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Weld Quality Assurance for Laser and Resistance Welding - Update

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Introduction

Defining, validating, and monitoring weld quality continue to be major issues for many manufacturing companies utilizing laser and resistance welding. This microTip provides an updated look at these issues.

Defining Weld Quality

Weld quality represents one or more quantitative metrics that ensure product safety and functionality for our customers.

Validating the Welding Process

Validating the welding process is a non-linear, iterative process that establishes a correlation between the weld quality *Process Qualification* (PQ) and the *Product Performance Qualification* (PPQ) metrics. Validation includes five steps: a) PQ weld quality metric selection, b) optimization, c) confirmation, d) PPQ validation, and e) setting welding process limits. Welding *Process Validation* (PV) confirms, by objective evidence, the correlation between the PQ weld quality metrics and PPQ metrics.

Selecting Weld Quality Process Qualification (PQ) Metrics

Selected PQ weld quality metrics <u>must</u> ultimately correlate with the PPQ metrics that ensure product safety and functionality. Selecting one or more PQ weld quality metrics is difficult because there is no certainty that the selected PQ weld quality metrics will correlate with the selected PPQ metrics. Reviewing the failure mode for each PPQ metric can help narrow the selection of PQ weld quality metrics and improve the probability of finding a correlation.

PQ weld quality metrics include weld set down, tensile strength, peel strength, and break mode characteristics. In many cases, PQ weld quality metrics, including lower process limits, are specified in advance of developing the welding process without considering their potential correlation to the PPQ metrics. Careful thought as to how the final product will be used helps in the selection of appropriate PQ weld quality metrics. Using invalid PQ weld quality metrics ultimately causes field failures, low process capability (Cpk), and high production costs.

PQ weld quality metrics fall into two main categories: a) non-destructive and b) destructive. PQ weld quality metrics can be further classified as (quantitative) variable or (qualitative) attribute. “Variables” are quantifiable metrics such as shear strength or weld penetration. “Attribute” examples include break mode characterization and the degree of weld flow. Variable metrics are preferred over attribute metrics because of the subjectively involved in assigning attribute values. The following table provides possible PQ weld quality metrics.

PQ Metric	Destructive	Type
Infrared Profile	No	Variable
Set Down	No	Variable
Weld Color	No	Attribute
Weld Flow	No	Variable or Attribute
Weld Geometry	No	Variable or Attribute
Weld Current	No	Variable
Weld Power	No	Variable
Weld Resistance	No	Variable
Weld Voltage	No	Variable
Bending Fatigue	Yes	Variable
Joint Area	Yes	Variable
Break Mode	Yes	Attribute
Peel Strength	Yes	Variable
Shear Strength	Yes	Variable

PPQ metrics fall into the same classification structure as PQ weld quality metrics. PPQ metrics are based on product functionality and are usually specified by the end customer before the product is developed by the manufacturer. The table below lists some common PPQ weld quality metrics.

PPQ Metric	Destructive	Type
Bending Cycling	Yes	Variable
Drop (Impact)	Yes	Variable
Fatigue Life	Yes	Variable
Hermeticity	No	Variable
Humidity	No	Variable
Kinking Cycling	Yes	Variable
Temperature Cycling	Yes	Variable
Thermal Shock	Yes	Variable
Twisting	Yes	Variable
Vibration	Yes	Variable

PQ/PPQ Selection - Magnet Wire Example

Appliance and automotive solenoid manufacturers use a process called “Magnet Wire Fusing” to terminate copper magnet wire to tin-plated brass or copper alloy terminals without the need to pre-strip

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the insulation from the wire. Weld heat and pressure remove the insulation, causing the tin-plating to form a reflow solder joint between the magnet wire and terminal. The dominant PPQ failure mode is excessive electrical resistance or an open circuit between the magnet wire and terminal.

PQ weld quality metrics that potentially correlate with PPQ weld quality metrics include: a) joint area between the magnet wire and terminal, b) amount of insulation burn-back on either side of the terminal, c) set down (welded terminal thickness), and d) RMS weld current. Joint area is a destructive PQ weld quality metric whereas the remaining PQ weld quality metrics are non-destructive. Note that RMS weld current is an input factor while joint area, insulation burn-back, and set down are output responses. All four PQ weld quality metrics can be used for developing, optimizing and monitoring the welding process. PPQ metrics based on the product functionality include:

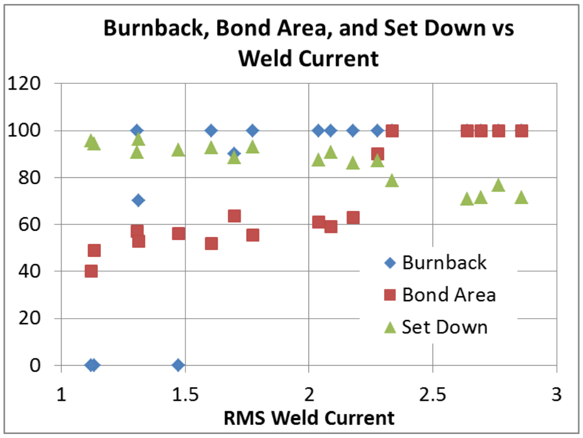
- Electrical conductivity of the joint
- Thermal shock capability
- Temperature cycling endurance
- Vibration tenacity

Optimizing the Welding Process – Magnet Wire Fusing Example

A Design of Experiment revealed that:

- Joint area is primarily controlled by the weld current.
- Set down is controlled by both the weld current and force.
- Insulation burn-back is controlled by weld current, force, and time.

The scatter plot below provides a good view of the interaction between all four PQ weld quality metrics.



While all four PQ weld quality metrics provide some indication of the quality of the electrical connection between the magnet wire and the terminal, changes in the slope of each PQ weld quality metric do NOT overlap perfectly in relation to the weld current. The question then becomes, "which PQ metric should be used for optimizing this weld?". Since the joint area is best representation of the weld quality, use joint area to optimize the welding. Optimization results in using a minimum weld current of 2.12-KArms in order to ensure a joint area of 100%.

Confirming and Validating the Welding Process – Magnet Wire Fusing Example

It is important to remember that the optimized welding process represents a very small slice in time of the production cycle. In the production environment, resistance welding electrode tips oxidize, become impregnated with part material, and "mushroom" in size. These changes over time negatively affect the weld heat. Thus one or more confirmation runs at different values of weld current must be conducted to find the minimum set down and weld current PQ values that will ensure that all PPQ metrics are met. Possible weld current confirmation groups include samples made at 2.15, 2.35, 2.55, and 2.75-KArms.

The lot size for the confirmation run should be based on the actual electrode life, which can be determined by monitoring the joint set down during the confirmation run. Should the set down increase above 80%, the confirmation run should be terminated. Use 100% inspection or a statistically significant sampling plan to gather the set down and insulation burn-back data. Confirmation run testing for this magnet wire fusing example revealed that using a weld current below 2.35-KArms resulted in producing some samples with marginally high electrical resistance. However, using a set down value of 75% or less in conjunction with a weld current of 2.50-KArms or greater resulted in passing all PPQ metrics, thus validating the weld process.

Setting Limits – Magnet Wire Fusing Example

Using insulation burn-back for a process control limit is not effective because a 100% burn-back value may represent a joint area of less than 60%. Using a set down limit 75% or less in conjunction with a lower weld current limit of 2.50-KAmps offers the best chance of ensuring 100% joint area and thus robust product functionality for the customer.