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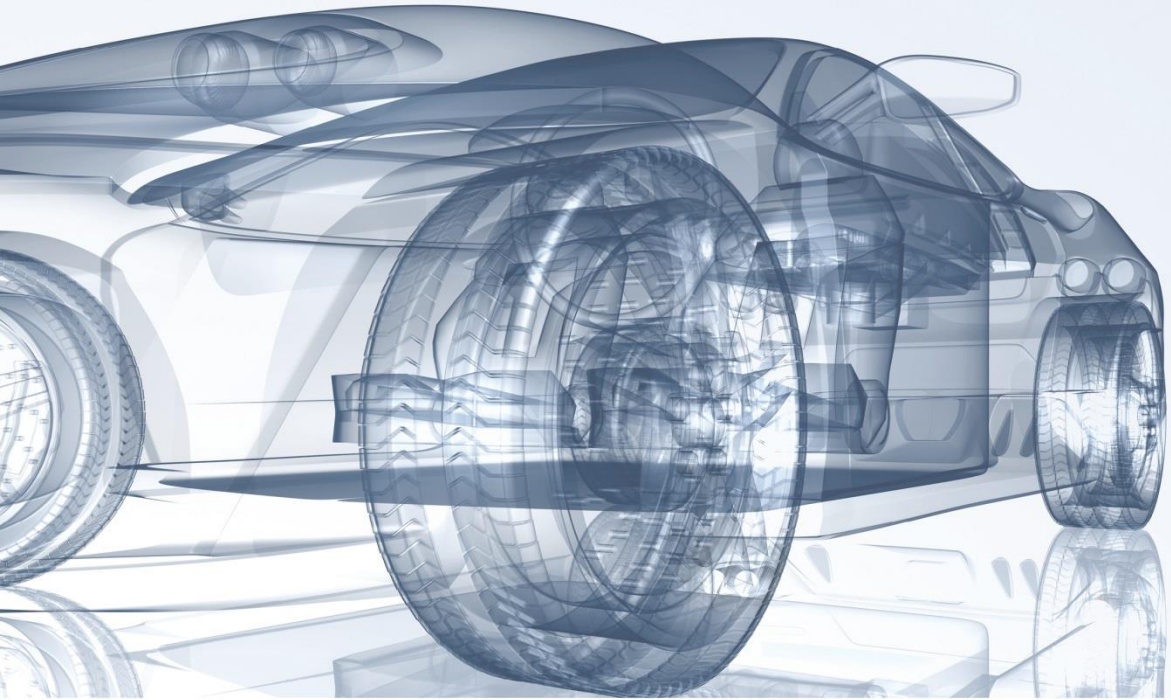

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Joining Technologies for Automotive Battery Systems Manufacturing

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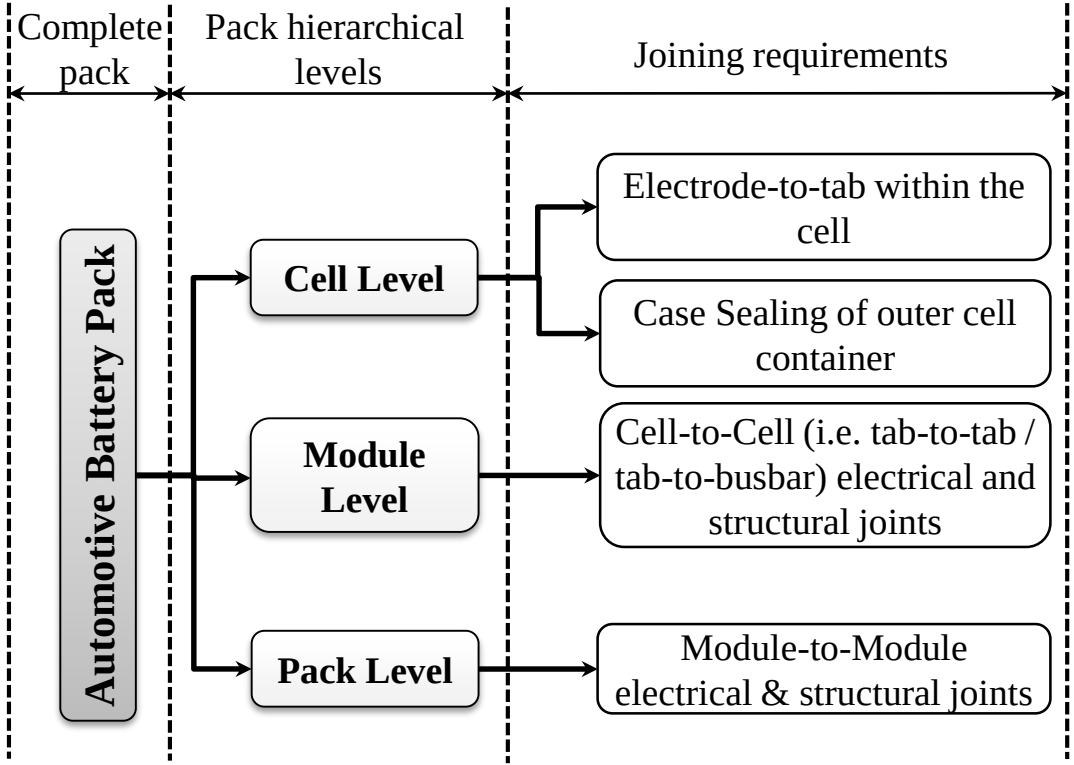
Presentation Outline

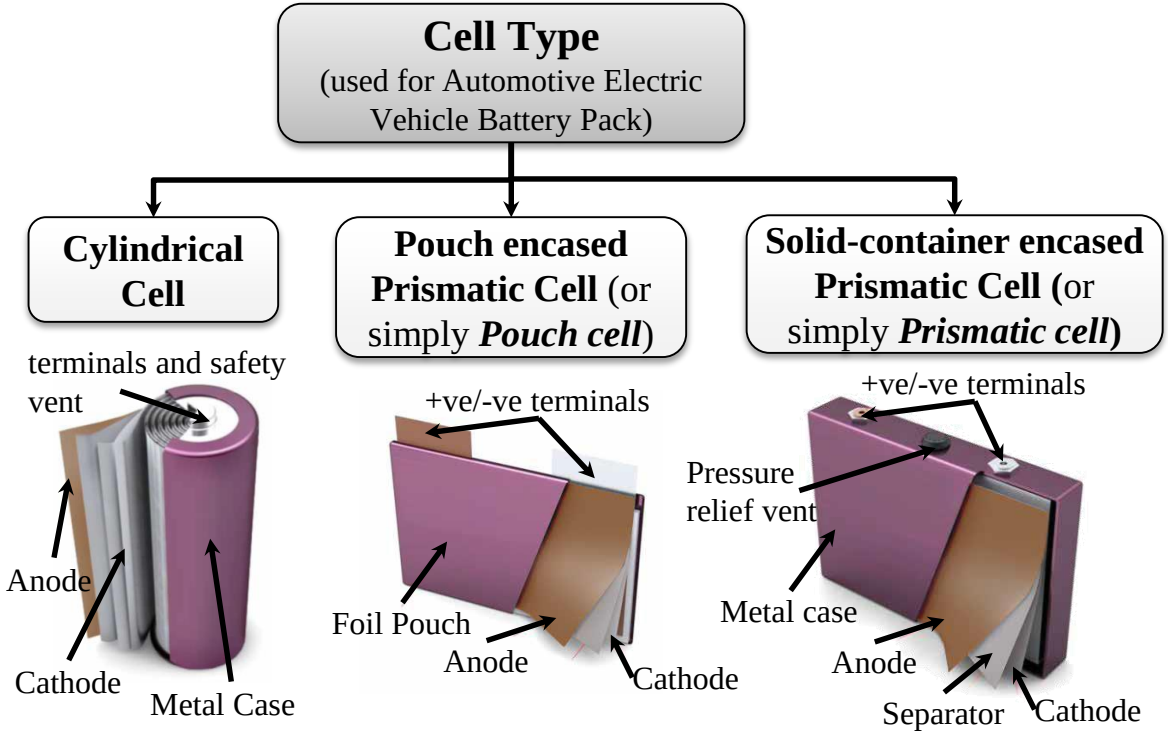
- Introduction
- Key Joining Challenges
- Overview of Joining Technologies and Applications
- Joining Technology Assessment
  - Based on Manufacturing Readiness Levels (MRLs)
  - Based on Pugh Matrix Scores
- Conclusions and Final Remarks

Introduction

- An automotive battery pack can be hierarchically decomposed into three levels: (a) cell level, (b) module level, and (c) pack level
- Typically, a standard automotive battery pack consists of hundreds, even thousands, of individual Li-ion batteries which are connected in series or parallel in order to achieve the required power and energy
- ... therefore, effective joining methods are required to produce robust and reliable joints



Introduction – Cell Format



(*Adapted from Johnson Matthey Battery Systems)

Choice of joining methods is largely based on the type of cell used, and subsequently, to satisfy electrical, thermal and mechanical key criteria.

Key Joining Challenges

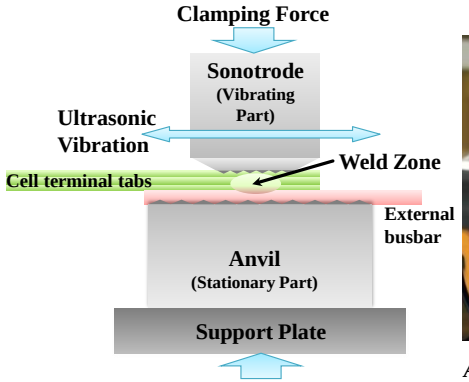
- ***Electrical and thermal challenges:***
  - ✓ Producing joints with low electrical resistance
  - ✓ Producing joints with low thermal input
  - ✓ High thermal fatigue resistance

- ***Material and metallurgical challenges:***
  - ✓ Compatibility for dissimilar materials joining
  - ✓ Variability of materials and surfaces

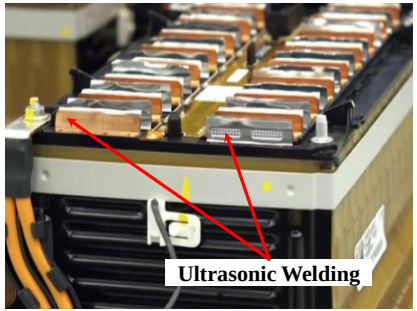
- ***Mechanical challenges:***
  - ✓ Durable joint strength
  - ✓ Avoid mechanical and vibrational damage when joining

Joining Technologies and Applications

1. *Ultrasonic Welding :*



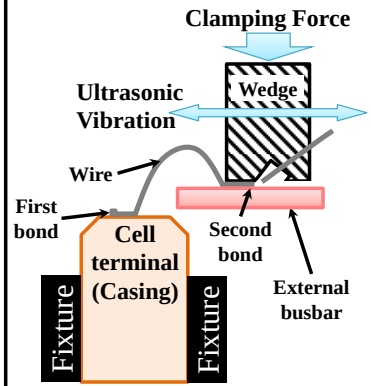
Schematic of ultrasonic welding



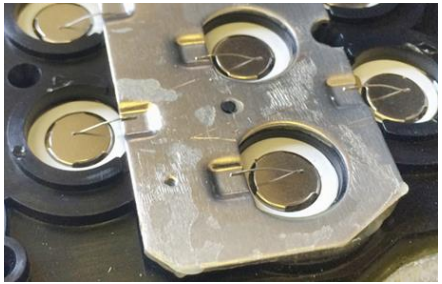
Application of ultrasonic welding for pouch cell-to-cell connection (adapted from GM Chevy Volt)

- ✓ *Cell level joining: Electrodes-to- Electrodes/Tab for all cell types*
- ✓ *Module level joining: Cell-to-cell connection for pouch cell based module*

2. *Ultrasonic Wedge Bonding :*



Schematic of ultrasonic wedge bonding

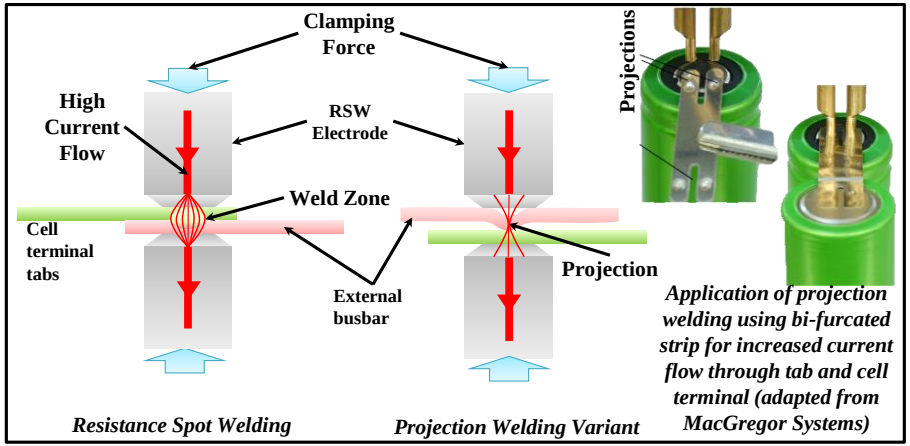


Application of ultrasonic wedge bonding for cylindrical cell terminal (i.e. case)-to-bus bar (i.e. current collector) connection (adapted from EV West)

- ✓ *Module level assembly: Cylindrical cell-to-busbar*
- ✓ *Need further investigation for applications to other cell types*

Joining Technologies and Applications

3. *Resistance Spot/Projection Welding :*

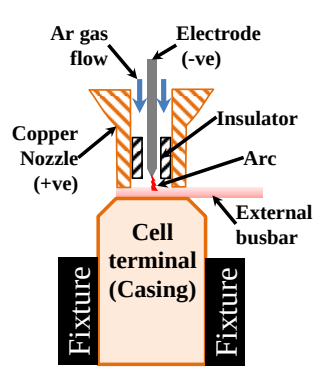


Resistance Spot Welding *Projection Welding Variant*

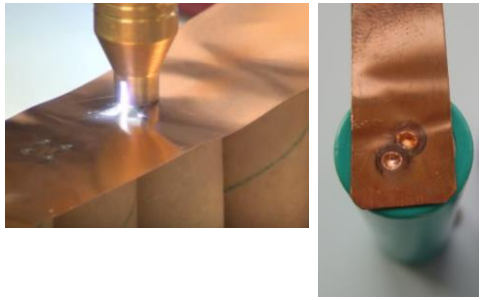
Application of projection welding using bi-furcated strip for increased current flow through tab and cell terminal (adapted from MacGregor Systems)

- ✓ *Cell level joining: Electrodes-to- Electrodes/Tab*
- ✓ *Battery Tab joining, including steel, nickel (Ni), copper(Cu) and aluminium(Al)*

4. *Micro-TIG or Pulsed Arc Welding :*



Schematic of pulsed arc welding

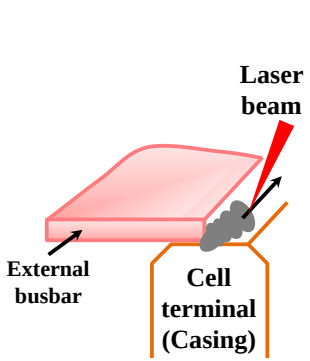


Application of pulsed arc welding for cylindrical cell terminal (i.e. case)-to-bus bar (i.e. current collector) connection (adapted from Sunstone Welders)

- ✓ *Suitable for nickel, copper or steel tabs and copper bus bars*
- ✓ *Potential application for cylindrical cell terminal-to-busbar connection*

Joining Technologies and Applications

5. *Laser Welding :*

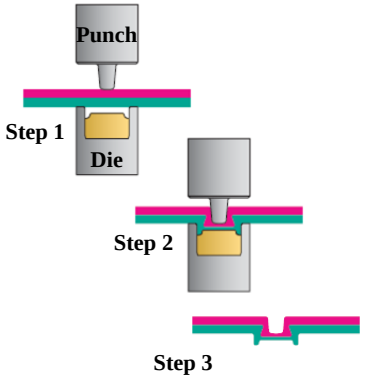


Schematic of laser welding

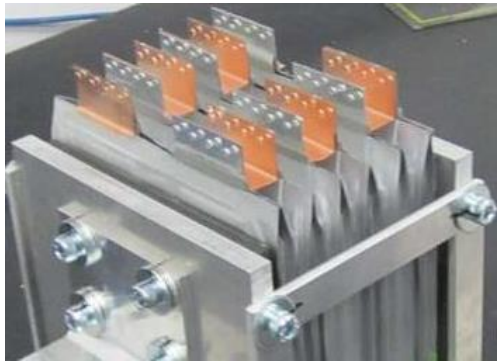
Application of laser welding for prismatic cell-to-bus bar connection (adapted from Fraunhofer Institute for Laser Technology ILT, BMW i3)

- ✓ *Cell level application: electrode foil-to-tab joining is feasible, case sealing for prismatic cell*
- ✓ *Module level application: Terminal-to-busbar for prismatic cells*
- ✓ *Need further investigation for other cell types at their hierarchical levels*

6. *Micro-Clinching :*



Schematic of clinching (adapted from Tox Pressotechnik Ltd)

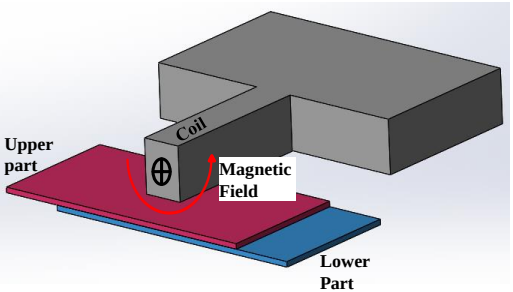


Application of clinching for pouch cell tab-to-tab connection (adapted from AVL Battery Solutions)

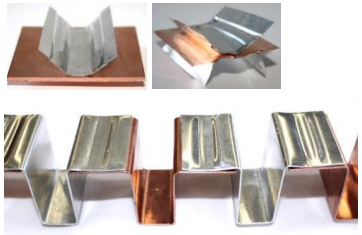
- ✓ *Module level application: Tab-to-tab connections of pouch cells are feasible with micro-clinching*
- ✓ *Clinching may not be feasible for cylindrical / prismatic cells joining as access to the both sides of the assembly is required*

Joining Technologies and Applications

7. *Magnetic Pulse Welding (MPW) / Electromagnetic Pulse Technology (EMPT) :*



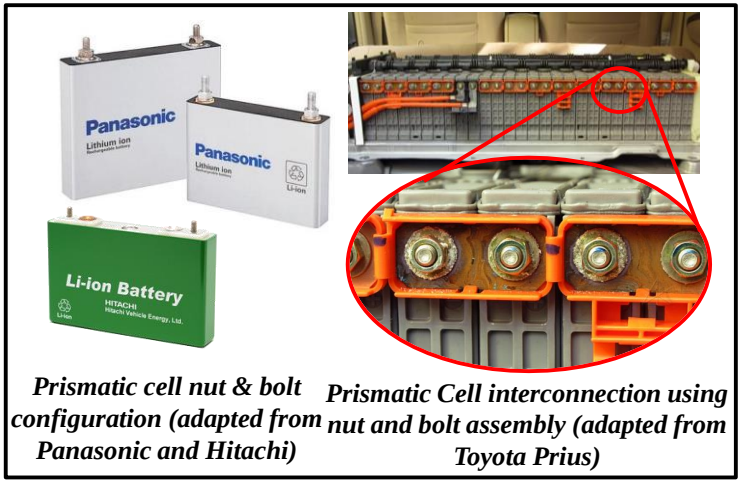
Schematic working principle of MPW/EMPT



Application of MPW/EMPT for tab-to-bus bar, tab-to-tab and bus bar-to-bus bar connection (adapted from PST Products)

- ✓ *Tab-to-tab or tab-to-busbar connections may be possible*
- ✓ *Detailed investigation is required for battery interconnects joining*

8. *Mechanical Assembly :*



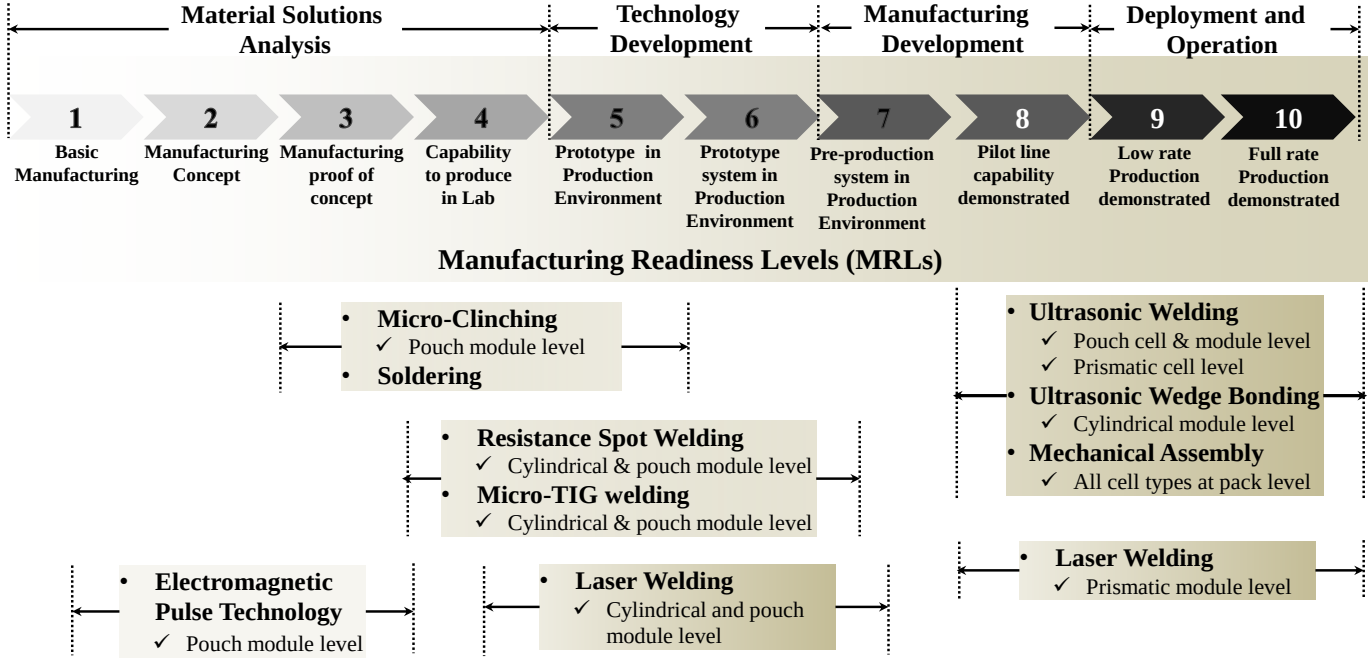
Prismatic cell nut & bolt configuration (adapted from Panasonic and Hitachi)

Prismatic Cell interconnection using nut and bolt assembly (adapted from Toyota Prius)

- ✓ *Mechanical fastening for battery interconnects joining, including nut & bolt, spring clasp, screws or snap-fits*
- ✓ *Nut and bolt assembly has been widely adopted at the pack level*

Assessment of Joining Technologies

MRLs for assessing technology maturity of current joining technologies for module level joining (e.g. terminal-to-tab, tab-to-tab or tab-to-bus bar)



Assessment of Joining Technologies

*Pugh matrix for evaluation of joining methods for manufacturing of **cylindrical cell** based module*

Factor	Weight	Joining technologies - Cyclindrical Cell					
		Resistance spot welding/ Projection Welding	Micro-TIG Welding/ Pulsed Arc Welding	Ultrasonic wedge bonding	Laser welding	Soldering	Mechanical joining
Total		**377**	**397**	**403**	**390**	**352**	**348**
Joint resistance							
Joint resistance-similar materials	5	4	4	4	5	5	2
Joint resistance-dissimilar materials	5	2	4	5	3	5	2
Joint strength							
Joint strength-similar materials	3	4	4	3	5	3	5
Joint strength-dissimilar materials	3	1	3	2	3	3	5
Heat transfer from process	5	3	3	5	4	1	5
Potential mechanical damage	5	4	4	4	5	5	2
Joint current capacity	5	3	3	2	5	4	5
Joint durability	5	4	4	3	4	4	3
Potential vibration damage	5	5	5	4	5	5	5
Joint corrosion resistance	4	4	4	5	4	2	2
In process quality control	5	4	4	5	2	2	3
Cycle time	4	4	4	4	5	2	1
Sensitivity	4	4	4	5	4	3	5
Repeatability	4	3	4	4	4	4	5
Cost per battery connection	4	5	5	4	4	3	2
Investment	3	4	4	4	2	5	5
Easy recycling	2	2	2	2	2	2	5
Easy automation	5	4	4	5	5	1	1
Delivery time	3	4	4	4	3	5	3
Standard Equipment	3	3	3	5	3	5	3
Flexibility ie easy to adapt	3	3	3	2	3	5	4
Used for similar applications elsewhere	4	4	4	5	3	1	2
Safety	5	4	4	4	3	4	5
Cost of ownership	2	5	5	3	4	5	5
Technique support	5	5	5	4	4	4	4

The Pugh matrix identifies micro-TIG as potential for production application, that would merit further investigation for cylindrical cell battery pack manufacturing

Assessment of Joining Technologies

*Pugh matrix for evaluation of joining methods for manufacturing of **pouch cell** based module*

Factor	Weight	Joining technologies - Pouch Cell						
		Ultrasonic Welding	Resistance Spot / Projection Welding	Micro-TiG / Pulsed Arc Welding	Laser welding	Clinching	Soldering	Mechanical Assembly (Nut & bolt)
Total		**413**	**359**	**379**	**401**	**361**	**357**	**356**
Joint resistance								
Joint resistance-similar materials	5	4	4	5	5	4	5	2
Joint resistance-dissimilar materials	5	5	1	4	3	5	5	2
Joint strength								
Joint strength-similar materials	3	4	4	4	5	3	3	5
Joint strength-dissimilar materials	3	3	1	3	3	3	3	5
Heat transfer from process	5	4	3	3	4	5	2	5
Potential mechanical damage	5	5	5	5	5	4	5	2
Joint current capacity	5	5	2	2	5	3	4	5
Joint durability	5	4	4	4	4	2	4	3
Potential vibration damage during welding	5	3	5	5	5	5	5	5
Joint corrosion resistance	4	4	3	3	4	4	2	2
In process quality control	5	4	4	4	2	3	2	3
Cycle time	4	4	4	3	5	2	2	1
Sensitivity	4	5	3	3	4	4	3	5
Repeatability	4	4	4	4	4	4	4	4
Cost per battery connection	4	5	5	5	4	4	3	2
Investment	3	4	4	5	2	5	5	5
Easy recycling	2	2	2	2	2	4	2	5
Easy automation	5	4	4	4	5	3	1	1
Delivery time	3	4	4	4	3	3	5	5
Standard Equipment	3	4	4	4	4	3	5	5
Flexibility i.e. easy to adapt	3	2	3	3	3	3	5	4
Used for similar applications elsewhere	4	5	2	2	5	3	1	2
Safety	5	4	4	3	3	3	4	5
Cost of ownership	2	4	3	3	4	4	5	5
Technique support	5	4	5	5	4	4	4	4

The Pugh matrix shows current and potential candidates for pouch cell based battery packs:

- Ultrasonic welding,
- Laser welding,
- Micro-TIG, and
- Clinching

Assessment of Joining Technologies

*Pugh matrix for evaluation of joining methods for manufacturing of **prismatic cell** based module*

Factor	Weight	Joining technologies - Prismatic Cell				
		Ultrasonic Wedge Bonding	Micro-TIG Welding/ Pulsed Arc Welding	Resistance spot / Projection Welding	Laser welding	Mechanical Assembly (Nut & bolt)
Total		**389**	**380**	**367**	**398**	**381**
Joint resistance						
Joint resistance-similar materials	5	4	4	4	5	2
Joint resistance-dissimilar materials	5	5	4	2	3	2
Joint strength						
Joint strength-similar materials	3	3	4	4	5	5
Joint strength-dissimilar materials	3	3	3	1	3	5
Heat transfer from process	5	5	3	3	4	5
Potential mechanical damage	5	4	4	4	5	2
Joint current capacity	5	1	2	2	5	5
Joint durability	5	3	4	4	4	3
Potential vibration damage	5	4	5	5	5	5
Joint corrosion resistance	4	5	4	4	4	2
In process quality control	5	5	4	4	2	3
Cycle time	4	4	4	4	5	1
Sensitivity	4	5	4	4	4	5
Repeatability	4	4	4	4	4	5
Cost per battery connection	4	4	5	5	4	3
Investment	3	4	4	4	2	5
Easy recycling	2	2	2	2	2	5
Easy automation	5	5	4	4	5	1
Delivery time	3	4	4	4	3	5
Standard Equipment	3	5	3	4	3	5
Flexibility ie easy to adapt	3	2	3	3	3	4
Used for similar applications elsewhere	4	2	1	1	5	5
Safety	5	4	4	4	3	5
Cost of ownership	2	3	5	5	4	5
Technique support	5	4	5	5	4	5

The Pugh matrix shows current joining application are

- Laser welding
- Mechanical assembly

and potential candidates for prismatic cell based battery module:

- Ultrasonic wedge bonding,
- Micro-TIG

Conclusions and Final Remarks

Recommendations for further investigation based on MRLs

Module level joining	*MRL*		
	Low (1-3)	*Medium (4-6)*	*High (7-10)*
Investigate pouch module level joining	MPW / EMPT		
Cylindrical & pouch module level, further extend to prismatic module level		Micro-TIG, RSW, Laser Welding	
Cylindrical module level, further extend to prismatic module level			Ultrasonic Wedge Bonding

- Joining techniques are described with respect to MRLs and suitability of the identified joining technologies is quantified.
- Recommendations for further investigation of joining technologies are made based on Pugh matrix scores, MRLs and application potential.

Thank You !

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