Materials Joining Challenges in the Cable and Wiring Systems of EV-HEVs

Introduction

The recent acceleration of electric (EV) and hybrid electric (HEV) automotive vehicle development is making a significant impact on materials joining technologies. In this review, we look specifically at the materials joining aspects of EV/HEV electrical wiring and cable systems. The increased role of electronics in the modern internal combustion engine vehicle (ICEV) has greatly expanded the wiring/cable networks. Generally termed "wire harnesses", these systems have greatly increased in length, number of interconnections and, significantly, total weight. EV/HEVs are placing unique additional demands on the electrical systems by imposing an electric-based propulsion system on already complex electrical networks.

Technology Requirements for Enhanced Electrification

The battery-powered electric vehicle and the hybrid electric vehicle (powered by a combination of batteries and internal combustion engine) are, after an earlier "false start" in the 1990s, enjoying a resurgence in interest, acceptance, development, and commercialization. Although statistics in this field vary, several original equipment manufacturers (OEMs) have introduced or reintroduced EV/HEV models, with future new products expected in the U.S. and internationally. In 2016, EV/HEV models accounted for 1% of worldwide vehicle sales By 2025, that figure is expected to hit 30%.[1]

The electrical systems of ICEVs have become increasingly complex as electronics have become more central to the functionality and cost of modern automobiles, trucks, and buses. "Wire harnesses," involving solid and stranded wires and flexible (typically copper) tapes, have likewise grown in complexity and weight. An example of an electrical wiring system – admittedly an upper-end one since it is from a Bentley Bentayga – is shown in Figure 1. While extreme due to the multiplicity of sensors, it captures the complexity of the modern electrical distribution system. It is also an indicator of the technology pull that will occur as such developments are introduced on lower-cost vehicles. The complex networks of Figure 1 are typically assembled as separate wire harnesses and then integrated in the vehicle during body fabrication.

Wire harness systems contain many electrical connections that use both mechanical fastening and welding. EWI has long been involved in improving the welded connections of ICEV systems. Ultrasonic, resistance, and laser welding processes have all found applications, although the former is favored due to its excellent ability to join copper and aluminum materials as well as thick/thin material combinations.

Figure 1. Wiring System in a Bentley Bentayga [2]

Within the battery pack itself, large numbers of battery cells (ranging from hundreds to thousands, depending on motor size) result in similar numbers of welds involving thin-gage foils and wires. Additional connections within the battery pack include heavy-duty cabling that alternately runs to the inverter (which feeds the electric motor) and accesses the regenerative braking system. Finally, in addition to these cable requirements, there is an added array of electronic components associated with sensing and control of the EV/HEV electrical system.

Welded Connections in Vehicular Wiring Systems

There will continue to be a multiplicity of electrical connections in EV/HEV/ICEVs with a significant proportion of mechanical connections in crimp or plug form. However, in both EV/HEVs and ICEVs, there are connections for which a welding process is a preferred approach to making viable connections.

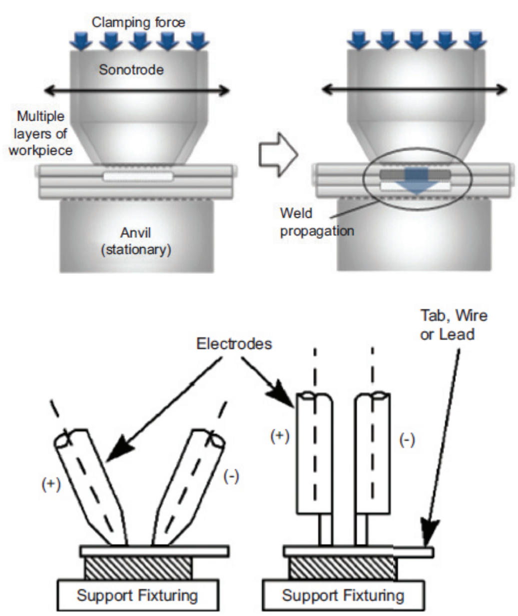

Figure 2. Welding Processes Used in Vehicular Wiring Systems[3]
a) US Metal Welding b) Resistance Spot Welding

Welding Processes for Wiring Systems

A range of welding technologies may be used to create connections in vehicular wiring systems. While the American Welding Society (AWS) identifies more than 70 different processes, only a small number find applicability to the materials and conditions of vehicular wiring systems. Cai [3] has summarized these processes as ultrasonic metal welding, resistance welding, laser welding, microbonding, and mechanical fastening, with their simplified illustrations shown in Figures 2, 3, and 4.

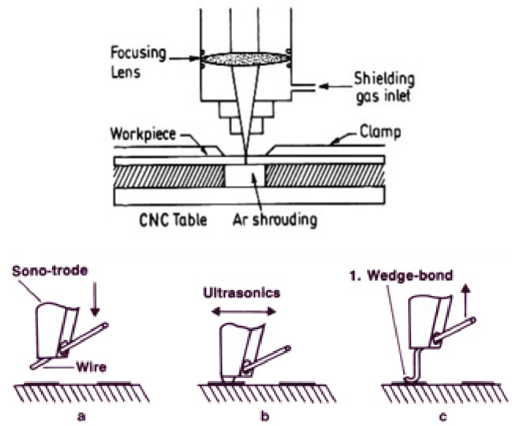

Figure 3. Welding Processes Used in Vehicular Wiring Systems
a) Laser Welding b) Microbonding

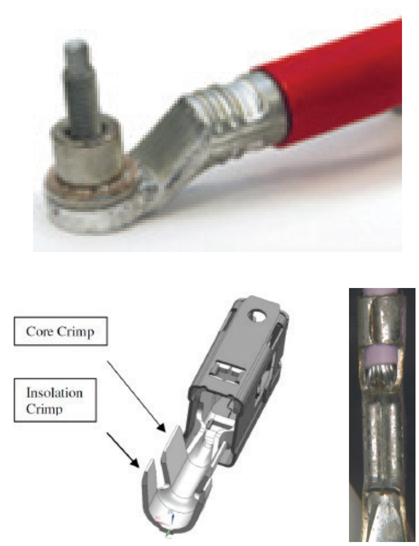

Figure 4. Mechanical Joining Used in Vehicular Wiring Systems.
a) Nut/bolt Connection (top) b) Crimp Terminal (bottom-left) and Connection (bottom-right)[3]

Welded Connections Common to EV/HEVs and ICEVs

The most common welded connections that will be found in the ICEV systems are:

- **Wire splices:** These are the connection of two or more stranded wires with a single weld – typically an ultra-sonic weld – is the most common welded electrical connection, as shown in Figure 5.
- **Wire to Strip/Foil:** Examples of strip/foil joints can be seen in Figure 6(b). The features of these joints involving stranded wires will be similar to those noted for wire splices discussed above, while the joint features involving thin foil and strips will be similar to those discussed for battery welds.
- **Cable Connections:** Examples of cable connections are shown in Figure 7.

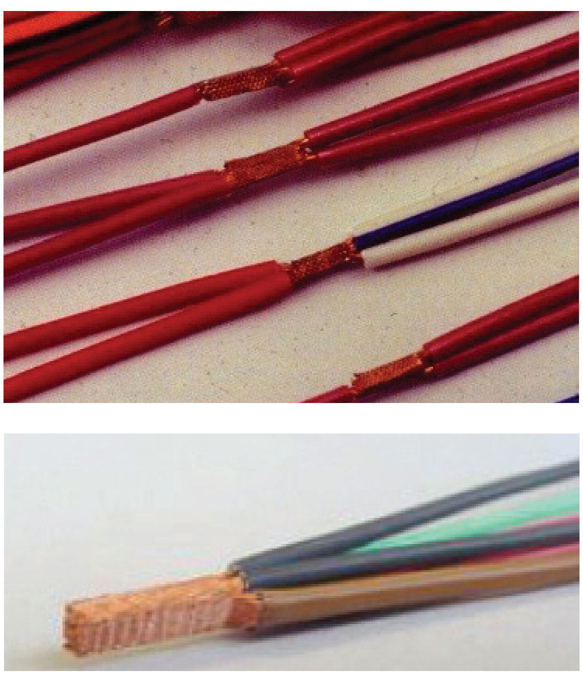

Figure 5. Welding Processes Used in Vehicular Wiring Systems. a) Wire b) End and parallel splices [4]

(Images from Telsonic Ultrasonics [6]*)*

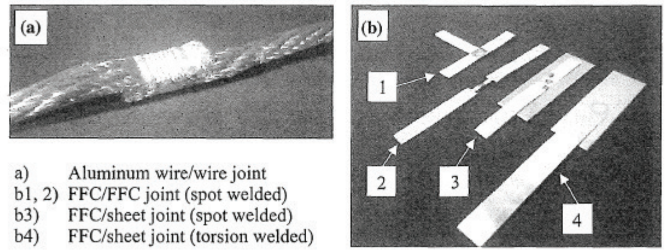

Figure 6. Wire, Cable, and FFC Joints [5]

Figure 7. Various Cable Connections. a) MAS type terminal b) welded connection to eyelet c) cable splice to wire, and d) bolted connection [6]

EV/HEV Electrical Connections the Battery Pack

Despite the obviously unique features of EV/HEV electrical systems relative to ICEVs, there are few differences in the welded connections. Thus, wire splices and cable connections previously discussed will again be found in EV/HEV harness systems, with the continued trends to higher power and/or higher voltage battery packs.

The Li-ion battery pack (BP) is key to developing electric drive systems. This pack is made up of an assembly of large numbers of individual, electrically connected Li-ion cells (large numbers are dependent on specifics of the power level of the pack and design details of the cells). Cai provides

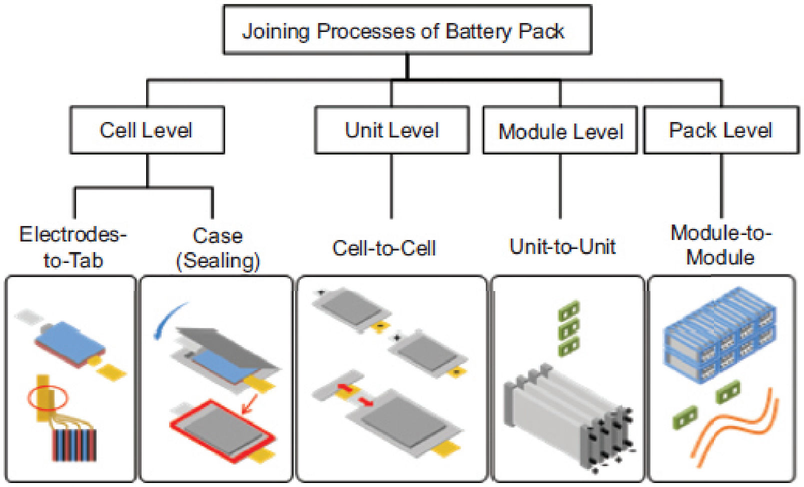

Figure 8. Materials Joining Challenges In Manufacturing EV/HEVs

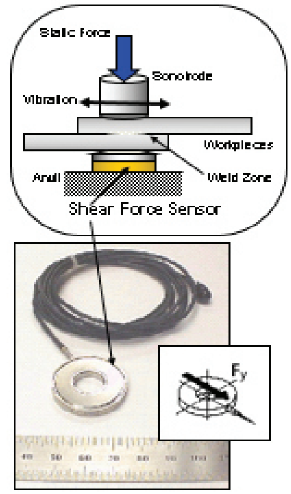

Figure 9. Concept of the shear force sensor

the details for assembly of a pouch-type BP used in the GM Volt, Figure 8. This includes the progression of steps to create the pouch-type cell, interconnection of cells to form a “unit,” interconnection of units to form a module, and connection of several modules to form the BP.

One key challenge in the application of welding technologies to vehicle electrification is quality assurance. In the many discussions that EWI staff have had with clients a recurring theme has been the difficulty (or impossibility) of in-process, or even post-process, assessment of weld quality. Throughout the execution of numerous development programs, EWI has investigated commercial sensing capabilities for weld quality monitoring. Examples include In-situ Shear Force Sensor Data Collection (Figure 9), Non-contact IR Thermal Sensing of Weld Temperature (Figure 10), and Non-destructive C-Scan of Spot Weld (Figure 11). While each of these techniques have added valuable insight into the performance of the weld process, little has been related to physical weld strength.

As these observations suggest, the development of a weld quality monitoring system is not a trivial undertaking. Methodologies will be unique to specific processes and must address a range of like-to-like or like-to-unlike materials such as aluminum, copper, and nickel-plated copper. Moreover, these material configurations can vary in size from thin-gauge, high-strand count wire to large-gauge, low-strand count cable to a multitude of end connectors.

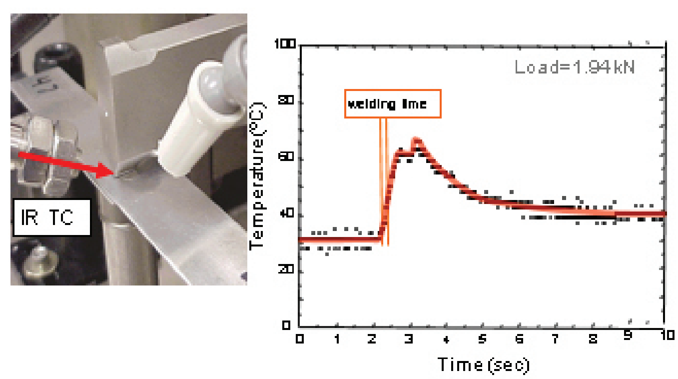

Figure 10. IR Sensing of US Metal Welds

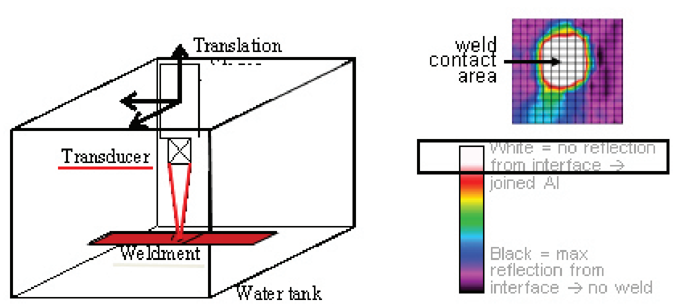

Figure 11. C-Scan Sensing of US Metal Welds

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[1] International Energy Agency, "Global EV outlook 2017."

[2] Zap-Zone-2017 Bentley-Bentayga-inline1.jpg.

[3] Cai, W.W., Kang, B. and Hu, S.J., "Ultrasonic welding of lithium-ion batteries," ASME Press, (2017).

[4] Sonobond Ultrasonics

[5] Heinz, S., Wagner, G., and Eifler, D., "Ultrasonic welding of wires and cables," Journal of Metals, Vol. 64, No. 3, (2012).

[6] Telsonic Ultrasonics

[7] Lindamood, Lindsey, "In Situ Monitoring of Ultrasonic Welding," EWI report.

Get Started

EWI is currently pursuing Internal R&D projects focused on maturing sensing technology while bringing them together as a collective group to quantify weld strength. If this is something you would like to learn more about or find out how to participate, please contact us at:

614.688.5152 or info@ewi.org

For more information regarding our capabilities and services, visit EWI.org

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