

Lead & Magnet Wire Connection Methods Using the Tin Fusing Method Joyal® – A Division of AWE, Inc.

Abstract

The technology for connecting lead and magnet wires for electric motors and electro-mechanical devices have changed little over the years. The most common methods include Strip & Braze or Strip & Cold Crimp and are the primary processes used with multiple magnet wires or magnet wire to lead wire connections. With either method, the magnet wire enamel must be removed and the wire bundle is brazed or crimped.

Newer methods used on smaller connection types include the use of various styles of piercing or Insulation Displacement Connections (IDC). While these technologies have improved productivity, their range is limited, requiring frequent and time consuming die changes. The process offers very little feedback for quality or SPC monitoring.

The latest advancements in lead connection utilizing Tin Fusing (Sn Fusing) technology address all of the concerns of today's manufacturer and is RoHS compliant. This method is fast and efficient, producing a very high quality connection with minimal safety or environmental risks to the operator. Furthermore, they offer feedback to maintain very tight controls on the process and insure that the connection is strong, low resistance and, most of all, **consistent**.

Fusing Versus Welding

How does a fused connection differ from a welded connection and why should we be concerned about this difference?

- Both a welded and a fused connection are made in a very similar manner.
- The connection is made by applying heat and pressure over time.
- Pressure is usually applied with a cylinder (unmonitored in welding) and monitored by a load cell or pressure transducer in a fused connection.
- Heat is generated by passing a high current at a low voltage through a very low resistance circuit.
- The result of that heat and pressure is what makes the difference and the process what we need to analyze.

Essentially, a weld is made when you pass a current through the circuit that uses chilled copper electrodes that are applying pressure to the metals that we wish to connect. Within this circuit, the interface between the metals is the highest resistance, heat is generated at this interface and the metals melt. Once the current is removed from the part, the metals are allowed to cool and we have produced a weld.

With fusing, we also use a very low resistance circuit; however since our work piece is copper we can not generate significant heat within the material. Instead, we use a high resistance chilled electrode. Since the electrodes have a relatively high resistance, heat is generated at this point and that heat is dissipated into our part. We then regulate this heat so that we do not melt the copper, but instead create a diffusion bond between the wires without micro plastic deformation of the work piece.

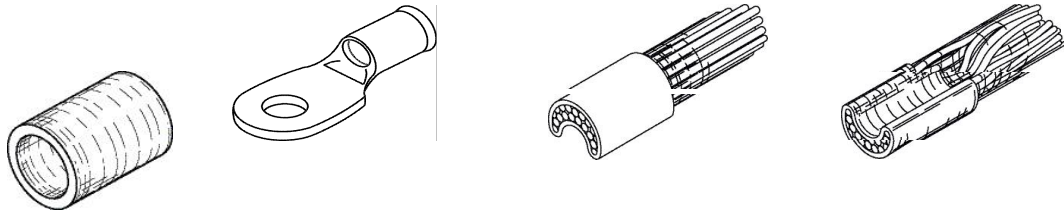
Since the goal is to create a connection with as low of a resistance as possible, the best process is to "fuse" these wires instead of "weld" them. If we have two clean copper surfaces, we can fuse them together at relatively low temperatures and relatively high pressures. Heat is needed to facilitate cleaning of the surfaces and to create the fuse at lower forces.

Tin Fusing /Tube Fusing

With Tin Fusing (Sn Fusing), a Joyal® patented process, contains the magnet wire(s) and lead wire if necessary, within a copper or brass terminal that is coated with tin. When used in conjunction with the fusing technology, we achieve the following process automatically

- Initial heat burns off the magnet wire insulation
- Further heat melts the tin coating. This “rinses” the copper wires and gives us a pure copper wire to fuse together.
- Further heat then evaporates the tin. This is important to minimize the non-copper impurities in the connection area.
- Finally, heat and pressure cause a diffusion bond of the ultra clean copper wires. Not only are the wires bonded to each other, but they are also bonded to the connector that they are contained within.
- Pressure is maintained on the part after the current has been stopped so that the bond will not break apart when the pressure is released.
- The resulting connection is very strong, durable and has practically zero connection resistance.

When talking about this process, there is often a concern about the quality of the tin and the amount of lead that has been mixed in with the tin. Today, commercial tin coatings are about 99.85% pure and have minimal lead content, far exceeding RoHS standards. At present, Joyal® has implemented Tin Fusing with hundreds of different applications and the quality of the tin has not been an issue.



Typical Tube Terminals

Tubes After Fusing

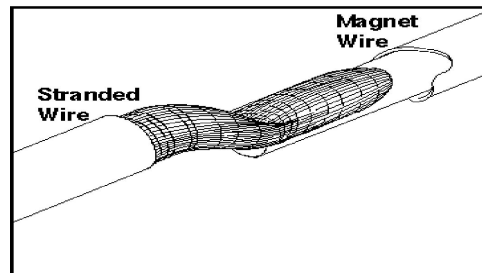
Terminals designed for “strip and crimp” applications are sufficient for the Tube Fusing process. If you are currently using these types of terminals in your process, they can easily be used with Tube Fusing. The only item to consider is that the terminals may have been sized for magnet wire that had its insulation (and typically a small amount of copper) removed. We have found that not all of the wire combinations will always fit within the same terminal and a resizing of the terminals/wire combinations should be considered.

Fuse-A-Wire™ Technology

Fuse-A-Wire™ is another patented Joyal® technology that uses tin fusing in a very unique way. In the Fuse-A-Wire™ process, insulated magnet wires are fused directly to tinned lead wire **without the need of an external connector**. The tinned wire stands will wrap themselves around the magnet wire to provide tin (Sn) to the connection area and to offer a relatively large surface area to fuse to.

In this process, the tinned wire is compressed to the magnet wire and “wraps” the individual strands of the wire around the magnet wire.

- Current is passed through the connection and the relatively high resistance electrodes dissipate their heat into the connection.
- The heat evaporates the magnet wire insulation.
- The tin melts to clean the fusing area and then creates a diffusion bond between the wires.
- This result is a mechanical strong connection which is typically stronger than any brazed or crimped connection, with a very low resistance.
- All of this is accomplished without the extra expense of a crimp connector.



When considering Fuse-A-Wire™ technology, there are a few rules that must be followed:

- The magnet wire must be placed in the bottom tool with the lead wire on top. This will give a conductive path for the current.
- As a general rule, the diameter of the tinned lead wire should be at least 15% larger than the diameter of the magnet wire.
- Up to three (3) magnet wires can be connected to a single lead wire, however the diameter of the tinned lead wire may need to exceed 20% of the total CMA of the magnet wires.

Advantages of Traditional Connection Methods

The major advantage of traditional methods is that manufacturers are comfortable with them.

- Their quality is known and a reasonable reliability is established
- Lead connecting still tends to be the highest percentage of labor in the assembly process.
- It is the highest cause of field failures.
- While customers are reluctant to change these traditional methods, Tin Fusing can produce a higher quality fuse with less labor and direct cost and its benefits are worth exploration.

Disadvantages of Traditional Connection Methods

Resistance

- IDC Terminals – Typically, IDC’s only pierce the magnet wire enamel in specific locations. This results in only point contact that has a relatively high resistance.
- Brazed Connection –There can be a high degree of variability that will result in inconsistency in manual enamel burn-off and the operator application of heat and brazing material. In addition, the connection area has a high degree of impurities and alloys that are of a higher resistance than the copper.
- Strip and Crimp Connections – The stripping process removes both enamel and some copper. This reduces the current carrying capacity of the magnet wire. If the copper is exposed for any period of time, it can oxidize, which increases the connection resistance.

Mechanical Strength

- IDC Terminals – Since the nature of this terminal pierces through the insulation and into the copper, strength can be compromised.
- Brazed Connection – Excessive heat from brazing can cause the wires to become brittle. This is because operators do not have any means to control heat, so they typically apply more than what is required.
- Strip and Crimp Connections – Strength of the entire connection bundle is usually equivalent to a fused part; however individual pull test show that there is inconsistency between wires in different parts of a terminal.

Cost

- IDC Terminals – While this technology has been around for many years, some IDC terminal applications suffer from a lack of competition and terminal costs can be relatively high.
- Brazed Connection – There are many cost involved with this operation including gas, brazing material and time to train and certify operators. There is also the cost of warranty returns and field failures that result from poor connections.
- Strip and Crimp Connections – Stripping blades are very costly and require a high degree of maintenance. There are methods that eliminate the blades, like induction heating or salt baths, but these methods carry high equipment cost with environmental and safety issues.

Process Control

- IDC Terminals – Many termination machines offer the capability to monitor both force and crimp height; however lack the ability to interface with SPC software or a corporate network.
- Brazed Connection – The control of this process relies purely on the quality of the operator. There is no possibility do document or record any part of the process.
- Strip and Crimp Connections – Most large crimping machines, for higher numbers of wires in parallel, have no feedback on the process.

Operator Training

- IDC – This process is actually a very simple to train an operator and equivalent to tin fusing.
- Brazed Connection – On a stator assembly line, the brazing operators usually require the highest degree of training and certification. Manufacturers who do not continually invest in training and certification usually experience a very high rate of rejects or field failures.
- Strip and Crimp Connections – Operators need to be vigilant about the correct tooling, quality of the stripping tools and be trained on evaluation and maintenance of tooling.

Speed

- IDC Terminals – Typically very fast.
- Brazed Connection –Operator dependant.
- Strip and Crimp Connections – While the crimping time is usually about the same as fusing, it can take minutes to strip and clean all of the magnet wires.

Advantages of Tin Fusing (Sn Fusing) Over Traditional Methods

The tin fusing process offers a significantly improved connection over all other forms of traditional connection methods including the following:

Resistance

- Since the result of fusing is a diffusion bond between ultra-clean copper wires in a low oxygen environment, the connection is far superior to any other method.
- With the Fuse-A-Wire™ process, we essentially wrap the lead wire strands around the magnet wire for maximum contact.
- With the Tube Fusing and Thermal Crimp processes, detailed analysis and customer testing against other methods, show that the wires of the fused connection have a lower resistance and are more consistent than other methods.

Mechanical Strength

- Since we have a bond between the wired and to a tube, the strength is far superior to all other connection methods.
- With large wire bundle Tube Fuse or the smaller Thermal Crimp applications, it is not possible to pull any of the wires out of the tube without breaking them first.
- Typically, these tests result in all of the wires breaking off and the connections remaining within the connector.

Cost

- With the Fuse-A-Wire™ process, there is no additional cost involved in your product since this technology eliminates the need for a connector.
- With Tube Fusing, tubes and lugs are readily available from a variety of sources and pricing is very competitive when compared to Cold Crimp and IDC terminals.
- With Thermal Crimp, the material is a very inexpensive strip of tin coated copper and we provide our customers with the specifications on this material so that they can source it locally.

Process Control

- With Fuse-A-Wire™, Tube Fusing and Thermal Crimp, we can monitor three variables of the process.
- Force is set by means of a proportional valve and can be confirmed and monitored by a transducer.
- The total height of the final connection is monitored by means of a linear encoder. In Tube Fusing, this can also monitor the diameter of the tube to make sure that the correct tube is in position for the fusing program.
- Current is monitored and maintained by means of a constant current controller.
- All of these attributes can then be compared against minimum/maximum limits and even written to an SPC program or network.

Reduced Operator Training

- Essentially, the operator only needs to enter the correct program number and place the connections within the tooling.

Speed

- For a Fuse-A-Wire™ and Thermal Crimp applications, the fusing cycle is usually less than 1 second.
- With Tube Fusing, (50) #18 magnet wires can be fused within 7 seconds and (100) #18 magnet wires can be fused within 10 seconds.

Conclusion

While many companies are reluctant to change, fusing is a “tried-and-true” technology, as proven in the armature process over many years.

- Tin Fusing offers even more opportunities to improve product consistency and quality.
- Manufacturing processes would be simplified with improved flexibility.
- Tin Fusing would also resolve safety and environmental issues in the assembly process and add SPC capabilities, not possible with previous methods.
- Justifications, based solely on these improvements, would be difficult with today’s “Discounted Rate of Return” and “Payback” requirements.
- With the additional benefits of reducing direct labor, training, setup, repair and warranty costs, justifications should be simplified.