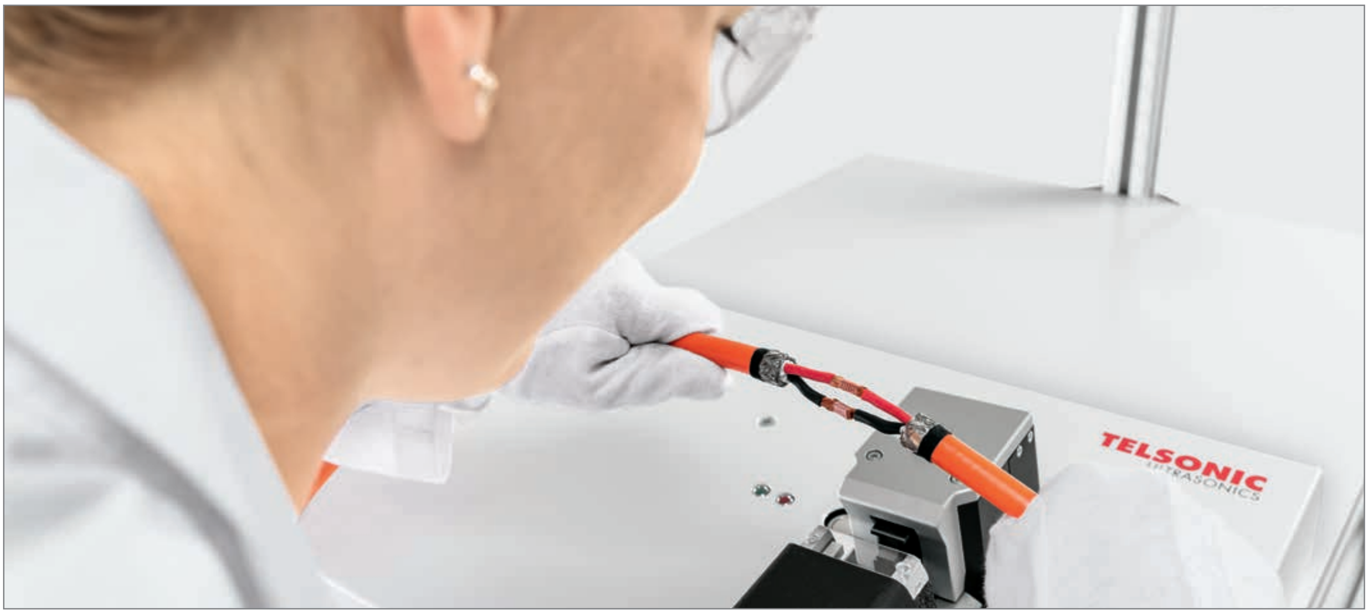
TELSONIC
ULTRASONICS

Metal Welding With Ultrasonics

An Insight Into This Flexible And Powerful Technology

PLASTIC WELDING | METAL WELDING | CUTTING | CLEANING | SIEVING



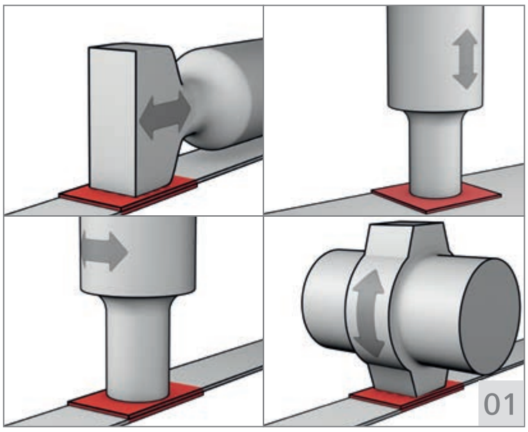
North Billerica (USA), 11/2022

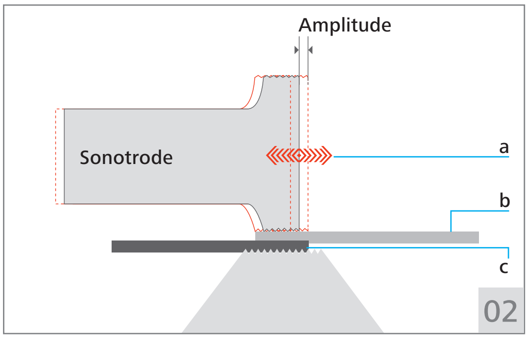
As a technology which has been widely used for welding and joining applications across multiple industries for decades, it is a natural progression that ultrasonic technology is fast becoming the preferred process for metal welding applications on many of the connector and harness components being manufactured for hybrid and full electric vehicles. With an increased focus overall on the use of ultrasonics for metal welding applications, Telsonic's Greg Ruscak – Applications manager for Telsonic in Boston, outlines the principles, methods, benefits, and crucially, the factors which influence weld quality, in this informative article.

Technology Overview At A Glance

Telsonic has developed four different ultrasonic welding processes, two linear and two torsional, which can be applied to a wide range of both plastic and metal welding applications. The linear processes are performed either horizontally or vertically and the torsional processes, which are unique to Telsonic, are known as SONIQTWIST® and PowerWheel®

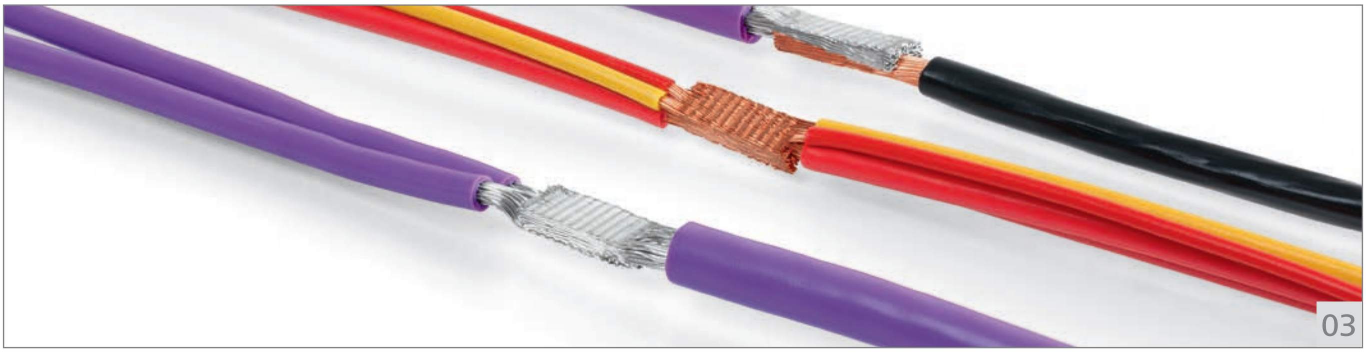
It is important to understand the principles of each of the different processes and also identify the benefits which each process brings. This diagram below illustrates the basic principles of the linear welding process. As the sonotrode moves back and forth, termed the amplitude, the part being welded also moves over the lower part, which is being clamped rigidly in the anvil.
The term 'amplitude' describes the extent of longitudinal expansion and contraction of the sonotrode. The amplitude correlates with the roughing effect at the interface of the weld seam. This roughing movement in combination with pressure is responsible for the welding process. The linear welding process can be performed in the horizontal attitude – shown – or the vertical orientation.





01 Top left to bottom right – Linear Horizontal, Linear Vertical, SONIQTWIST® and PowerWheel®

02 a. Relative movements within the wire and in the direction of the terminal cause the weldingprocess
b. The part to be welded moves with the sonotrode (in the welding area)
c. The lower part is fimly attached to the anvil and must not move



The linear ultrasonic welding process fulfils many of the requirements in metal welding applications and is capable of joining dissimilar metals. The resultant welds provide very good electrical conductivity and strong welds with no structural changes in the parent material.

Telsonic's SONIQTWIST® torsional welding process opens up additional opportunities and applications. This unique process results in minimal linear vibrations in the part, an important charactaristic in applications where sensors or other electronic components may be present. Other benefits of this technique include the ability to perform successfully in applications where there is limited access, and fast process cycle times. SONIQTWIST® can also be used for both plastic and metal welding, and in applications with foil or films, using SONIQTWIST® eliminates the possibility of a "membrane" or rippling effect on the surface. (See image 01a on page 1)

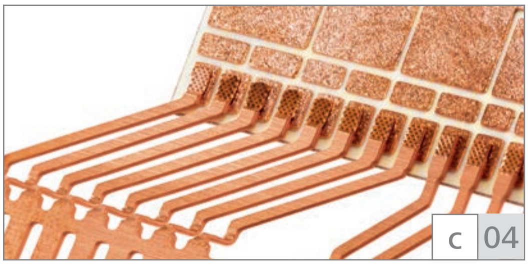
In metal welding applications where there are large cable diameters, large terminals or tubular cable lugs, and terminal to terminal welding, Telsonic's PowerWheel® technology offers the optimum solution. Providing excellent accessibility to the weld zone, PowerWheel® is capable of welding up to 200 mm² of copper material whilst achieving up to 30 % narrower welds. This process also significantly improves wire compacting and delivers excellent weld strength. (See image 01b on page 1)

Factors Which Influence Weld Quality

Material Selection

There are a variety of factors which affect weld quality including, the materials being joined, surface condition, the welding parameters and equipment being used, the design of the workpiece, and of course any human influences. The metal types most suited to the ultrasonic welding process are Aluminum and Copper.
In general, the purer the material, the more suitable it is for ultrasonic welding. However, following evaluation, brass (e.g. Ms63, CuZn37) and not containing lead, nickel silver and bronze (up to 8.5 % Sn), may be considered depending upon the individual alloy. In addition, gold, silver, and nickel coatings on a copper substrate are also suitable for the ultrasonic welding process based upon certain parameters.

For nickel (Ni) the coating thickness should be between 3 to 12 µm, with the chemical electroless process preferred and less than 1 % phosphorus present. silver (Ag) coatings ideally should have a thickness of between 3 and 5 µm on a nickel (Ni) base, and the surface should be smooth and fine or polished if possible. Gold (Au) provides good weldability, and the coating process should be carried out as the last step, following any punching or bending operations. When ultrasonically welding aluminum, it is important that it has a purity of at least 99.5 %, and it must not be anodized, hard anodized or coated in any way.



03 Wire splices of copper/aluminum combinations

04 Examples of SONIQTWIST® applications include (a): Bolt welded to current connector, (b): Hermetically sealed metal cans, and (c): Electrical connection on IGBT

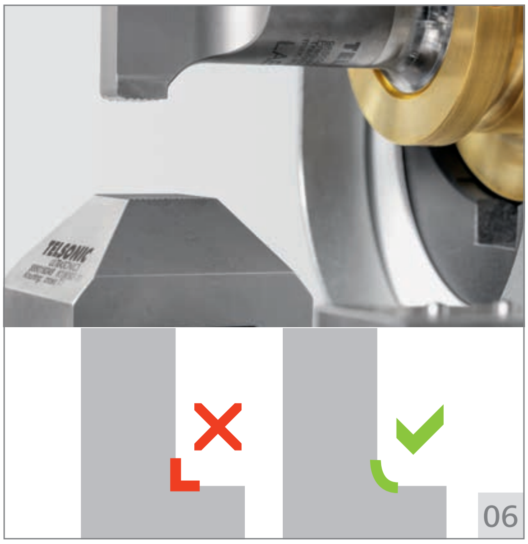
Surface Condition

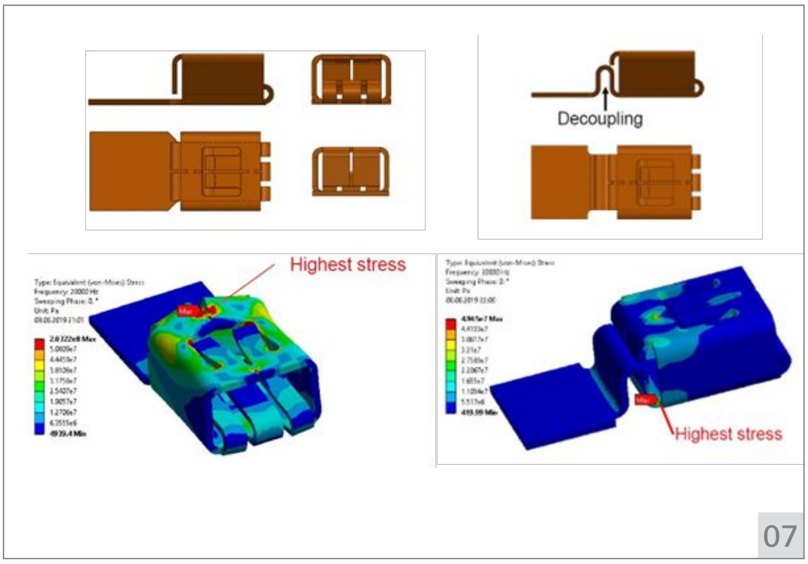
Other factors relating to the material and which can affect the quality of the welding process are the presence of extraction oils and additives which will have a negative influence on the quality of the weld. Manufacturing processes, which may have been performed prior to welding, such as punching, rolling or laser cutting can induce hardening of the material and once again have a negative impact on the ultrasonic welding process. In addition, rough or uneven surfaces, surfaces which have oxidised, or are lead or tin coated and surfaces containing fillers will not be suitable for ultrasonic welding.

It is also important to maintain consistency in the specification of the material being used, and be concious that material sourced from different suppliers could actually be different enough to adversley affect the welding process.

Workpiece Design & Setup

As for any manufacturing process, there are a number of areas which need to be reviewed, relating to both component design and process set-up, to ensure efficient and consistent ultrasonic welding results.
At a basic set-up level it is omportant to ensure that the anvil is placed directly underneath the welding area. It is also important to have knurling on both the anvil and the sonotrode. When welding terminals, the force retaining the terminal plays an important role in the resultant weld quality, and terminals should only exhibit small protruding surfaces or preferably no protruding surfaces at all. Another characteristic which needs to be considered is that there should be no sharp corners or edges on the contact.
The importance of ensuring that the component is designed correctly can be illustrated in the following example. This shows the real world FEM simulation of a contact with a hard coupling, where the incorrect design of the terminal was causing failures to occur. A copper wire was being welded lengthwise onto the contact surface, and the ultrasonic vibration was being transmitted to the plug contact, which was being heavily stressed.
By involving Telsonic in the design process, the component design was optimised by de-coupling the plug contact from the welding surface. This meant that just a few vibrations were being transmitted to the contact, eliminating the damage which was being seen previously.

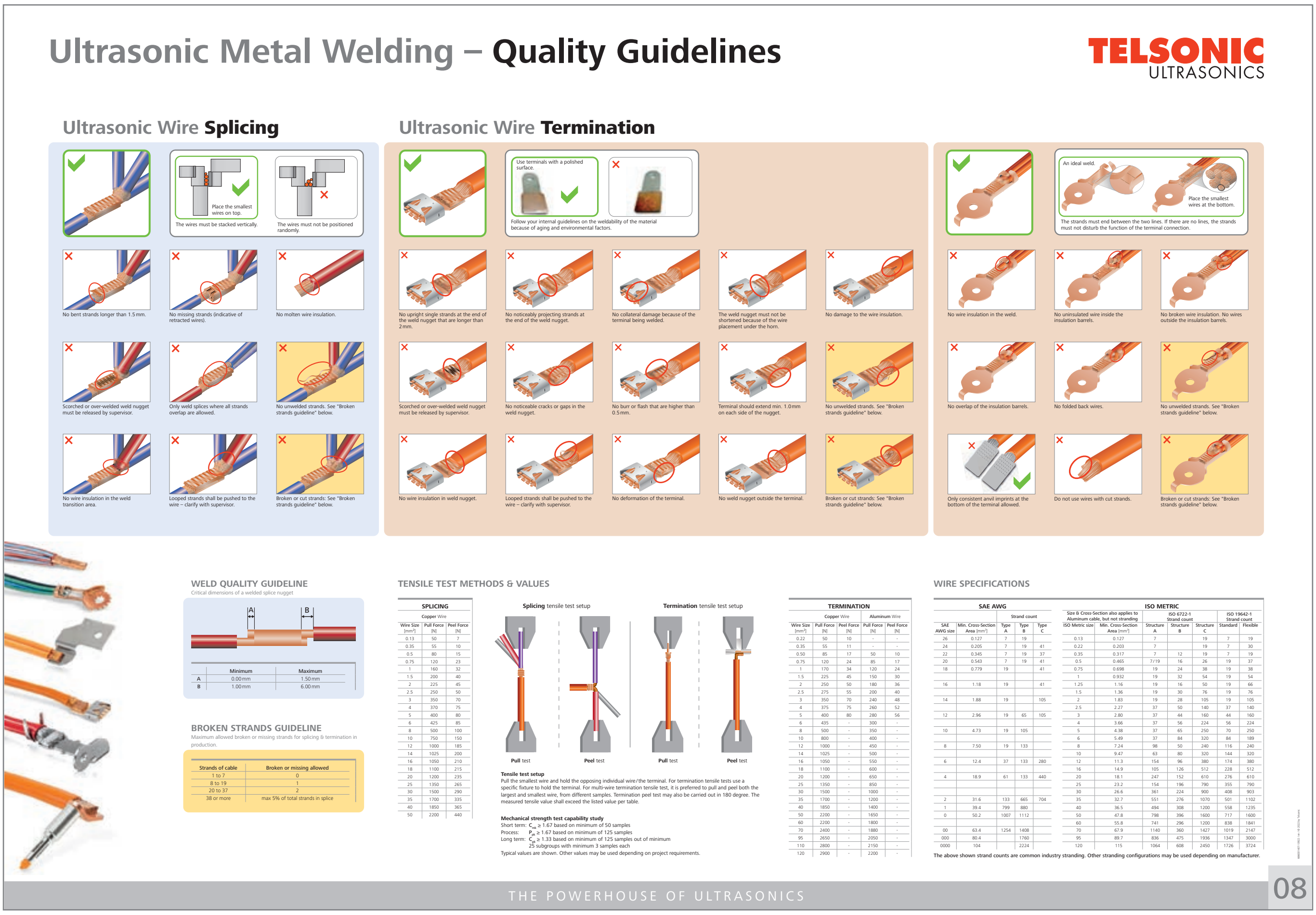




05 The condition of the surface of the material will impact the quality of the welding process

06 Contact design guidelines

07 The original design – LEFT was causing high stresses and failure. – RIGHT Telsonic’s de-coupling design eliminated the issue



08 By following a few basic steps and recommendations, a good weld can be guaranteed

Influencing Factors And Characteristics Of A Good Weld

There are a number of factors which will influence the outcome of the ultrasonic metal welding process. In the case of wire splicing and cable termination, these include: the strip length and cable position prior to welding, the weld bond height, width and length, the positions of the end of the conductor and insulation, and of course the weld time. It is also important to consider any differences in wire sizes, taking steps to avoid side splices, and placement of any delicate terminals. Get these steps right and the ultrasonic metal welding process will produce high quality and consistent results. When applied to wire splicing applications, the following characteristics define a good weld: All of the wire strands are welded and the overall weld length is sufficient. The strand ends, or "brushes" should be short and flat with no cut strands on the outside of the weld area and no burn marks. In addition, all of the wires should be overlapped, with no excessive flash or burrs and there should be no damage to the insulation material.
Telsonic has produced a comprehensive and informative single page poster to act as a guide covering common wire splicing and wire termination welding applications. Important quality and operational criteria are highlighted using text and images, together with test criteria and a useful table of wire sizes.

Understanding And Defining Welding Parameters

Not withstanding the other criteria previously discussed, such as selecting the linear or torsional process, material selection, surface condition, product design and physical set up and configuration, it is essential that the correct welding parameters are chosen for the application under consideration.

To make appropriate selections it is important to understand the individual elements which influence the welding cycle. The formula for Power is influenced by: Time, which is the duration of the ultrasonic vibrations, Amplitude, which is the longitudinal displacement of the vibration, and Force the compression force applied perpendicular (normal) to the direction of the vibration. The Power required to initiate and maintain vibration (motion) during the weld cycle is defined as: $P \approx C \times Fo \times A \times f$ where C = Predefined Constant, P = Power (watts), Fo = Force (Newton), A = Amplitude (microns), f = Frequency (Hz).

*Note: Force is determined by multiplying:
Force = Applied Down Force × Friction Coefficient = Pressure × Cylinder Area × Friction Coefficient

Energy is calculated as: $E = P \times T$, where E = Energy (Joules), P = Power (watts), T = Time (seconds).
Therefore the complete "Weld to Energy" process would be defined as: $E \approx 4 \times Fo \times A \times f \times T$

A well designed ultrasonic metal welding system will compensate for normal variations in the surface conditions of the metals by delivering the specified energy value. This is achieved by allowing time (T) to adjust to suit the condition of the materials and deliver the desired energy.

Rule of thumb for application design when welding copper and aluminum

	Copper	Aluminum
Power*: Weld area [mm^2] × power [W/mm^2]	33 W/mm^2	24 W/mm^2
Force**: Weld area [mm2] × force [N/mm^2]	20 N/mm^2	15 N/mm^2
Amplitude***: @ 90 % generator output power	30 µm	24 µm
Tensile force (wire to terminal welding)	Depending on the material. USCar 38-1 serves as a guideline	

In order to compensate for tolerances and application variations, the following safety margins should be noted in calculations:

* Designed for max. 80 % of the generator welding power

** Designed for max. 90 % of the nominal welding force

*** Designed for min. 80 % to max. 90 % of the generator output amplitude

09 The infographic on the top highlights the different welding modes, parameters and results in the ultrasonic metal welding process

Defining And Controlling The Welding Process

The following infographic highlights the different welding modes, parameters and results in the ultrasonic metal welding process.

Welding modes choose 1 of 3	Welding parameters require 3, depending on the mode	Welding results always obtain 6 results
Time	**Welding time** [s]	**Welding time** [s]
E Energy	**Energy** [J, Ws]	**Energy** [Ws]
abs diff **Distance** abs/diff	**Distance** [mm]	**Absolute distance** [mm]
		Differential distance [mm]
	Amplitude [%]	**max. power** [W]
	Pressure [bar]	**max. force** [N]

The **TIME** welding mode is often used for new applications to help determine the energy required. This mode has the advantage of preventing overwelding, thanks to a short welding time. Users can then switch to energy welding mode once the correct energy level is established. It should be noted that increasing the welding time also increases the energy output, if amplitude and pressure remain the same.

The **ENERGY** welding mode is the recommended welding mode for more consistent pull test results, and is used when the required energy is defined. The advantage in this case is that the same amount of energy is always used for welding, which compensates for minor material or tool fluctuations. Increasing the energy also increases the welding time, if amplitude and pressure remain the same. Also, an increase in amplitude reduces the welding time, if energy and pressure remain the same, and an increase in pressure also reduces the welding time if energy and amplitude remain the same.

10 Greg Ruscak, Applicatons Manager, TELSONIC Solutions, LLC

Human Influences

The final factor which can influence the success or otherwise of the ultrasonic metal welding process is that of human interaction. It is essential that operators are suitably trained to understand the need for any material preparation and handling both prior to and following the welding process. The repeatability of any manual processes or tasks will also have an influence on the outcome of the weld process.