microJoining Solutions – microTips™

5563 Hallowell Avenue • Arcadia, CA 91007
Phone: 626-444-9606 • Fax: 626-279-7450 • Email: mjs@microjoining.com • Web: www.microjoining.com

Magnet Wire Fusing of Automotive Motor Armatures and Solenoids
By David Steinmeier

Copper Magnet Wire Mechanical Properties

Copper magnet wires come in controlled diameters that follow metric or NEMI specifications. Drawing a large copper wire through a series of decreasing diameter dies results in work hardening the copper wire. Feeding and spooling the wire during the insulating process further work hardens the copper. Work hardening the copper wire makes the wire more brittle and prone to failure when under stress. Annealing the insulated copper magnet wire will remove the brittleness, but will damage the insulation due to the high annealing temperatures.

High Temperature Magnet Wire Insulation Properties

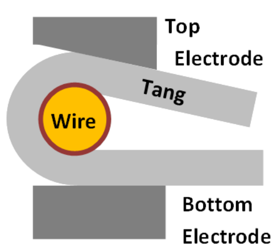
Automotive magnet bonding applications involving operating temperatures of 200°C or greater are pushing manufacturers to use more polyimide, polyesterimide, or polyimide-imide insulated wire. Since these insulations have “cut through” temperatures of 340°C or greater, common tin-lead or lead-free solder-dipping will not remove these insulations.

High Temperature Insulated Magnet Wire Removal Methods

High temperature magnet wire insulation removal methods prior to bonding include: a) cutter blades, b) abrasive wheel, c) chemical etching, and d) excimer laser stripping. All of these pre-bonding removal methods add time and expense to the bonding process.

Magnet Wire Fusing Process

Resistance welding offers a method for removing the wire insulation and creating a metallurgical bond between the copper magnet wire and terminal containing a “tang” in a single process.



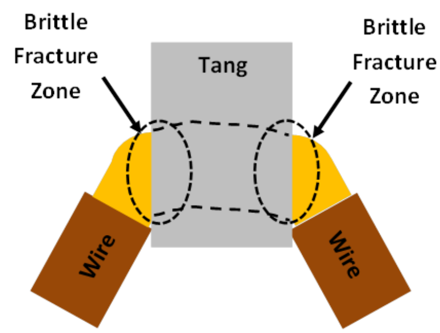
This bonding process is called “magnet wire bonding or fusing”. The tang captivates one or more magnet wires and provides an electrical path for the weld current to flow. The weld current flows through the electrode tips and tang, generating sufficient heat to “cut through” the insulation and create a bond between the magnet wire and terminal.

If the tang is tin plated, the joint will be a reflow solder joint. Without plating, the resulting joint will be a solid state bond.

Magnet Wire Fusing Failure Mechanisms

Passing weld current through tang alters the magnet wire mechanical properties in a failure-prone manner:

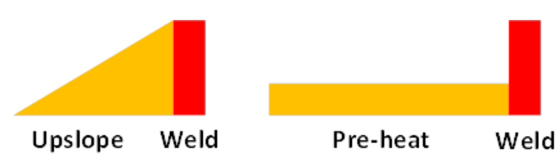
a) Tang collapse crushes the wire diameter, reducing the wire tensile strength.
b) Weld heat anneals the magnet wire captivated within the tang. The bulk of the magnet wire exiting the tang remains work hardened which meets the fully annealed and collapsed wire segment exiting the collapsed tang.



c) When subjected to thermal expansion and vibration over time, this brittle transition zone fractures, resulting in an open electrical circuit and product failure as shown in the photo below.

Magnet Wire Fusing Weld Heat Profiles

Use an upslope/weld profile on wires less than 0.3-mm in diameter. The corresponding tang thickness should be less than 0.4-mm.



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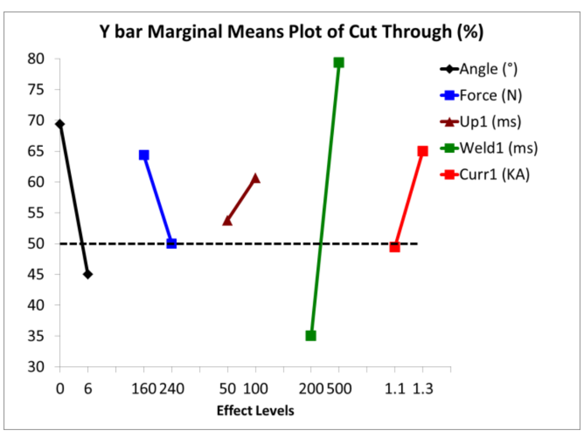
The upslope softens the insulation, allowing "cut through" to occur near the end of the upslope period. The weld period completes the bond without exploding the "U" shaped bend in the tang.

Use a pre-heat/weld profile on wires greater than 0.3-mm in diameter. The corresponding tang thickness can range from >0.4-mm to over 0.8-mm. The long pre-heat period softens the insulation, but at a lower weld current value compared to the upslope/weld profile. A minimum of 50% of the insulation inside the tang must be removed. With a weld current path now established through the tang, a relatively high weld current can be used to complete the bonding without exploding the "U" shape portion of the tang.

This microTip will describe a successful pre-heat/weld profile for a 0.50-mm diameter copper magnet wire placed inside a brass alloy tang 0.8-mm thick. The complete assembly has 6-tangs.

Pre-heat Weld Heat Profile Development
Conduct separate design of experiments (DoE's) for the pre-heat and weld periods. The build-up of weld heat in each electrode tip during the sequential fusing process dictates that each tang must have its own DoE for optimization purposes. Single and double wires also have different output responses.

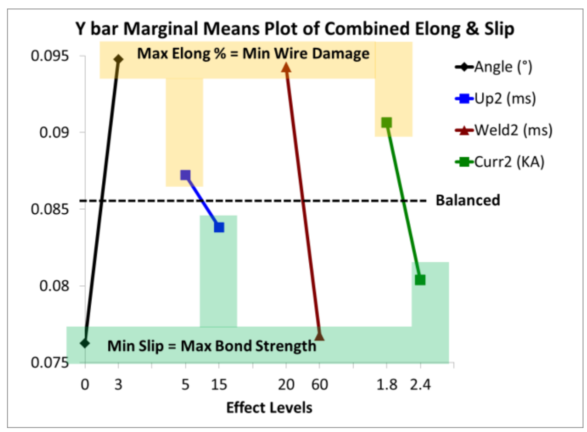
Pre-Heat DoE (Weld Pulse-1)
Use Weld Force, Upslope-1 Time, Weld-1 Time, Weld Current-1, and top electrode angle as input factors. Use "Cut Through", as the output response. 100% represents insulation removal across the entire tang width. Construct a ½ Fractional Factorial model with 2 to 4 replicates.



The resulting "Cut Through" model for a single wire tang has an Adjusted R-Squared value of 92%. Optimize the weld parameters to produce a minimum "Cut Through" of at least 50%. Minimize Weld-1 Time to reduce waste weld heat in the electrode tips.

Weld DoE (Weld Pulse-2)
Use top electrode angle, Upslope-2 Time, Weld-2 Time, and Weld Current-2 as input factors. Construct a Full Factorial model with 2 to 4 replicates to find what input factor values will provide a balance between minimizing wire damage and maximizing the bond between the copper magnet wire and the tang. Use the elongation % as the magnet wire damage metric. Use wire slip in the fused tang as an indication of the bond quality between the wire and tang.

The resulting elongation % model for a single wire tang produced an Adjusted R-Squared value of 88.3%. The slip model Adjusted R-Squared value is 75.4%. A combined Marginal Means Plot shows the conflict between maximizing elongation % and minimizing slip. The dashed line represents the best compromise or balance point between damaging the magnet wire and maximizing the bond or fusing strength.



Conclusions
1. Fusing magnet wire to a tang always produces some degree of wire damage.
2. Pre-heat/Weld profile offers the best opportunity to control both wire damage and the degree of wire bonding to the tang when fusing large diameter magnet wire to a thick tang.
3. Fusing large diameter magnet wire to thick tangs is a balancing act between minimizing wire damage and maximizing the bonding between the wire and tang.
4. To prevent failures in the armature or solenoid design stage, provide magnet wire strain relief from temperature cycling and vibration stresses.