# Quality Resistance Welding Solutions: Defining the Optimum Process

## INTRODUCTION

Aquality resistance welding solution both meets the application objectives and produces stable, repeatable results in a production environment. In defining the optimum process the user must approach the application methodically and consider many variables. In this article we will look at the following key stages and principles to be considered when defining the optimum resistance welding process:

- Materials and their properties
- Basic resistance welding principles
- Weld profiles
- Approach to development
- Common problems
- Use of screening DOE's
- Use of factorial DOE's

## RESISTANCE WELDING – A MATERIAL WORLD

The first consideration in designing a quality welding solution is the properties of the materials to be joined and the quality requirements of the desired welded joint. At this stage, it is worthwhile to review the way the resistance welding process works and the likely outcome when the parts are resistance welded. There are four main types of structural materials:

- Metals (silver, steel, platinum)
- Ceramic (alumina, sand)
- Plastics/polymers (PVC, teflon)
- Semiconductors (silicon, geranium)

Of these, only metals can be resistance welded because they are electrically conductive, soften on heating, and can be forged together without breaking.

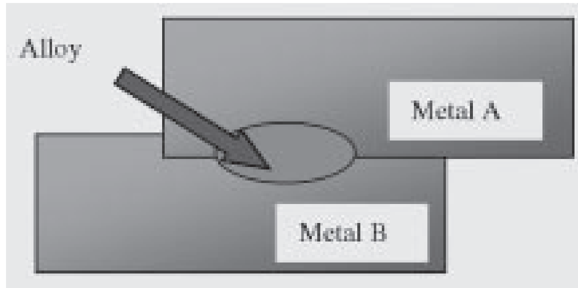

*Figure 1*

Alloys **(Figure 1)** are a mixture of two or more metals. An alloy is normally harder, less conductive, and more brittle than the parent metal which has bearing on the type of joint one can expect when resistance welding a combination of different metals.

Metals atoms are naturally attracted to other metal atoms even in different parent materials. Metals and alloys will bond together once surface contaminants such as dirt, grease, and oxides are removed. Resistance welding generates heat at the material interface which decomposes the dirt and grease and helps to break up the oxide film. The resultant heat softens or melts the metal and the applied force brings the atoms on either side into close contact to form the bond. The strength of the joint develops as it cools and a new structure is formed.

There are three main types of bonds that can be formed using the resistance welding process:

### • Solder or Braze Joint

A filler material such as a solder or braze compound is either added during the process or present as a plating or coating. Soldered joints are typically achieved at temperatures less than 400°C and brazed joints such as Sil-Phos materials melt at temperatures above 400°C.

### • Solid-State Joint

A solid state joint can be formed when the materials are heated to between 70-80% of their melting point.

### • Fusion Joint

A fusion joint can be formed when both metals are heated to their melting point and their atoms mix.

Many micro-resistance welding challenges involve joining dissimilar metals in terms of their melting points, electrical conductivity and hardness. A solid-state joint can be an ideal solution for these difficult applications; there is no direct mixing of the two materials across the weld interface thus preventing the formation of harmful alloys that could form brittle compounds that are easily fractured. Remember that in a solid-state joint, the metals are only heated to 70-80% of their respective melting points, resulting in less thermal stress during heating and subsequent joint cooling in comparison to a fusion weld. As there is no real melting of the materials in a solid-state joint, there is less chance of weld splash or material expulsion. Aweld nugget can still be achieved with a solid-state joint.

## CONSIDER THE MATERIAL PROPERTIES

The important material properties to be considered in the resistance welding process are:

- Electrical and thermal conductivity
- Melting point
- Plating and coating
- Oxides
- Hardness

**Figure 2** illustrates the variance in resistivity and melting points for some of the more common materials used in micro resistance welding today. The materials can be grouped into three common categories; the types of joints achievable within each of the main groups are detailed below:

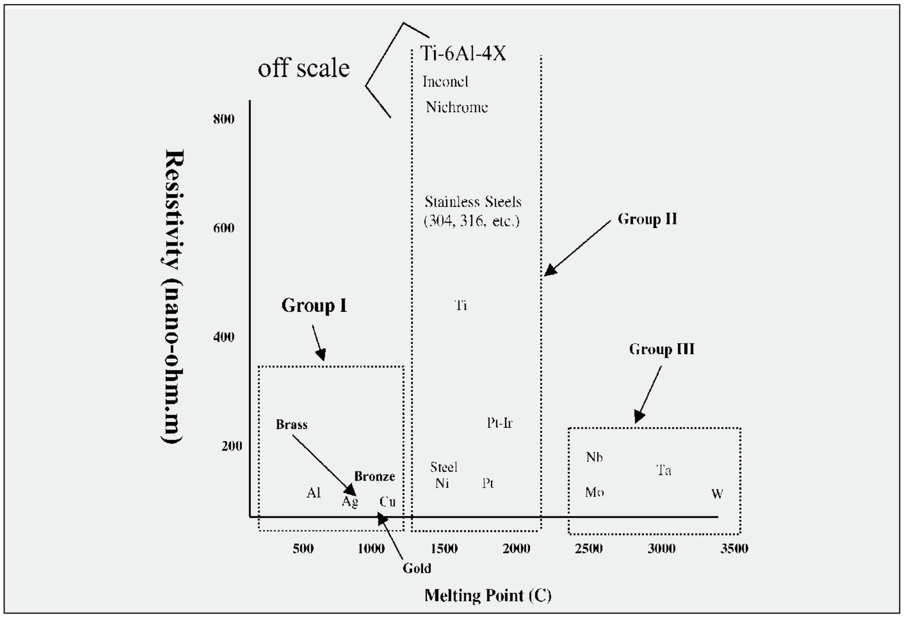


*Figure 2*

### • Group I – Conductive Metals

Conductive metals dissipate heat and it can be difficult to focus heat at the interface. Asolid-state joint is therefore preferred. Typically, resistive electrode materials are used to provide additional heating.

### • Group II – Resistive Metals

It is easier to generate and trap heat at the interface of resistive metals and therefore it is possible to form both solid state and fusion welds depending on time and temperature. Upslope can reduce contact resistances and provide heating in the bulk material resistance.

### • Group III – Refractory Metals

Refractory metals have very high melting points and excess heating can cause micro-structural damage. A solid-state joint is therefore preferred.

**Figure 3** gives some guidance on the type of joint that can be expected and design considerations required when joining materials from the different groups.

| | Group I (Copper) | Group II (Steel) | Group III (Moly) |
|---|---|---|---|
| Group I (Copper) | • Solid-State<br>• W/Mo electrodes | • Solid-State<br>• Projection on Group I | • Solid-State<br>• Fine projections on Group III |
| Group II (Steel) | | • Solid-State or Fusion | • Solid-state or braze of II on III<br>• Projection on III |
| Group III (Moly) | | | • Solid-State |

*Figure 3*

## BASIC PRINCIPLES

**Figure 4** shows the key resistances in a typical opposed resistance weld and the relationship between contact resistances and bulk resistances over time, during a typical resistance weld:

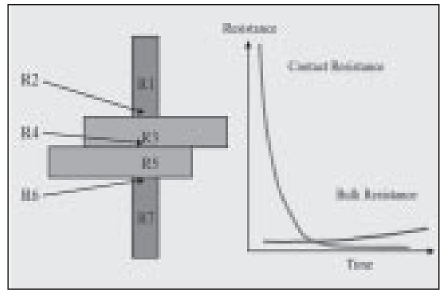


***Figure 4***

**R1 & R7 –** The electrode resistances affect the conduction of energy and weld heat to the parts and also the rate of heat sinking from the parts at the end of the weld.

**R2, R4 & R6 –** The electrode-topart and part-to-part "Contact Resistances" determine the amount of heat generation in these areas. The contact resistances decline over time as the parts achieve better fit up.

**R3 & R5 –** The metal "Bulk Resistances" become higher during the weld as the parts are heated.

If a weld is initiated when the contact resistances are still high, the heat generated is in relation to the level and location of the contact resistances, as the materials have not had a chance to fit up correctly. It is common for the heat generated at the electrode-topart and part-to-part resistances to cause multiple welding problems when welding resistive materials including:

- Part marking and surface heating
- Weld splash or expulsion
- Electrode sticking
- Weak welds

Alternately, conductive materials can be welded by using high contact resistance and fast heating because their bulk resistance is not high and cannot be relied upon for heat generation.

If a weld is initiated when both parts and electrodes are fitted up correctly, the contact resistance is lower and bulk resistance now controls the heat generation. This type of weld is achieved with a slower heating rate and normally longer time is preferred for welding resistive materials, which can generate heat through their bulk resistance.

The contact resistances present at the weld when the power supply is fired have a great impact on the heat balance of a weld and, therefore, the heat affected zone. **Figure 5** shows a weld that is fired early on in the weld sequence when the contact resistance is still quite high. **Figure 6** shows a weld that is initiated when the contact resistance is lower; in this example we are using bulk resistance to generate our weld heat.

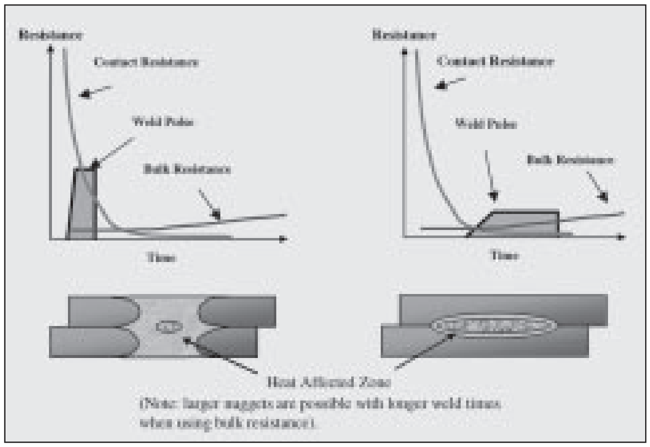


*Figure 5 & 6*

In general, conductive materials benefit from a faster heating rate, as the higher contact resistances assist heat generation in the weld. Resistive materials benefit from slower heating rates which allow the contact resistances to reduce significantly. Bulk resistances, therefore, become the major source for heat generation. The heat affected zone is also much smaller in this case producing a weld with less variation.

**Figure 7** shows the three stages of heat generation for resistive materials in a fusion weld. In the first stage, the heat is focused in the part-to-part and electrodeto- part contact areas, since contact resistance is high relative to bulk resistance. In the second stage, contact resistance decreases as the electrodes seat better to the parts. Less heat is generated in the electrode-to-part contact areas, and a greater amount of heat is generated in the parts as the bulk resistance increases. In the third stage, the bulk resistance becomes the dominant heat generating factor and the parts can reach their bonding temperature at the part-to-part interface. The stages of heat generation for conductive materials will be similar to that of resistive materials, but there will be less heat generated in the bulk resistance due to the conductivity of the materials.

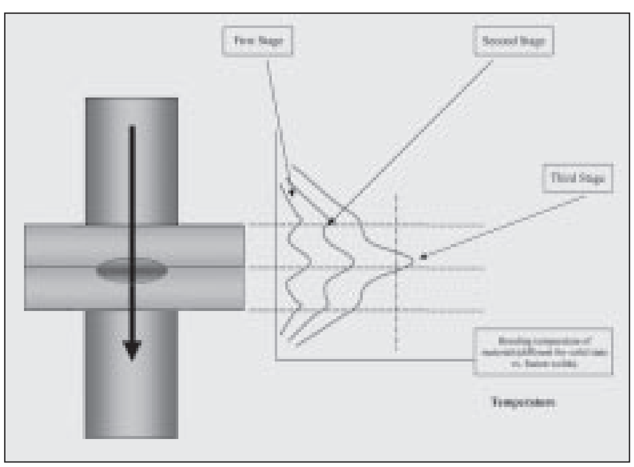

*Figure 7*

## WELD PROFILES

The basic welding profile (or schedule) consists of a controlled application of energy and force over time. Precision power supplies control the energy and time and therefore heating rate of the parts. The weld head applies force from the start to finish of the welding process. **Figure 8** shows a typical welding sequence where the force is applied to the parts; a squeeze time is initiated which allows

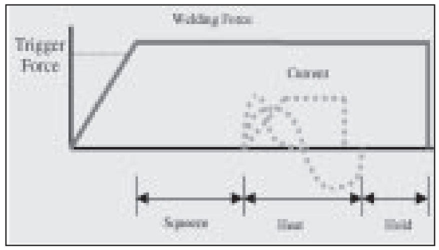


***Figure 8***

the force to stabilize before the current is fired. Squeeze time also allows time for the contact resistances to reduce as the materials start to come into closer contact at their interface. A hold time is initiated after current flows to allow the parts to cool under pressure before the electrodes are retracted from the parts. Hold time is important as weld strength develops in this period. This basic form of weld profile is sufficient for the majority of small part resistance welding applications.

Power supply technology selection is based on the requirements of both the application and process. In general, closed loop power supply technologies are the best choice for consistent, controlled output and fast response to changes in resistance during the weld (for further details comparison see the Amada Miyachi "slide rule" tool).

## APPROACH TO WELD DEVELOPMENT

The first stage in developing a quality welding process is to fix as many of the variables as possible in the welding equipment set up. Welding variables can be grouped in the following categories:

**• Material variables**
– Base material
– Plating
– Size
– Shape

**• Weld head & mechanical variables**
– Force, squeeze, hold
– Actuation method
– Electrode material and shape

**• Power supply variables**
– Energy
– Time (squeeze, weld, hold)

**• Process variables**
– Tooling, level of automation
– Repetition rate
– Part positioning
– Maintenance, electrode cleaning

**• Quality requirements**
– Pull strength
– Visual criteria
– Test method, other weld joint requirements

At this stage it is good practice to document the welding set up so that it can be referred to at a later date (request Amada Miyachi "Process Audit Worksheet" for an example). Once the equipment set-up has been documented the next stage is to fix as many of the process and material variables as possible to reduce variation in the subsequent welding trials. The main welding parameters such as energy, force and time cannot be fixed at this stage but many of the other variables such as repeatable part positioning should be fixed.

## INITIAL WELDING TRIALS – THE "LOOK SEE" TESTS

"Look see" welding tests are a series of mini welding experiments designed to provide a starting point for further statistical development of the welding parameters. The user should adjust the key welding variables (energy, force, time) in order to identify the likely good "weld window." Close visual inspection of the weld parts will promote better understanding of the heating characteristics of the application.

The mini-experiments should also be used to understand the weld characteristics from both application and process perspective. Key factors in this understanding are as follows:

## APPLICATION PERSPECTIVE

- **Materials:** Resistivity, melting point, thermal mass, shape, hardness, surface properties.
- **Heat balance:** Electrode materials, shape, Polarity, heating rate (upslope).
- **Observation:** visual criteria, cross section, and impact of variables on heat balance.

## PROCESS PERSPECTIVE

- What are the likely variables in a production process?
- How will operators handle and align the parts?
- What tooling or automation will be required?
- How will operators maintain and change the electrodes?
- What other parameters will operators be able to adjust?
- What are the quality and inspection requirements?
- What are the relevant production testing methods and test equipment?
- Do we have adequate control over the quality of the materials?

## COMMON PROBLEMS

During this stage of process development it is important to understand that the majority of process problems are related to either materials variation, or part-to-electrode positioning. Some examples are given here **(Figure 9)**: The changes detailed above generally result in a change in contact resistance and always affect the heat balance of the weld. During weld development these common problems must be carefully monitored so as not to mislead the course and productivity of the welding experiments.

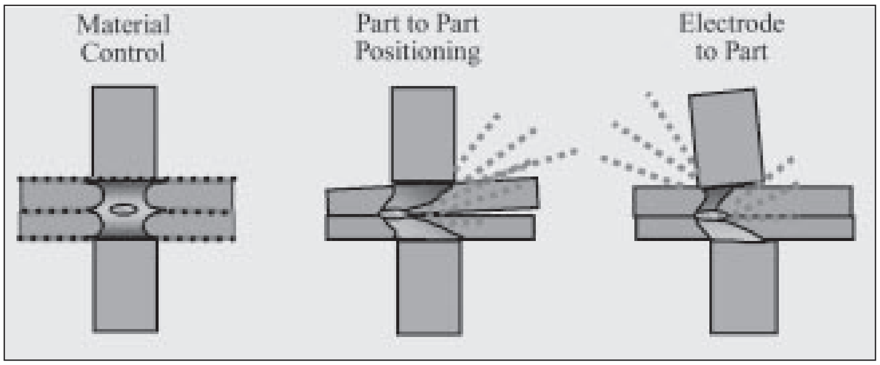


***Figure 9***

In summary, the “look see” welding experiments should be used to fix further variables from an application and process perspective and also to establish a “weld window” for energy, time and force. This part of weld development is critical in order to proceed to a statistical method of evaluation (Design of Experiments or “DOEs”). Random explosions or unexpected variables will skew statistical data and waste valuable time.

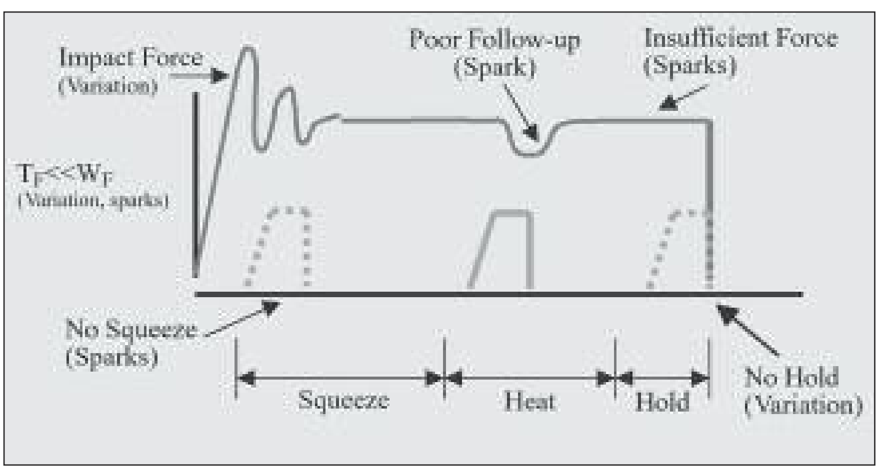


***Figure 10***

Common welding problems can often be identified in the basic set up of the force, energy and time welding profile detailed below in **Figure 10**. These problems can lead to weld splash, inconsistency and variation (contact Amada Miyachi for further information and support).

## WHAT ARE SCREENING DOE'S?

The purpose of a Screening DOE is to establish the impact that welding and process parameters have on the quality of the weld. Quality measurement criteria should be selected based on the requirements of the application. A Screening DOE will establish a relative quality measurement for the parameters tested and also the variation in the welded result. This is important, as identifying variation in process is critical in establishing the best production settings. Typically, welded assemblies are assessed for strength of joint and variation in strength. A Screening DOE tests the high and low settings of a parameter and will help establish the impact of a parameter on the process. A Screening DOE is a tool that allows the user to establish the impact of a particular parameter by carrying out the minimum number of experiments to gain the information. A five-factor screening DOE can be accomplished in as few as 24 welds, with three welds completed for each of 8 tests. By comparison, it would take 96 welds to test every combination. The DOE promotes understanding of many variables in a single experiment and allows the user to interpret results, thus narrowing the variables for the next level of statistical analysis. If many variables are still not understood, multiple Screening DOE's may be required. Amada Miyachi provides a simple Screening DOE tool that is run in Excel® and is sufficient for the majority of possible applications (contact Amada Miyachi for details). Sophisticated software is also available from other vendors designed specifically for this purpose.

## CRITERIA FOR SUCCESS

Before running the series of experiments the user must establish an acceptable window for energy, time and force, thus preventing voided results. It is common practice to include one or all of the above variables in a Screening DOE. This is only recommended if sufficient understanding has been established for the other application and process variables that can impact quality Users should first try to screen out all common application and process variables that require further exploration from the results of the "look see" mini experiments and then include the three key welding variables (energy, force and time). Several Screening DOE's may be required.

Results should be interpreted carefully. Typically one would look for the highest result in terms of quality with the least variation. A Screening DOE provides only a measurement that indicates the relative importance of a parameter and not the ideal setting. Factorial DOE's should be used to establish the correct or best setting for a parameter once many of the other variables have been screened and fixed. This is also the time to assess the measurement accuracy and consistency of the test method and procedure. Variation in test method can invalidate the test and lead to misinterpretation of results.

## WHAT ARE FACTORIAL DOE'S?

The purpose of a Factorial DOE is to narrow in on the optimal setting for a particular parameter. This method is generally used when the critical or main key variables have been identified, and we need to establish the best settings for the process. A factorial DOE may also give an indication as to how wide the acceptable weld window is in relation to quality requirements. We recommend data be gathered from a monitoring perspective so that this can provide a starting point for establishing a relationship between quality and the monitored measurement parameter.

## CRITERIA FOR SUCCESS

Critical parameters should be identified from the list of unfixed variables left from the Screening DOE's. A mini-experiment may be required establishing reasonable bounds for the combination of parameters to be tested. This will prevent void data and wasted time. At this stage it is useful to record multiple relevant quality measurement or inspection criteria so that a balanced decision can be reached. For example, if part marking and pull strength are the relevant criteria, a compromise in ideal setting may be required. As with all experiments, the test method should be carefully assessed as a potential source of variation and inconsistency. Once the optimum parameters have been established in this series of experiments, a validation study can be run which looks at the consistency of results over time. It is good practice to build in variables such as electrode changes and cleaning, as well as equipment set up by different personnel. This will ensure that the solution is one that can run in a real production environment. Welded assemblies should be tested over time and under real use conditions to ensure that all functional criteria will be met. Validation testing is usually required to prove the robustness of the process under production conditions.

## CONCLUSION

The resistance welding process can deliver a reliable and repeatable joining solution for a wide range of metal joining applications. Defining the optimum welding process and best production settings can be achieved through a methodical and statistical approach. Time spent up front in weld development will ensure a stable welding process and provide a substantial return in quality and long term consistency. Welding problems can more easily be identified and solved if sufficient experimental work is carried out to identify the impact of common variables on the quality and variation of the welded assembly. Amada Miyachi frequently uses the Screening DOE tool to establish the impact of key variables and also to assist customers with troubleshooting. Often, the testing described above will provide the information and understanding to predict common failure modes and causes. A troubleshooting guide can be requested in the form of a slide rule, to assist users in identification of welding problems and likely causes.


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