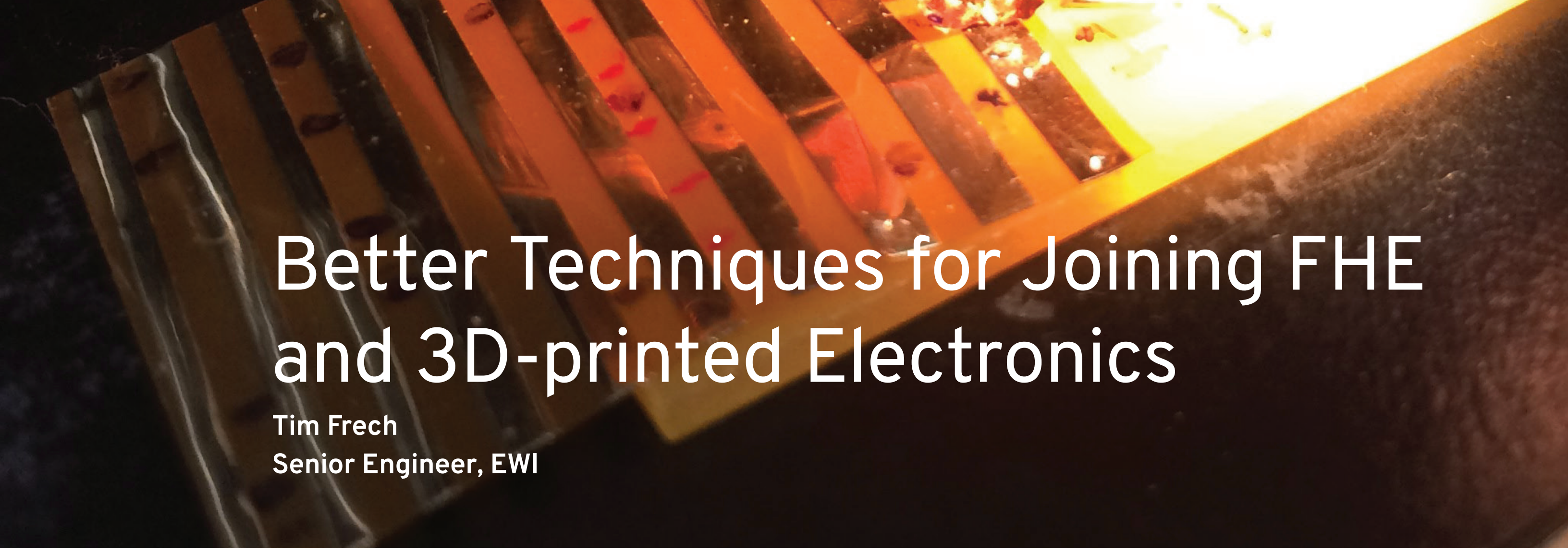

Better Techniques for Joining FHE and 3D-printed Electronics

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Flexible electronics and 3D-printed electronics are both emerging applications in consumer, medical device, and military electronics. The development of joining technologies for manufacturing of products using flexible hybrid electronics (FHEs) and 3D-printed electronics is critical.

Currently, soldering is used in prototyping. However, soldering may not be a viable process for high-volume manufacturing due to limitations of speed, joint size, reliability, and strength.

The long-term reliability of soldered joints is a major limitation, especially for military applications. With a lead-free soldered joint, the silver and tin start to migrate away from each other after about seven years, resulting in an area of significantly reduced strength where the tin has congregated. Any thermal cycling or vibrations in conjunction with this reduced strength can cause the joint to fail. This is a principal concern for electronics such as soldier health monitoring systems and solar arrays in desert terrain, which require longevity and consistent strength of electrical connections under harsh conditions. There are similar needs for more reliable processes than soldering in consumer products and medical devices as well.

Parallel gap and ultrasonic welding are mature joining processes that have been used in mass production for decades and could effectively replace soldering in FHE and 3D-printed electronic manufacturing. Both are fast processes with minimal heat input. Welded joints with these processes would be smaller, higher strength, more reliable, and withstand higher temperatures than soldered joints. Joints could be made at a lower cost (no filler required and with faster weld times) and with better electrical performance (e.g. lower resistance). In military applications, which require long-term strength and reliability, these joints would retain their integrity much longer than a soldered joint.

EWI recently completed a study evaluating these two welding process for joining flexible hybrid and 3D-printed electronics. With more than 30 years of experience in the development and deployment of advanced joining technologies for industry, EWI is well-positioned to help transition this developed technology into existing manufacturing operations.

Construction of Flex Materials

To understand more fully the metal thicknesses of the two types of flex (“traditional” and “printed”), cross-sections of each were prepared, examine, and photographed.

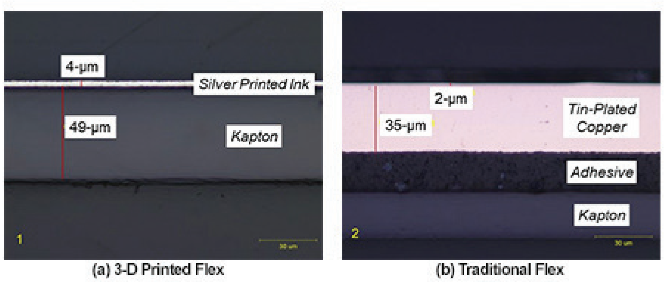
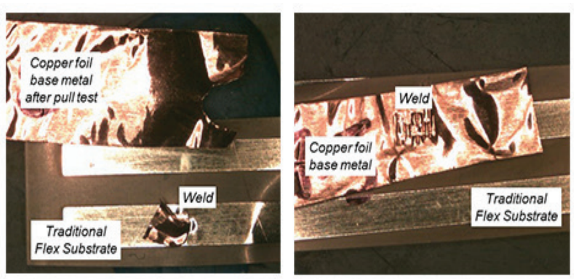


Figure 1. Construction of 3D-printed flex and traditional flex

Weld Study

EWI utilized parallel gap resistance and ultrasonic metal welding for this initial study. For both processes, EWI attempted to join a 25-µm thick piece of copper foil to the metal surface of the flex material. A wide range of process settings was introduced for each process to determine joining feasibility and the process window if feasibility was demonstrated. Figure 2 shows a top view of the copper foil welded to traditional flex substrate.



(a) Parallel gap resistance weld after a pull test. Note the weld remained intact with the flex substrate, and the foil base metal failed during the pull test.

(b) Ultrasonic metal weld still intact.

Figure 2. Top view of copper foil welded to traditional flex substrate

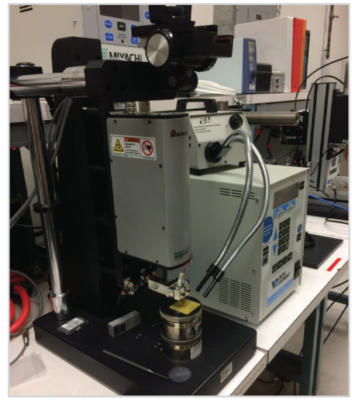


Figure 3. Parallel-Gap Resistance

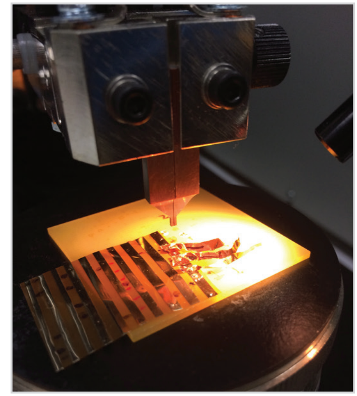


Figure 4. Close-up of Parallel-Gap Electrodes, Copper Ribbon, and Flex.

Parallel Gap Resistance Welding

EWI used an Amada-Miyachi Series 300 Electronic Light force weld head, coupled to a UB-25 linear DC resistance weld power supply.

Process settings investigated:

- *Material: Flex, Printed*
- *Cu Foil: 0.001"*
- *Force (lb): 1.0 & 2.0*
- *Weld Time (ms): 2,5, & 10*
- *Voltage (V): 0.5 through 2.0*

Results: Parallel Gap Resistance Welding – Traditional Flex – A wide range of settings produced copper to trace welds

Results: Parallel Gap Resistance Welding – Printed Flex - No settings produced suitable welds between copper foil and the printed silver trace.

Ultrasonic Metal Welding

For this process, EWI used a Branson MWX 100 Metal Welder with with knurled sonotrode and anvil to help grip the foil and substrate. A series of tests was conducted to methodically vary vibration amplitude, welding force, and welding energy.

Process settings investigated:

- *Material: Flex*
- *Cu Foil: 0.001*
- *Pressure: 10 psi (70N)*
- *Amplitude: 10, 15, 20 µm*
- *Energy: 5-20 J*

Results: Ultrasonic Welding on Traditional Flex - A wide range of settings produced excellent results.

Results: Ultrasonic Metal Welds on Printed Flex, all welds at 70N weld force. Though a wide range of settings was attempted, no suitable results were obtained.

Figure 4. Ultrasonic Weld on Traditional Flex

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Figure 5. Branson MWX 100 ultra-sonic metal welder

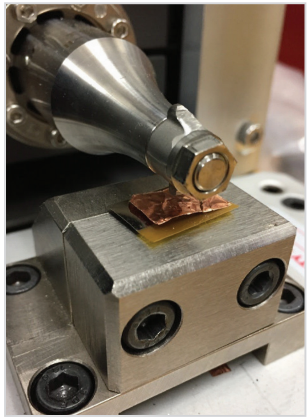

Figure 6. Close-up of welding tip (sonotrode) and anvil

Summary of Work

0.001" copper was able to be welded onto the traditional flex by means of parallel gap resistance welding and ultrasonic welding.

- *These welds caused minimal damage to the plated silver and the Kapton.*
- *Ultrasonic welding using the ultrasonic wire bonder was also able to produce welds using the 0.0007" copper.*

These same processes were not able to weld the copper foils onto the silver printed flex.

- *Attempts to weld the copper onto the printed flex would either cause a hole to appear in the printed silver or the copper foil.*

Reflow soldering was also attempted with both types of flexes.

- *Reflow soldering was able to work with the traditional flex. However, reflow soldering was not successful on the printed flex.*

Future Work

While parallel gap and ultrasonic welding show promise, research on better joining for these materials is still in preliminary stages. The following next steps for future studies are recommended:

Future Work with flexible circuits: Welding of nickel-plated copper foil to bare and plated copper traces on flex would be application-specific but could be investigated with both parallel gap and ultrasonic welding.

Future work with printed flex: More development work to involving construction of printed flex is needed. For example, some of the welding challenges were caused by poor adhesion of the ink to the substrate; a bonding layer could be engineered to improve this and increase feasibility of welding. Other inks, beside silver, should also be investigated. Potential candidates include copper and aluminum. Finally, increased density of the print material may be required for successful welding, which may be realized with finer-mesh inks or a range of meshes to increase packing density.

To learn more about joining to electronics, please contact **tfrech@ewi.org**.

Tim Frech *is a Senior Engineer with expertise in the areas of microwelding, ultrasonic metal welding, ultrasonic soldering, wire bonding, and resistance welding. He is also experienced in plastics joining, laser welding, and helium leak detection. Tim has been responsible for numerous contract R&D projects for various clients in the electronics, automotive, and medical device industries. He has directed projects and conducted hands-on work in welding of electronic modules, electric vehicle batteries, and medical devices and holds two U.S. patents in welding process technologies.*