

RSW Fracture Modes

Resistance Spot Welding (RSW) is a very robust process for the joining of metallic materials together. While the Resistance Welding (RW) industry is ever evolving, it was the advent of Mid-Frequency Direct Current (MFDC) power supplies, coupled to modern weld controls, that has really seen things change for the better with regard to RSW process stability and control. The ability of the properly configured weld control to utilize various inputs (voltage, etc.) to both adjust specific parameters while the weld was actually being made, and record those results for historical review, was nothing short of revolutionary. One big reason for this is it gave those in the RW community an ability to almost look inside the weld *while it was occurring*. It is really incredible the advances we have seen in this regard.

However, even if we are dealing with a robust RSW process that has been certified to the specified procedure, once a weld has been made, how do we determine its acceptability? From my perspective, questions about the acceptability of a weld are sometimes as much a discussion about the philosophical nature of welding as they are the physical aspects of the weld. I say this for the following reason: It is not possible to state with finality what evaluation process or acceptance criteria may be used to determine the quality of a weld. The principal reason is that there does not exist a universally accepted definition or understanding of what constitutes a satisfactory weld. Simply put, a weld that may be satisfactory for one application or material may not be for another. An important aspect required to determine weld quality requirements is an understanding of the available testing procedures capable of characterizing a weld.

There are potentially many different ways to determine the acceptability of a weld, and they include utilizing both destructive and non-destructive evaluation (NDE) elements. It should be noted that the various NDE elements are becoming more robust all the time, and are rightfully an integral part of any RSW quality program. They are also allowing for a reduction, maybe even the outright elimination, of some of the destructive evaluation elements. That being said, the destructive evaluation process still has its place, and one of the more common destructive elements employed is to mechanically separate the spot-welded parts in question.

It is acknowledged the destructive separation of spot welds has its own limitations. These would include, but by no means are limited to, the cost associated with scrap, the time and facility requirements needed to support the effort, and potential difficulty in separating some assemblies. It is this last point (the difficulty of separation) that really comes to the fore with folks as the steel used in many automotive body structures began to evolve over these past many years. Finally, while the following discussion is potentially applicable to the non-ferrous alloys (think aluminum, etc.), they typically do not have nearly as many issues with their destructive evaluations as do those working with steel and other ferrous based alloys (think stainless steel, etc.) simply because of their lower strength.

All that being said, it can still be quite revealing what one can learn once the actual welds are separated. However, before we go further, now might be a good time to define up front a few of the terms we are going to be using to talk about spot welds once they have been separated.

- **Nugget:** The recast structure created by the spot-welding process. For our purposes, the best way to exam this is with a cross-sectioned metallographic evaluation.
- **Button:** The portion of the spot weld, including all or part of the nugget, that tears out during the destructive evaluation process.
- **Faying Surface:** The interface between the metallic materials being joined
- **Fracture Mode:** The appearance of the spot weld after destructive evaluation. Possible variants include a button pull, partial thickness fracture, full interfacial fracture, or any combination of the three.
- **Fused Area:** The measurable area of the nugget at the faying surface. It may include the button pull, partial thickness fracture, full interfacial fracture, or any combination of the three.

A Bit of History

The answer to the question of how to interpret a spot weld after it has been destructively separated requires that we review and understand the prevailing wisdom of those associated with RSW as it pertained to weld integrity before the advent of the Advanced High-Strength Steels (AHSS). See Figure-1 below for more details on Conventional Steel vs. AHSS.

From a quality and engineering perspective, the understanding was the desirability to achieve a button during the destructive evaluation of a resistance spot weld. It was felt the presence of an adequately sized button would be evidence of the weld's ability to provide the necessary engineering properties (strength, energy absorption, etc.) for the application. The definition of 'adequately sized' would vary from manufacturer to manufacturer, but all agreed that weld buttons were necessary.



There were also other benefits to weld buttons. From a quality perspective, they offered, within the limits of operator repeatability/reproducibility, an objective method of determining the quality of a weld. An additional benefit was that the weld button size could be tracked and trended over time, and thus the quality of the weld could be used in a proactive manner to gauge, and if necessary, improve process robustness.

Steel Becomes Stronger

However, the need to use stronger materials, such as High-Strength Low-Alloy (HSLA) steels, in ever stiffer sections started to have an impact on the ability of the destructive evaluation to consistently produce weld buttons. What was occurring was at greater thicknesses, less effort was required to fail through the weld nugget than to shear the peripheral area. This meant buttons were often not being pulled from thicker materials.

One approach to rectify this issue and ensure that buttons were produced was to increase the required minimum weld size (MWS). This idea was supported not only from the inspection community but also from the design community (*ref, Ultimate Strength and Failure Mode of Spot Welds in High Strength Steels, D. J. VandenBossche, SAE Paper 770214 – Published Feb-1977*) who felt that larger welds were needed in order to take full advantage of the stronger materials' properties.

However, there are constraints limiting the potential size to which one can grow a weld. Specifically, from a practicality standpoint, how large a spot weld can be economically and robustly produced. Also, it soon became apparent that an increase in weld size can quickly reach a point of diminishing return with regards to an increase in mechanical properties (strength, etc.).

Since the conventional wisdom, based on tests of conventional steels, held that adequate strength was provided by welds that produced a full button in excess of the required minimum size upon destructive evaluation, it stands to reason anyone associated with resistance spot welding did not hold welds exhibiting fracture modes other than a full button as acceptable. The challenge to this line of reasoning came in the form of spot welds that required substantial force to separate, produced significant material deformation, but resulted in the formation of (at least at the time) an undesirable fracture mode.

The initial motivation to investigate the viability of different fracture modes was feedback from the manufacturing facilities. The hard-working folks on the shop floor were being confronted with unique situations and sought help from their corporate engineering organizations. At this point in time each Original Equipment Manufacturer (OEM) began addressing the issue. Among the many concerns to address was not just the ability to maintain the strength of the welds they were producing, but how to inspect them and determine their acceptability.

Despite evidence that substantial strength could be achieved by a resistance spot weld that did not produce a weld button, it was not until AHSS came on the scene that the shift in thinking that started with the onset of HSLA material was solidified. The end result of this work can be seen in Table-1 below.

Characterizing with Fracture Modes

The welding community as a whole began to come to grips with the issue of understanding the fracture modes by way of standards committee meetings within both the American Welding Society (AWS)* and Auto/Steel Partnership (A/SP)**. These committee meetings brought to light the fact these concerns were wide spread within the industry and that each OEM approached the issue of the fracture modes in resistance spot welding from a slightly different perspective. The reality was despite the variations of their solutions; they were addressing a common concern. Specifically, does a satisfactory resistance spot weld require a button when mechanically separated, and if not, what is needed in its place as evidence of an acceptable weld.

The approach taken to address these issues was at times laborious and required the hard work and dedication of professionals from many facets of the welding community, including manufacturing, the supply base, and research. A summary of their efforts includes the identification of eight distinct fracture modes (see Table-1 below), and establishing three critical elements that should be characterized to determine the disposition of the resistance spot weld; Fused Area size, presence of Parent Metal Deformation, and calculated Aspect Ratio (based on the value of both the Major and Minor fused area diameters).



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Fracture Mode	Elements	Side View
Mode 1	Bottom Pull	
Mode 2	Partial Thickness Fracture with Button Pull	
Mode 3	Partial Thickness Fracture	
Mode 4	Interfacial Fracture with Button Pull and Partial Thickness Fracture	
Mode 5	Interfacial Fracture with Button Pull	
Mode 6	Interfacial Fracture with Partial Thickness Fracture	
Mode 7	Interfacial Fracture	

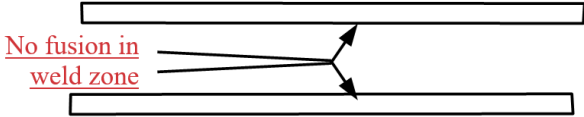
Mode 8	No Fusion	
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Table-1: RSW Fracture Modes***

The Fracture Modes listed above are a combination of the three (3) possible outcomes (other than No Fusion) when a spot weld separates: Button Pull, Partial Thickness Fracture and/or Interfacial Fracture. While it may seem fairly fundamental, the creation of these modes was a breakthrough and gave the welding community the ability to fully characterize spots weld in any material.

All of the aforementioned items have been chronicled in any of the following. The latest release of these specifications should be referenced for more details.

- AWS C1.1 (Recommended Practices for Resistance Welding)
- AWS D8.1M (Specification for Automotive Weld Quality - Resistance Spot Welding of Steel)
- AWS D8.2M (Specification for Automotive Weld Quality - Resistance Spot Welding of Aluminum)

The wide-spread use of AHSS brought to the fore the idea that there may be more than one way to view the quality of a resistance spot weld. Just as AHSS's achieve their unique properties from different methods than the more conventional grades of steel, so too must the welding community view its final product from a different view point when welding on these unique materials.

*The American Welding Society (AWS) (www.aws.org) is a non-profit organization dedicated to advance the science, technology and application of welding and allied joining and cutting processes, including brazing, soldering and thermal spraying.

**The Auto/Steel Partnership (A/SP) (www.a-sp.org) is a professional consortium consisting of both automotive and steel OEM's.

***The images in Table-1 are courtesy of my former supervisor and mentor, Jim Dolfi. After Jim retired from Ford, we still kept in touch discussing all manner of topics, but typically drifted to welding. These images are from documents he shared about the early days of trying to understand the weld separation issues. Later versions of these images have appeared in all manner of documentation, to include the aforementioned AWS standards noted above. What Jim shared were imbedded images and could not be edited, hence the red font. Thank you for sharing, Jim. RIP my friend.

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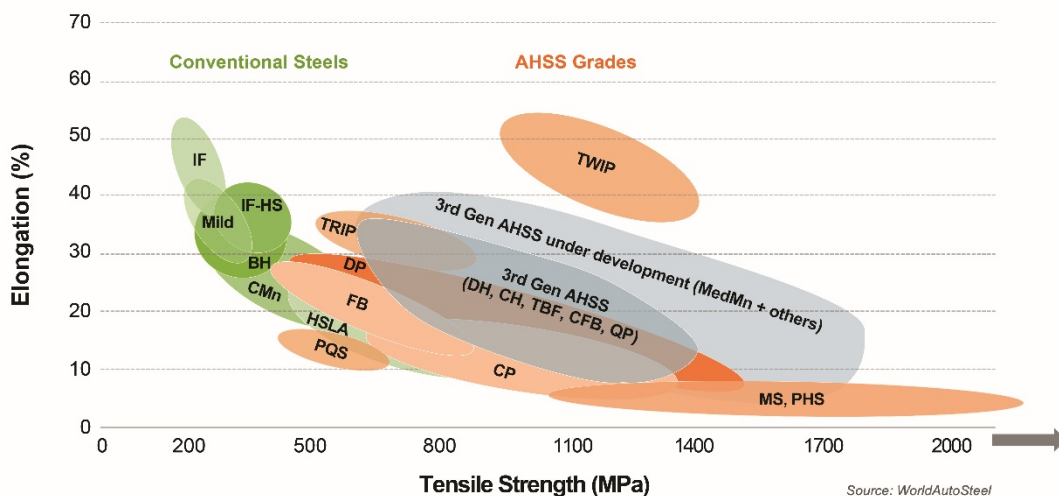


Figure-1: Global Formability Diagram courtesy of WorldAutoSteel. It has also been referred to as the 'Steel Banana Chart'. That is the description I have heard, and use, most often, for this image.