvanized). Coating thickness, composition, and finish need to be considered and held constant. Coating variability will influence resistance at the interface, bulk material resistance, and potential for contaminants at the interface. Considerations for coating variability should not be restricted to only the expected or intended coatings. Both the fastener and the workpiece go through manufacturing processes that can potentially leave behind lubricants, scales, oils, and other undesirable residues that may harden or absorb undesired contaminants from the environment, limiting conductivity and affecting consistency.

Thickness Range of Metals

Material thickness impacts bulk material resistance and the heat developed during welding. Change in material thickness will modify the heat balance in the workpiece. While the workpiece's desired thickness may remain constant over a product's life, the actual material being received from the rolling mill supplier may not. Bowing in the rolls may make the received thickness dependent on where it is slit from in the coil width. Rolls may change dimensionally because of temperature cycles and features in the stamped part may cause the material to thin and vary in thickness.

Weld Schedule

The resistance weld control is another influential variable frequently assumed to be consistent over a product's life. From a weld consistency standpoint, it is important the weld control be set up to deliver the same current over the same amount of time by the same means. Unmonitored wear or changing conditions on the secondary, combined with fluctuations in plant power associated with large equipment draws or the robustness of the supply infrastructure, can influence a controller's ability to perform as expected.

Metal Cleaning and Surface Preparation

Inconsistency in the presence and amount of die oils, residue from stamping, and processing fluids have always been a part of the resistance welding environment, but ideally, parts to be welded are clean and contaminant free. Typically, the application of the surface contaminant is not formally controlled in amount or method of application. While it may not be entirely resistant to the flow of current, there is certainly the potential that it will absorb other contaminants from the environment that may influence contact resistance and final weld quality.

Electrode Force Range

In resistance welding, the actuator is expected to control contact resistance at all critical interfaces by providing the required force as the current is passed. For projection welding, this means maintaining the desired force follow-up as the projections

collapse and avoiding impact loads on contact. Insufficient follow-up will allow rapid expansion of the molten material at the interface, potentially to the point of uncontrolled expulsion and depleted weld quality. Impact loads may partially collapse the projections or embed the projections into the coating, and influence mechanical wear in the actuator. Mechanical wear, unexpected leaks, and failure to adhere to the manufacturer's suggested operating window restrictions, can contribute to inconsistency in the delivered force.

Equipment and Tooling

Tooling can be simple or complex, but regardless, it is responsible for completing the weld loop on the secondary side of the transformer(s). When improperly grounded/insulated, where there are loose connections, or when electrodes have the potential to make unexpected contact with the part, the current may be offered preferred paths through the tooling, without first passing through the projections. In such situations, it becomes difficult to predict or control the amount of current that passes through the alternate path. Beyond the tooling design itself, inconsistencies can result from poor or inadequate tool maintenance. A piloted nut or a welding stud allowed to drift in a stamping hole may arc, thus providing a new and unexpected path to the part. In a similar way, unmonitored electrodes that have been allowed to wear excessively may no longer support the stamping adequately and force the current to find alternate paths.

Weld Location and Quantity

Whether through a tool or through a part, current takes the path of least resistance. In spot welding, shunt paths through nearby spot welds are normally considered but, unfortunately, this is rarely a consideration in projection welding applications. In scenarios where there are nearby spot welds that create an easier path through the material, certain projections may become preferential depending on fastener orientation. Most applications do not control the fastener/projection orientation, so the preferred path will vary as the orientation varies. Relative to weld location, there is an additional concern for AC systems, which are sensitive to the amount of ferrous material in the equipment throat. Ignoring the impact of impedance on an AC system may create unwarranted consistency concerns associated with the same fastener welded with the same weld schedule at two different points in the weld loop.

Material Condition

The presence of wrinkles on the stamping can impact the consistency of the projection weld, especially as stamping complexity and material strength increase. As industry replaces mild, low-carbon steel with high- and ultrahigh-strength steels, it is no longer reasonable to rely on the force of the weld actuator to flatten the stamping in the weld location. If the stamping is not completely flat in the weld area, there is the potential for the fastener to make inconsistent contact with the workpiece.

Burrs in the holes that locate the fastener may also alter the contact area at the weld interface. Depending on the manufacturing process and condition of the tools, burrs may occur. When left unaddressed, they have the potential to create alternate paths for the current, reducing flow through the projections.

Flaws in the surface finish are usually less visually apparent than burrs, but important nevertheless. Surface roughness (contact resistance) contributes the majority of the resistive heat to a resistance weld, so it is important to monitor consistency in this regard. The surface finishes between electrode and fastener, fastener and workpiece, and workpiece and electrode, are critical.

Fastener Properties

To this point, the essential variables discussed would be relevant to any resistance welding process. Fastener projection welding is unique because it uses a fastener and projections to focus the current delivery to the workpiece. Their integral role in the quality of the final product makes consistency in projection geometry (shape and height) critical. It is important to evaluate a fastener's projection height for consistency relative to other projections on the same fastener, but also fastener to fastener. If the material is kept flat but the projection height varies, only certain projections will make contact with the material. As the number of projections increases, sensitivity increases because the potential to have more projections out of contact with the material increases. When projections do not make contact with the workpiece, the contact area and current density change during the weld.

Another key consideration is consistency of the projection profile. Die wear and consistency of the forming force affect stamped and coined projections. In the commonly applied three-projection conical design, if two projections come to a point and the third is flatter, the current paths will differ from a fastener where all projections consistently come to a point.

Choice of fastener manufacturing

process can also influence consistency. In general, there should be concern for machined or cast fasteners. The supplier's attention to tooling wear, cleanliness, and material choice affects the consistency of machined fasteners. An occasional burr can introduce an alternate current path, heat treatments may create an insulating scale, and improved machining efficiency through the use of easily machined material, like leaded stock, may create issues with weld solidification. Fasteners cast or manufactured using powdered metallurgy tend to have inconsistent composition, which results in current path inconsistencies.

Looking beyond the fastener in isolation, the fastener's interaction with mating surfaces is also of concern. Variability in the parallelism at the contact surface between the head of the fastener and the electrode creates variability in contact resistance. This can affect current transfer to the fastener and the amount of current that flows through each projection. Similarly, there should be consideration for the amount of contact area between the electrode and fastener. The surface of every projection-welded fastener should have a consistently flat and sufficiently large area in place to allow for current transfer from the electrode. Variability will change the current density at the interface between electrode and fastener.

Summary

Unfortunately, in the production world there is not typically one individual or group that controls and manages all essential variables. The product user, components supplier(s), and equipment manufacturer all control different elements. In most industries, the end user provides specifications and tolerances, but it is important for equipment manufacturers to understand how the tolerances were developed and whether projection welding was considered in their development.

In resistance projection welding, the most consistent push-out values occur when base material is pulled on all projections such that the yield strength of the material dictates the failure point. In the absence of pulling base material, a comparison of push-out values may not give an accurate picture of machine consistency. Too many essential variables that influence the push-out value are beyond the equipment manufacturer's control. Equipment manufacturers may need to prove the equipment's capability by isolating and demonstrating capability for only those essential variables the equipment influences.◆

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Correction

In the Electrode Cooling section of the RWMA Q&A that ran on pages 16 and 17 of the July *Welding Journal*, the term "gap" was changed to "root opening" in error. The correct sentence is as follows: "The reason for this is that each test is a singular condition among many possibilities and cannot account for the potential litany of material combinations, gap or fitup concerns, general conditions of the tooling, or other production variables." A correction has been made to the copy archived on the AWS Web site at *www.aws.org*.