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## Batteries need strong connections – are resistance, laser and micro TIG welding the best suited joining technologies?

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**Abstract:** The contacting of battery cells is very essential and technologically challenging step during the battery pack manufacturing. The goal is to achieve best weld joint without defects to enable high current flows. This requires high quality welding and joining process. A number of technologies is already well established respectively is typically used to solve most common applications. All three technologies resistance, laser and micro TIG welding are well suited for integration into production lines that may be either standalone or automated operation. To maintain the required throughput that offers high quality and yields, it is important to have a clear understanding of which process is best for the particular battery pack size, tab and terminal material, type, and thickness. In addition, the selected process and integration solution should include process monitoring, process data management, and weld quality assessment.

**Keywords:** resistance welding, laser welding, micro TIG welding, battery welding

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### Introduction

The world becomes more mobile and components become smaller and therefore the batteries and battery packs have become an integral part of everyday life. Batteries are used for portable electronic devices, cordless power tools, energy storage, hybrid and EV cars and in many other different application fields. The need for longer lasting batteries and battery packs, which continuously meet the increasing quality and production requirements is increasing. There are a number of materials joining requirements for battery manufacturing, depending on the specific type, size and capacity of the battery. Internal terminal connections, battery can and fill plug sealing, tab to terminal connections,

and external electrical connections are a few key examples.

Several joining options can be considered for each of these requirements, including resistance, ultrasonic, micro TIG and laser welding. The decision to use one or the other is generally dictated by the specific type of weld required and production requirements. Ultrasonic welding is commonly used for the joining of the internal electrode battery materials, which are usually constructed of thin foils of aluminum and copper. The remaining joining requirements – including the connections inside the can, and external terminal tab connections – are well suited to resistance, micro TIG, and laser welding. For can and plug

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applications (seam sealing), laser welding is the joining technology of choice.

The following is an overview of resistance, micro TIG and laser welding technologies, along with examples of battery joining applications, detailing the key features of each technology.

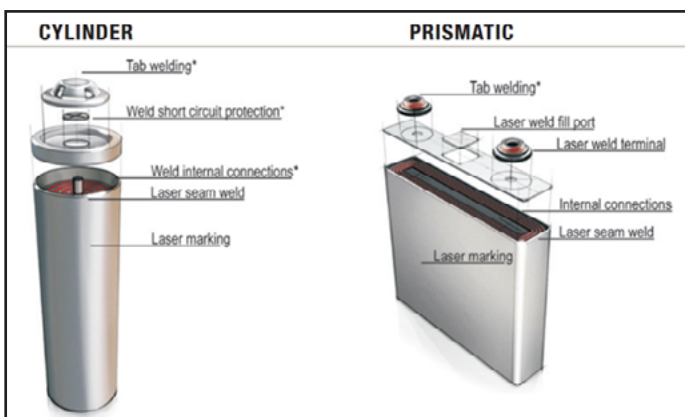
### Battery Packs Basics

Today's battery packs come in a variety of configurations, as shown in Figure. 1.



Fig. 1. Typical battery pack configurations.

Battery packs use several different battery types, including cylindrical, prismatic, ultra-capacitor, and pouch. Materials joining requirements vary depending on the battery's specific type, size and capacity. Tab to terminal connections, internal terminal connections, tab welding, seam welding, fill port welding, short circuit protection, laser marking, and external electrical connections are a few key examples. Figure 2 shows the typical joining requirements for the different battery types. This article focuses primarily on welding tabs to terminals.



### Welding tabs to terminals in battery pack manufacturing

In most cases, pack manufacturers receive individual batteries from vendors, so the critical process step for pack manufacturing is joining the individual batteries together using a collector plate, which consists of tabs for the individual cells to be welded to both the positive and negative terminals. In addition, many packs will need a smaller number of collector plate to busbar connections. Along with considerations of materials, joint geometry, weld access, cycle time and budget, the welding technology selected will also be affected by the manufacturing flow and production. Reviewing all these factors will usually point in the direction of the joining technology most suitable for the application: resistance welding, micro TIG and laser welding.

The traditional material for battery tabs is nickel because of its great welding properties. This can be easily welded to nickel, steel, stainless steel, nickel plated steel and HILUMIN® battery case materials. But nickel also has a relatively high cost, high weight, high electrical resistance and high stiffness. Copper is the most electrically conductive material for battery tab connections; only silver and gold are more conductive. Copper is relatively expensive. So, manufacturers may choose for aluminium in some applications. Copper's electrical resistance is only two-thirds that of aluminium, which makes copper 1.5 times better from an electrical pack performance point of view. However, the price of copper battery tabs

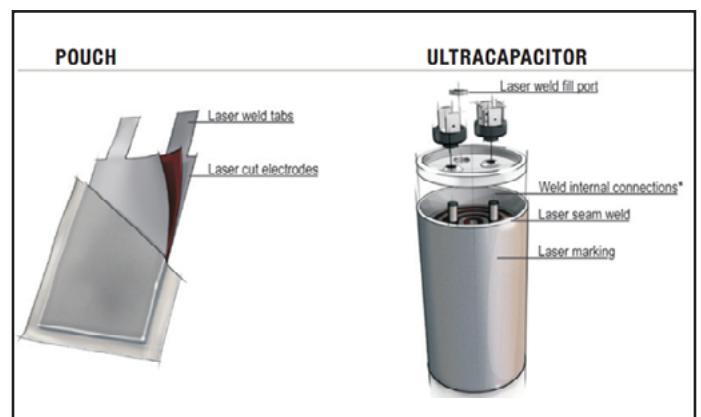


Fig. 2. Typical joining applications for the different battery types.



Fig. 3. Tabs to terminals connections manufactured by three most common welding techniques: left: resistance welding, middle: micro TIG, right: laser welding.

is about 15 times higher than that of aluminium and the weight is about four times higher. Manufacturers should select copper for all applications where they are looking for maximum electrical efficiency or those that require the highest peak currents. Examples of tabs to terminals connections manufactured by above mentioned three welding techniques are shown in Figure 3.

**Battery pack welding technologies – advantages and disadvantages**

There are several different alternatives available for battery tab to connector welding, including laser welding, resistance welding, micro TIG (also known as micro-arc or pulse-arc welding) and ultrasonic welding. The right one depends upon the battery type, material and thickness of tabs, and the required production volume.

**Resistance welding**

Resistance welding is the traditional welding technology used for battery pack manufacturing. This reliable technology has been around for years and requires relatively low investment levels [1, 2]. Resistance welding is a relatively straightforward process – the operator simply pushes down the battery tab with a weld head, which is operated by a cable or footswitch, and starts the weld. Recently also weld heads integrated into automatic or semi-automatic

welding system as shown in Figure 4. are becoming more and more popular.

Because one is physically touching the part, resistance welding offers the easiest process data management and monitoring. The equipment can easily measure the welding process, including electrical parameters like current, voltage, resistance, power and mechanical parameters like force, height and movement of electrodes during welding. One disadvantage of resistance welding is that the manufacturer is limited by the need to direct and concentrate the weld current using projections or dimples. The electrical connections are limited to one or two projections on each side of the battery, creating a total of two or four small area (typically 0.5mm<sup>2</sup>) weld spots. Once these connections are made, further welding current will

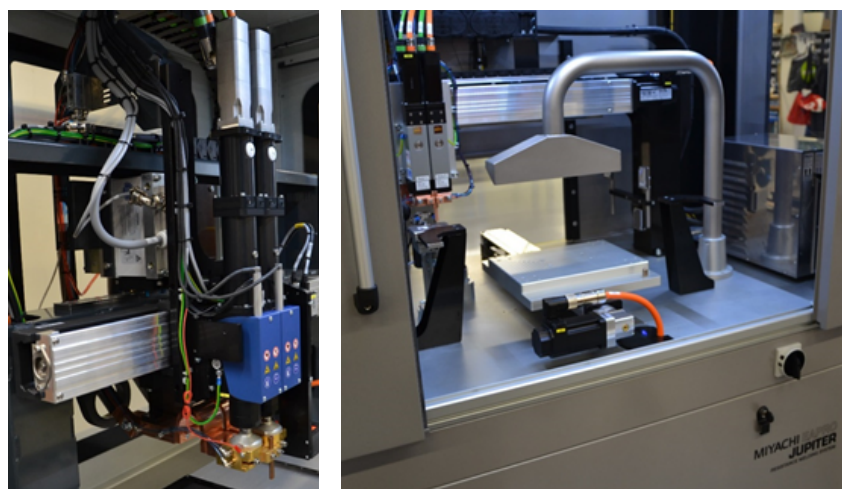


Fig. 4. Example of state of the art resistance welding weld head integrated into automatic welding system: left: motorised MFP250-D with spring follow-up system from Amada Miyachi, right: motorised MFP60-D from Amada Miyachi.

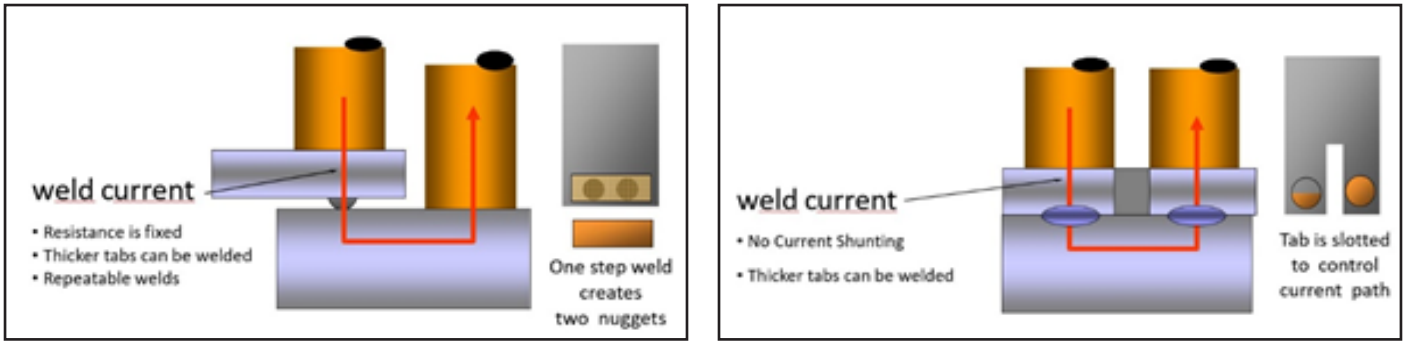


Fig. 5. Scheme of basic configurations to weld tab to a battery pole, left: one electrode is touching the tab; right: both electrodes are touching the slotted design battery tab

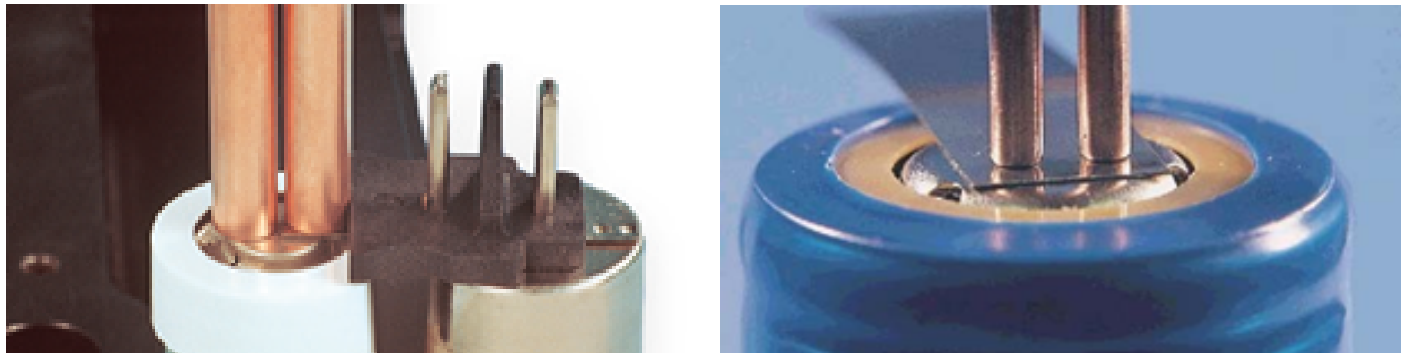


Fig. 6. Application examples of basic configurations to weld tab to a battery pole as described in Figure 5.

flow over these connections, causing current shunting and preventing creation of any further connection area. The welding process of a battery tab can be carried out by two basic options. In the first option the welding electrode is in direct contact with the tab to be welded and the contacting electrode is contacting the surface of the battery pole (see Figure 5 left). In the second option both welding electrodes are touching the tab and a slotted design of the tab needs to be used to enable defined welding current path through the tab and to increase the weld strength (see Figure 5 right)

A further disadvantage of resistance welding in today's market stems from the fact that the process requires electrical resistance to create

the connection by melting material. As batteries become more efficient and powerful (with more energy current from a certain sized battery), there must be lower resistance in the connections between batteries. In past battery applications, the traditional materials used have been either nickel or HILUMIN<sup>®</sup>, an electro nickel-plated diffusion annealed steel strip. Recently manufacturers have begun to use higher electrical conductor materials that feature lower electrical resistance, like copper or aluminium. Thicker materials are also being used to get a higher efficiency battery pack, since thicker material lowers resistance and makes it easier to pass current. As resistance draws closer to zero, resistance welding becomes more and more difficult.

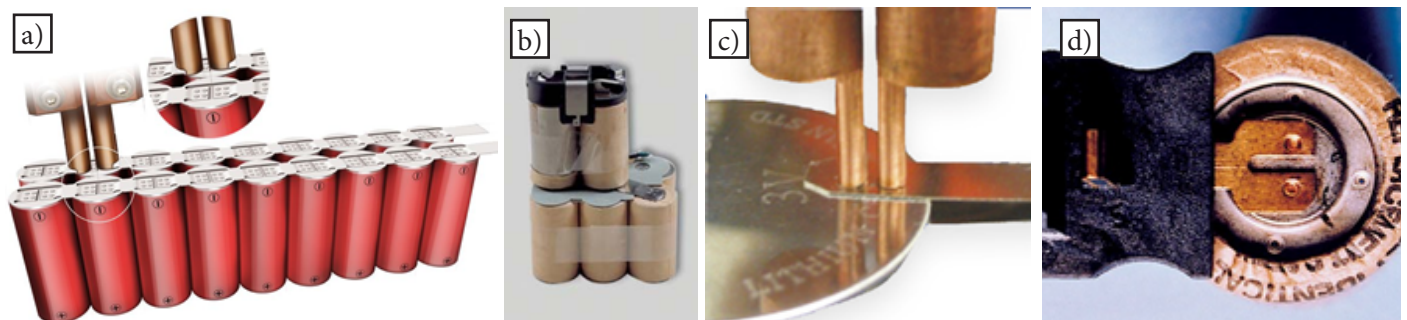


Fig. 7. Examples of battery packs welded with resistance welding technology. a) typical pack used in e-bikes, b) battery pack used in power tools, c) battery pack used in small size portable devices, d) battery with integrated connector.

Experience shows that resistance welding is extremely well suited to welding nickel tab material up to approximately 0.4 millimeter thickness, and nickel or steel clad copper tab material to around 0.3 millimeter thickness to a wide variety of terminal materials [3].

### ***Laser welding***

An important advantage of laser welding is its fast cycle time, so manufacturers will obtain more output than with resistance welding. In addition, laser welding is a non-contact process. No electrodes touch the part and there is very low pollution of the part. However, this can also be considered somewhat of a disadvantage; because one is not physically touching the part, it is more difficult to achieve quality control compared to resistance welding. Laser welding is also not as strong as resistance welding when it comes to process monitoring.

When welding battery tab connections, it is critical to ensure a zero air gap between the battery and the tab. This zero air gap is inherent to the resistance welding process, but is not a feature of laser welding. Therefore, laser welding equipment selected must take this into consideration. For example, Amada Miyachi recently developed a battery welding head that uses an integrated tab down holder to achieve the zero air gap as shown at Figure 8.

### ***Laser welding: challenges of the state of the art battery packs***

Over the last years the designers of battery packs for hybrid and electric automobiles, motorcycles, buses, heavy industrial vehicles, and hand-held power tools are looking for more energy to support the vehicle or device and increase its life. To do this, they must change the batteries' electrode, isolator, and electrolyte, and lower its internal resistance to reduce energy losses on a battery cell level. The lower the loss, the more efficiently energy is stored in the battery. These improved batteries store more

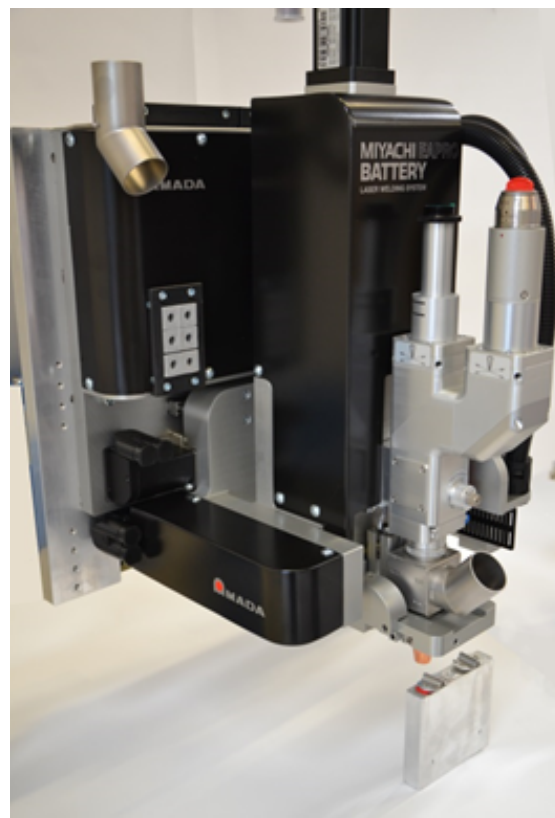


Fig. 8. Example of a battery welding head with an integrated tab down holder to achieve the zero air gap. This battery laser welding head works up to 5kW CW, it has integrated: tab down holder for zero airgap, XY stage for laser beam movement, shielding gas nozzle, fume extraction nozzle, Z axis for tab down holder, camera for process, force and height measurement, it is designed and manufactured by Amada Miyachi.

energy and can also charge and discharge faster, as measured by the battery's "C" rate – the ratio between the charge/discharge acceptance and its capacity.

The higher voltages and currents generated by improved batteries means the battery interconnection (battery tab) must improve its electrical conductivity. The higher electrical conductivity results in lower electrical losses when charging and discharging, so more electrical energy is available for the vehicle or device powered by the pack. By improving the electrical conductivity, the pack also stays cooler during operation, which provides additional performance and battery lifetime benefits. Last, but not least, improving battery performance lowers costs, because fewer batteries are required for a particular performance level. The three options for improving battery interconnect performance are:

- a) using thicker tabs to carry more current,
- b) using different tab materials (for example, copper or aluminum) with higher conductivity,
- c) creating a larger tab to battery pole contacting area.

In the past, steel and nickel-based materials were commonly welded to the CRS (cold rolled steel) terminals. However, more recently, as batteries have move towards higher capacity and higher “C” values, designers began looking at using aluminum or copper materials for tabs to reduce electrical losses.

*Laser welding: challenges of using traditional Nd:YAG lasers for welding dissimilar metals*

This rise in the use of dissimilar material welding comes with a variety of challenges for traditional welding options like pulsed Nd:YAG (neodymium-doped yttrium aluminum garnet) lasers, which typically make spots that are 0.5 mm in diameter with one pulse. Each weld pulse takes between 1 and 10 milliseconds; depending on its power level, the laser can generate about 10 of these pulses every second [5]. To create a joint with sufficient electrical and mechanical properties, between 2 and 50 welding spots must be placed on each battery pole (see Figure 9).

This method worked well for the traditional battery tab materials because of their weldability. However, welding of dissimilar materials is significantly more challenging because of:

- Different melting temperatures (see Table 1)
  - Different thermal expansion coefficients
  - Different absorption coefficient of laser light
  - Incompatible chemistry and atomic structures
- Joining aluminum to stainless steel has always been an impossible welding combination.

The mixing of these two metals creates a brittle intermetallic zone leading to weld cracks.

Table 1. Melting points of alloys

Combination	Melting Temperature, °C
Aluminum/Steel	660/1500
Aluminum/Cooper	660/1080
Aluminum/Titanium	660/1700

*Laser welding: innovative laser welding technologies*

New laser technologies are rewriting the textbooks on which materials can be joined together. Single mode fiber lasers and lasers with nanosecond pulses are joining new combinations of metal that were previously not considered compatible. The single mode laser can be focused to spot diameters of 20-50 microns. This makes a very small welding line of 20-50 microns wide, which can be pulsed like “a hot knife through butter” to make a weld. The linear speed of this laser beam movement is typically in the 100 to 1000 mm/sec (4-inch-40-inch/second) range [6] (See Figure 10).

To create sufficient joint area, the length of this joint needs to be 10 to 100 mm per battery pole. To fit this onto the 3 to 6 mm diameter available on a battery pole, the line must



Fig. 9. Traditional laser weld of battery tab showing several large (200-600 micron) weld spots. Weld spots or seam can be tailored to both strength and conductivity, left: approx. 60N peel strength, middle: approx. 250N peel strength, approx. 180N peel strength in all directions.

be in a spiral shape or concentric circles, rather than spots. Using a galvo scanning weld head, the total weld can be very fast; it takes about 50 milliseconds of weld time.

Another method of welding dissimilar metals is to concentrate the laser energy in time by using nanosecond pulsed fiber welding instead of the traditional millisecond pulse. The weld pulses are typically 100,000 times shorter, providing energy in a much shorter period. This increases the laser peak power level by the same amount. The spot size is also very small, about 30 to 40 microns. The high peak power on a small area results in such a high peak power density that all metals are molten. This process can be best described as “pushing a hot needle in the material and pulling it out again.” The spots are very small, so a great many spots are needed, typically 10,000 or more. As the timeframe for creating one spot is very small, the laser can be fired at high repetition rates, typically 30 kilohertz (kHz) and above.

The best method of getting enough weld spots with the nanosecond laser on a small area like a battery pole is to make a line coiled into a spiral. This spiral is typically welded from the inside to the outside, so the laser beam always “sees” a fresh and cold piece of metal in front of it. If the laser went from the outside to the inside, there would be heat build-up and increased penetration depth towards the center, as the part heats up during the welding. Figure 11 shows an example of a spiral weld made on aluminum tab material.

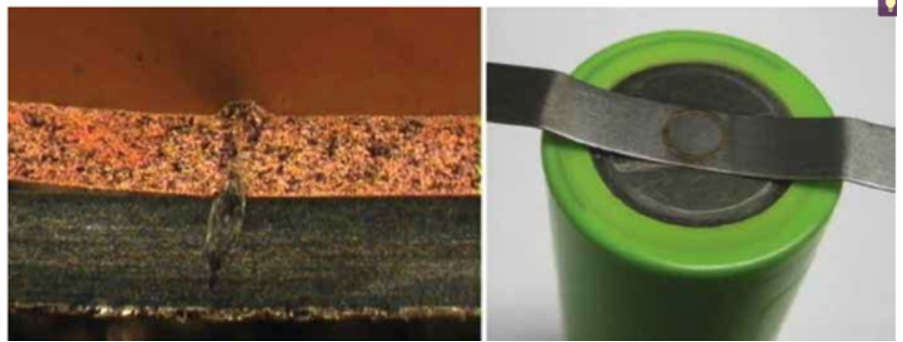


Fig. 10. Copper battery tab welded to steel battery can with single mode laser

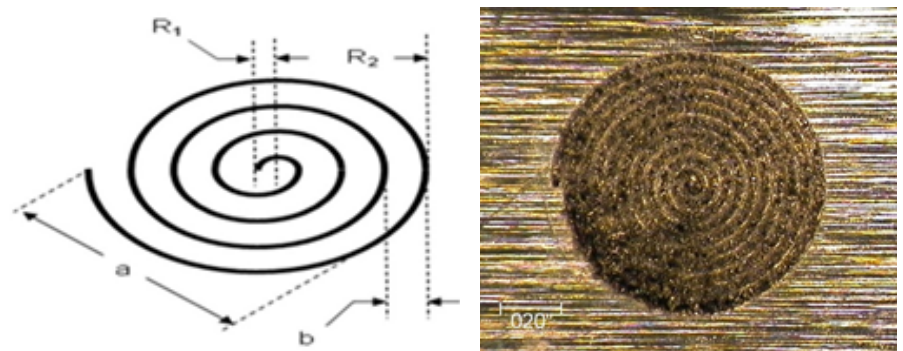


Fig. 11. Aluminum battery tab welded to a nickel plated cold rolled steel can using the spiral weld technique (R1: Inner Radius = 0.02mm, R2: Outer Radius = 0.5mm, a: Ramp = 3mm; b: Rise = 0.02mm)

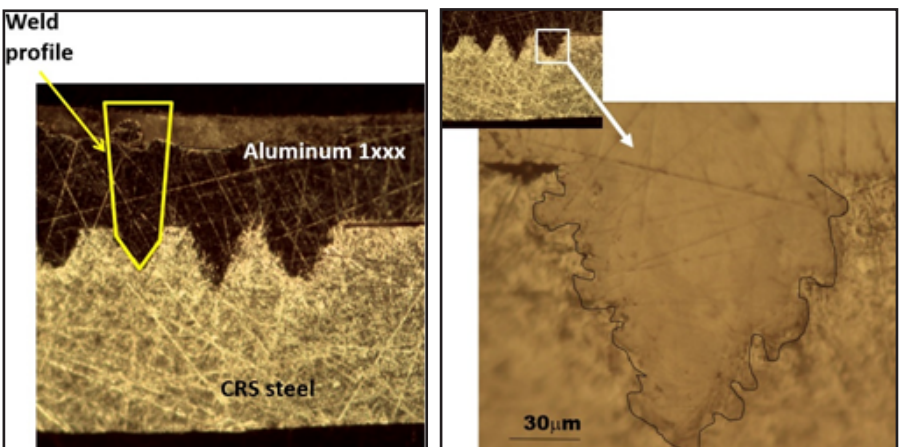


Fig. 12. Application photo of aluminum battery tab welded to a nickel plated cold rolled steel can using the spiral weld technique

Testing showed single layers shear strengths of around 44 N (10 pounds) and double layer shear strength at around 88 N (20 lbs.). Figure 12 is an application photo showing an aluminum battery tab welded to a nickel-plated cold rolled steel can using the spiral weld technique.

A closer look at the cross sections reveals that the spot welds do not show the characteristic form of conventional pulsed spot welds – they more closely resemble multi-staking. The intermetallic zone was less than 10 microns. Pull strength was good and peel strength was

adequate. There was barbed solidification of aluminum into steel.

One example of the new technology is 70-Watt LMF70-HP OEM fiber laser, which can be integrated into the LMWS pulsed fiber laser welding system from Amada Miyachi. Such a unit is an advanced processing system for welding battery cans with wall thicknesses of 300-350 microns. It features shorter pulses, resulting in less mixing of materials, and hence less of an intermetallic zone and less brittleness with aluminum tab materials. This laser solution is good for contract manufacturing settings, where operators may be producing one product one day and something different the next. The xy galvo program quickly positions welds; a new program can be loaded in as little as five minutes, and operators can be ready to start the next product.

*Laser welding: summary conclusion laser*

New laser sources, including single mode fiber lasers and lasers with nanosecond pulses, provide an important opportunity for dissimilar metal joining by enabling the joining of aluminum and copper battery tab material, which reduce electrical resistance and improve battery performance. Tests have shown the technology works well with metal thickness of less than 0.25 millimeters (mm), providing good pull and peel strengths in these dissimilar joints. With that this new technology shows great promise for a wide range of industries.

**Micro-arc Tungsten Inert Gas (TIG) welding (micro TIG welding)**

Micro TIG welding is a highly efficient non-contact method for generating localised heat and is frequently used for welding conductive battery interconnects. Precision micro TIG welding requires a controlled current to be passed into an electric arc. The heating effect is directly proportional to the current and resistance of the arc, which itself depends upon the arc gap. With a fixed gap, the arc resistance develops

a voltage across it by virtue of the welding current, this can then be used as a process monitoring variable [7].

A wide range of closed-loop controlled current micro TIG welding units which are suitable for conductive material welding to battery packs are available on the market. In combination with custom TIG torches that provide electrical return contacts and arc shielding, these units are readily configured for manual battery pack assembly or high volume, multi-spot battery pack assembly with automatic step and repeat torch positioning.

As stated already, similarly to resistance welding, a controlled and therefore easily monitored current is passed into the elements to be

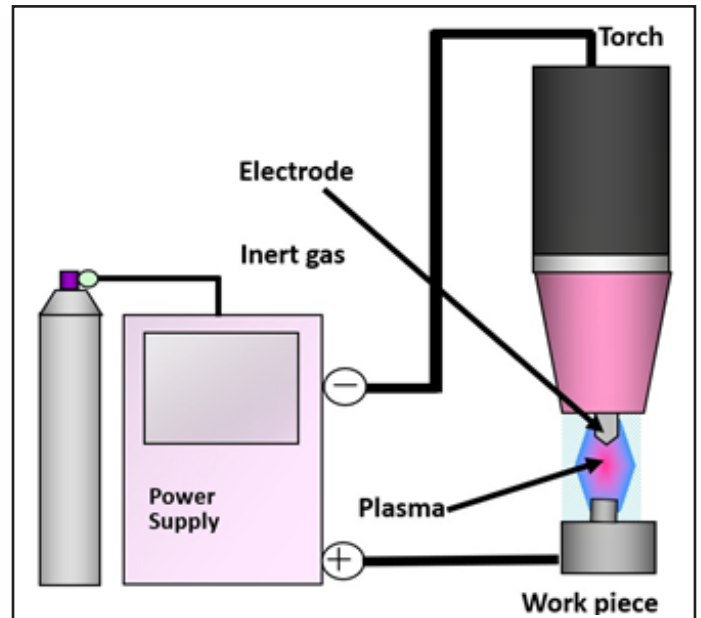


Fig. 13. The generic schematic of a micro TIG welding machine



Fig. 14. Example of state of the art micro TIG welding components: left: PAXXP Pulsed Arc Power Supplies, right: TR-16A Touch Retract Torch from MacGregor Welding Systems.



welded. Compared with resistance spot welding, localised heating into the battery itself is generally lower. Unlike resistance welding, the heat generated is due to the resistance of the electric arc and its associated current, and hence is independent of the product conductivity. This therefore provides a highly controlled method of developing localised welding temperatures that are suitable for joining materials up to 0.5 mm in thickness onto conductive battery cans.

For example, the TIG battery welding process has been tested and proven with a number of high integrity lithium ion designs with excellent electrical and mechanical results, using nickel, aluminium and copper flat sheets to a maximum thickness of around 0.5 mm. The high degree of control offered by the power source enables the resultant spot welds to be optimised to size while minimising battery can heat penetration. In addition with micro TIG welding, manufacturers can make use of multiple heads from one unit and they are also able to weld plated materials.

The major disadvantage of the micro TIG process for welding battery packs is the large heat affected zone. The tungsten electrode wears over time and requires cleaning and sharpening.

### **Ultrasonic welding**

Ultrasonic welding was originally used in battery pack applications because of its ability to

weld dissimilar metals, for example, welding aluminium to copper. As laser welding has developed this capability, it has largely supplanted ultrasonic welding for welding dissimilar metals. The main disadvantage of ultrasonic welding is the potential for the vibration to damage parts. In addition, ultrasonic welding requires use of a sonotrode – a tool that creates the ultrasonic vibrations. The sonotrode is a stack of piezoelectric transducers attached to a tapering metal rod. The tool gradually wears out, so the process will shift over time. Ultrasonic welding is also very sensitive to any pollution between the two materials. Pollution as insignificant as the grease of a fingerprint can completely throw off the process. Ultrasonic welding also creates more heat than other processes, which can damage batteries. The mechanical strength is less and electrical resistance is higher

### **Understanding which technology to select for battery pack manufacturing**

Battery pack production volumes are driven by the demands of consumer electronics and electric vehicles. Likewise, the manufacturing and joining needs are determined by the pack size, type and thickness of the busbar, and tab and terminal materials. All described in this article joining technologies, i.e. resistance, micro TIG, laser and ultrasonic welding technologies each have specific features that align well to these joining needs. A clear understanding



Fig. 15. Battery welding by micro TIG, left: examples of TIG welded battery tabs, right: TIG torch and battery spot weld

of the technologies and application is needed to implement an efficient and reliable production battery pack welding system.

### Automating the welding process of battery pack tabs

Ensuring quality is an important driver for all battery pack manufacturers. The human factor causes the largest variation in quality. Different operators working over several days using the same equipment will create wide variation. That is why it is critical for manufacturers to select equipment that provides the highest level of quality control, while producing a stable and reproducible process. Minimising or reducing labour costs is a consideration, but automating the battery pack tab welding process is not done only to lower labour costs. By selecting equipment that puts all the movements into the system, operator variation is removed and quality improved.

Among others Amada Miyachi designs and manufacture a complete range of resistance welding and micro TIG as well as laser automated or semi-automated systems specifically designed for both low and high-volume manufacturing processes.

Application experts recommend the right system based and application-specific parameters. These systems are suited for integration into bigger multi-processes production lines. They are being used for welding battery modules by a variety of manufacturers, including high-performance lithium battery module manufacturers located in many countries, like the Netherlands, Germany, UK, Ireland, Israel and several further countries of mostly in central Europe. Such efficient, automated systems will help move the industry forward by accommodating their growing production requirements. Figure 16 shows some examples of integrated systems for battery pack

Table 2. Comparison of the most widely used battery pack welding technologies.

Welding technology	Advantages	Disadvantages	Material thickness	Speed (welds per second)	Consumables
<b>Resistance</b>	Closed loop feedback and monitorable process Self-tooling Able to weld plated materials	Limited connection area Cannot be used with higher electrical conductor material	0.2 to 5mm	Up to 1	Electrode
<b>Laser</b>	High speed Small heat affected zone Tailored weld patterns Various joint geometries Weld dissimilar metals Able to weld plated materials	More difficult to achieve quality control More difficult to achieve process monitoring	0.2 to 2mm	Up to 20	Cover gas Cover glass
<b>Micro TIG</b>	Multiple heads from one unit Able to weld plated materials	Large heat affected zone Electrode wears	0.2 to 2mm	Up to 1	Electrode Cover gas
<b>Ultrasonic</b>	Weld dissimilar metals Self-tooling	Vibration damage Higher heat can damage batteries Expensive consumables	0.2 to 2mm	Up to 1	Sonotrode



Fig. 16. Examples of integrated systems for battery pack manufacturing. top: Jupiter Resistance Welding System, bottom: Jupiter Laser Welding System, both from Amada Miyachi.

manufacturing, including resistance welding system with integrated two motorized twin-weld heads and a laser tab welding system with galvo head and fiber laser source both with fire suppression deployment.

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