

Material selection and assembly method of battery pack for compact electric vehicle

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Abstract. Battery packs become the key component in electric vehicles (EVs). The main costs of which are battery cells and assembling processes. The battery cell is indeed priced from battery manufacturers while the assembling cost is dependent on battery pack designs. Battery pack designers need overall cost as cheap as possible, but it still requires high performance and more safety. Material selection and assembly method as well as component design are very important to determine the cost-effectiveness of battery modules and battery packs. Therefore, this work presents Decision Matrix, which can aid in the decision-making process of component materials and assembly methods for a battery module design and a battery pack design. The aim of this study is to take the advantage of incorporating Architecture Analysis method into decision matrix methods by capturing best practices for conducting design architecture analysis in full account of key design components critical to ensure efficient and effective development of the designs. The methodology also considers the impacts of choice-alternatives along multiple dimensions. Various alternatives for materials and assembly techniques of battery pack are evaluated, and some sample costs are presented. Due to many components in the battery pack, only seven components which are positive busbar and Z busbar are represented in this paper for using decision matrix methods.

1. Introduction

The Lithium-ion battery industry has additional significance well beyond its value chain. The battery pack system has various performance requirements related to battery performance, durability, vibration, thermal properties, safety and others, as shown in Figure 1 with related trade-offs among these requirements. Therefore, the design process involves solving the problem of these trade-offs and determining suitable specifications for the system components to achieve a well-balanced overall system with minimum cost.



2. Methods

This paper is established in order to study about material selection and assembly methods of battery pack for small electric vehicles by using DECISION MATRIX methods. The research used "Battery Pack Development for a Compact Electric Vehicle" as a case study, which is a cooperative project between National Science and Technology Development Agency (NSTDA) and Thailand Automotive Institute (TAI) in Thailand.

The researchers and engineers have studied various strategic decision-making tools to analyse and evaluate decision options, which are materials alternatives and assembly technique alternatives. These are the main factors for producing battery pack to cover efficiency and effectiveness at the lowest production cost. Decision matrix was used as a decision-making tool for selection of material and assembly technique for the battery module and the battery pack helping to examine competing alternatives based on multiple criteria that involve various ratings and weights by mathematical model. By working through a series of decision-process steps, criteria can be established for the assessment and comparison of different possible alternatives and then compare choices. This method allows us to list and weight various decision criteria deemed important for a given business situation or problem alternative. The criteria used for the selection are main variables impacts on production consist of material cost, performance, complexity as well as difficulty in assembling process, time spent and safety. Decision based on logic by considering all possible alternatives including all information about upcoming result in the future in order to apply for selection.

3. Methodology

This research studies each component of the new conceptual battery pack and provides the information regarding the material selection and the manufacturing method selection. In each component, the design criteria are specified and discussed with researchers and engineers who are the designer of the battery pack. For the material selection, the material options are filtered to a small number of alternatives. Then the decision matrix is used as the decision aid tool in order to choose the appropriate alternative. The design criteria of the new concept battery are used as the selection criteria in the decision matrix. For the manufacturing method selection, the manufacturing methods that are related to the concerned component are listed and discussed. The brief information of the related manufacturing method is also provided. After that, the selection of the manufacturing method is based on the gathered information.

4. Scope of Work

This work used "Battery Pack Development for Compact Electric Vehicle" as a case study, which is a cooperative project between National Science and Technology Development Agency (NSTDA) and Thailand Automotive Institute (TAI). The battery pack in the project uses 18650 battery cells, which accordingly have 18 mm of diameter and 65 mm of length while the number 0 means cylindrical shape.

Figure 1 shows one battery sub-module including 22 Lithium-ion battery cells that connected in parallel connection to increase capacity. At the positive side, each positive terminal of the battery cells is connected to the positive busbar via fuse wire. At the negative side, each negative terminal of the battery cells is welded with the negative busbar by spot welding. In Figure 2, one half module demonstrates eight battery sub-modules in serial connection to up voltage.

Due to many components in the battery pack, only 4 components which are positive busbar, negative busbar, Z busbar and upper battery holder are represented in this paper. To select materials such as nickel, copper, aluminium and ABS, DECISION MATRIX method is used in decision in term of cost, safety, function, performance and manufacturing. Some component is analysed via Finite Element Method (FEM) software to check safety and performance.

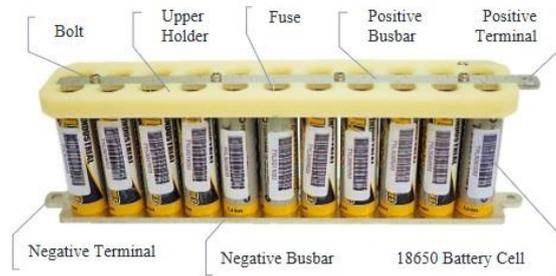


Figure 1. Twenty Two Battery Cells in Parallel for One Battery Sub-Module

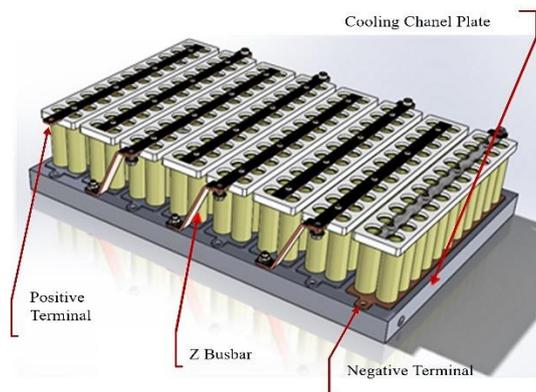


Figure 2. Eight Battery Sub-Modules in Serial Connection for half Module

4.1 Architecture analysis method

Application of product architecture design methodology to system design.

The application of architecture analysis and core competencies to identify design items and sequence of design through empirical knowledge of experienced engineers. The three underlining techniques in this approach are:

- Clarifying the relationship between performance attributes and specification of Battery Pack.
- Extraction of battery pack design items.
- Setting an efficient sequence for process of battery pack design.

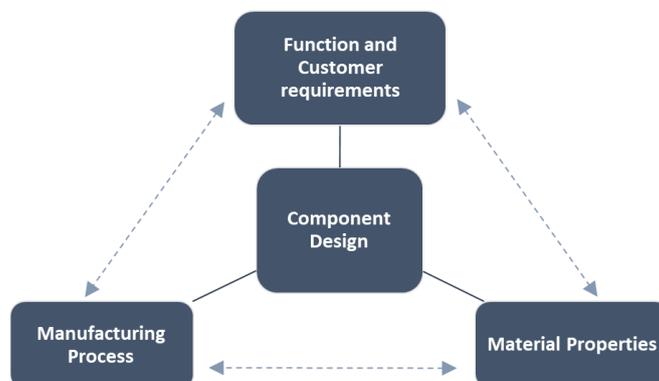


Figure 3. Factors that should be considered in component design

4.2 Decision Matrix

The decision matrix is a decision aid tool that qualitatively evaluates and prioritizes a list of abstract solutions. It also provides a system which relationships between sets of information are identified, analyzed, and rated. The decision matrix is also known as alternatives evaluation matrix, criteria-based matrix, COWS decision matrix, decision grid, opportunity analysis, problem selection matrix, Pugh matrix, weighted criteria matrix, and etc. The decision matrix is frequently used when only one option can be implemented. In addition, it can be used as a method to rank all the alternatives. Moreover, it can also help reduce the number of options in the list by filtering out the unsuitable alternatives. The procedure of the decision matrix is provided following.

- Identify alternatives - The alternatives can be product features, service features, process steps, or potential solutions.
- Identify selection criteria - The criteria may result from an affinity diagram or a brainstorming activity in the team. The customer needs are also included if possible. The list of criteria should be discussed and refined within the team.
- Assign a relative weight to each criterion - All criteria are weighted depending on the relative importance of each criterion to the concerned situation. The criterion that is more important than others is assigned the higher weight factor.

There are several options for weighting scales as shown in the following examples.

1 - 10 : 1 = the least priority, 10 = the most important

Percentage: Each criterion is assigned its weighting percentage. The summation of all weighting percentage is equal to 100 percent.

- Design scoring system - There are three options for scoring system.

Method 1 - A scoring range is established for all criteria. There are also many options for scoring range. Examples are given following.

- 1, 2, 3 : 1 = low, 2 = medium, 3 = high
- 1, 2, 3, 4, 5 : 1 = little to 5 = great
- 1, 4, 9 : 1 = low, 4 = moderate, 9 = high

Method 2 - Each alternative is ranked according to its performance for the concerned criterion. Number 1 means that it is the least desirable, while the best performance alternative in each criterion gets the highest number.

Method 3 (Pugh matrix) - One alternative is chosen as a baseline. The baseline is given the 0-score in all criteria. Then other alternatives are evaluated by comparing with the baseline. The better performance alternatives get the positive scores such as +1, +2, or +3. Meanwhile the worse alternatives get the minus scores such as -1, -2, or -3. A three-point scale (-1, 0, 1), a five-point scale (-2, -1, 0, 1, 2) or a seven-point scale (-3, -2, -1, 0, 1, 2, 3) can be used.

- Rate the alternatives - The scores of all alternatives for each criterion may come from the average values of the scores given by individual team members, or the scores may come from the consensus decision of the team.
- Total the scores - All the scores in each criterion are multiplied by their weighting factors. Then the overall score of each alternative can be obtained from the summation of the multiplied scores.

The decision matrix tables are generally formed with the list of all criteria and the list of all alternatives. The list of all criteria is located on the first column, while the list of all alternatives is placed on the first row. The second column usually stores the weighting factors.

Therefore, the decision matrix is a L-shaped matrix with 2-dimension variation.

5. Result

This research provides the feasibility study of the new concept battery production. A single sub-module of the new concept battery consists of seven components which are battery cell, positive busbar, negative busbar, cooling plate, battery mount, male electrical connector, and female electrical connector. The battery pack can comprise many battery cells which can be electrically connected in either series or parallel layout. This research studies each component of the new concept battery, and the information regarding the material selection and the manufacturing method selection is gathered and provided in this research.

Moreover, the decision matrix is utilized as the decision aid tool in order to choose the appropriate material. Meanwhile, the selection of the manufacturing method is based on the gathered information.

5.1 Positive Bus Bar and Z bar

In the material selection process for the electrical connectors, this research provides four aspects of consideration which are material compatibility aspect, electrical conductivity aspect, density aspect, and material cost aspect. All four aspects are discussed in the following subsection. Aluminium and copper are the two most popular materials that are used to produce electrical connectors, and there are also many discussions concerning the selection between these two materials.

(a) Material Selection

Aluminium conductors are a viable alternative for bus bar applications. Using Aluminium as conductor doubles the conductivity per mass in comparison to Copper and saves more than 30% of the costs. For Data Centre applications, Aluminium Busbar is the perfect alternative to Copper, as they offer reduced cost whilst maintaining the mandatory reliability and sustainability criteria.

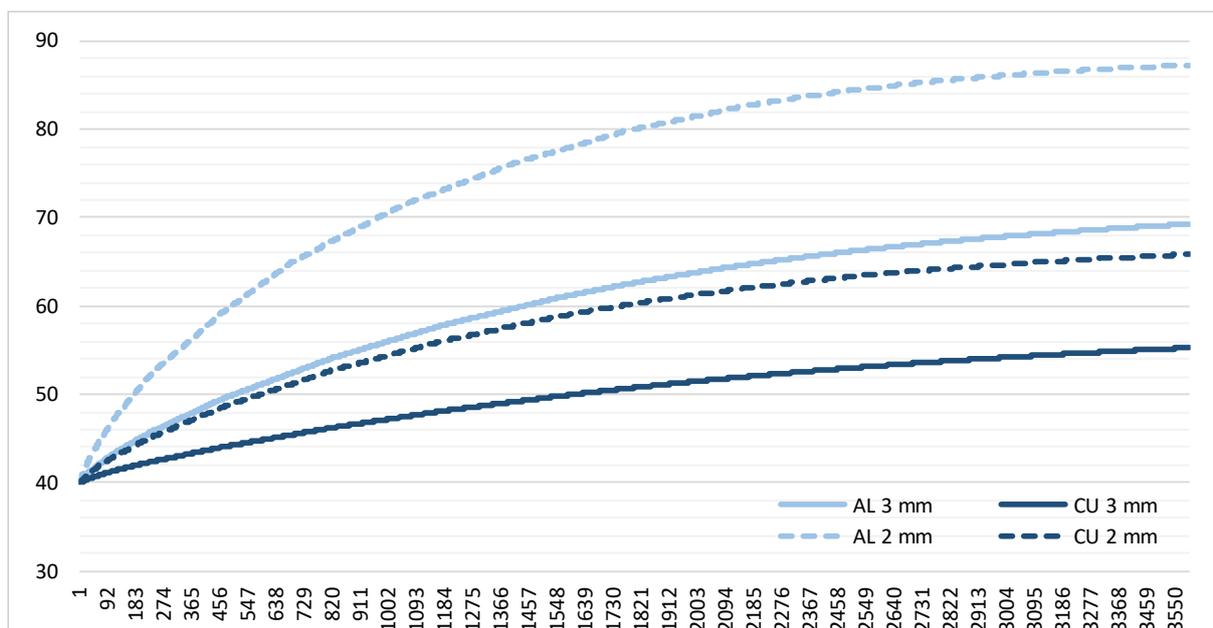


Figure 4. Comparison of temperature increasing for each material at 40 ° C by FEM software.

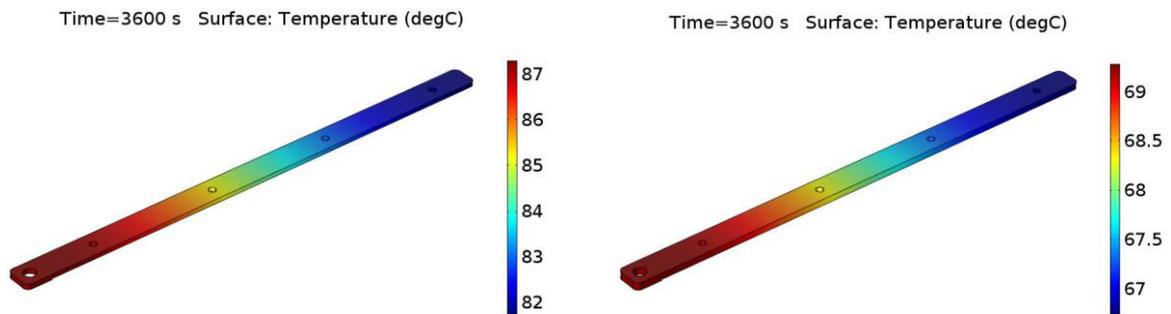


Figure 5. Thermal expansion of AL 2 mm and 3 mm

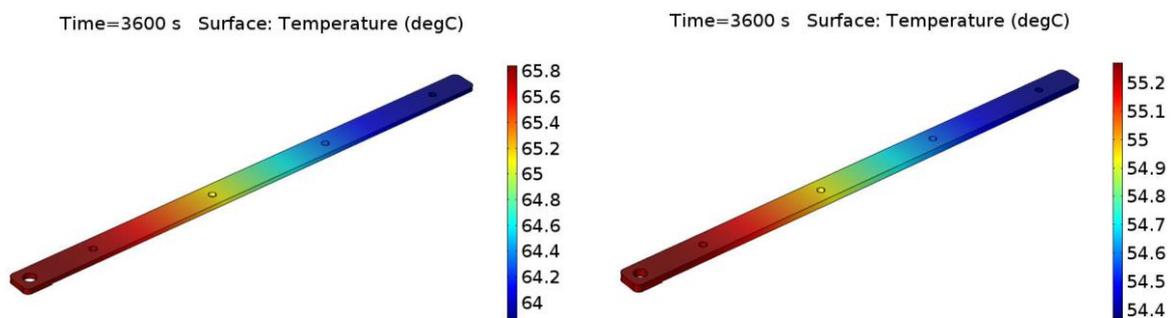


Figure 6. Thermal expansion of Cu 2 mm and 3 mm

This research increase the thickness of the positive bus bar and Z bar from 2 millimeters to 3 millimeters by using an aluminum material. The purpose is to reduce the resistance and temperature of positive bus bar and Z bar, reduce costs and reduce weight compared to copper. The results showed that Z busbar 3 mm of aluminum had lower electrical resistance.

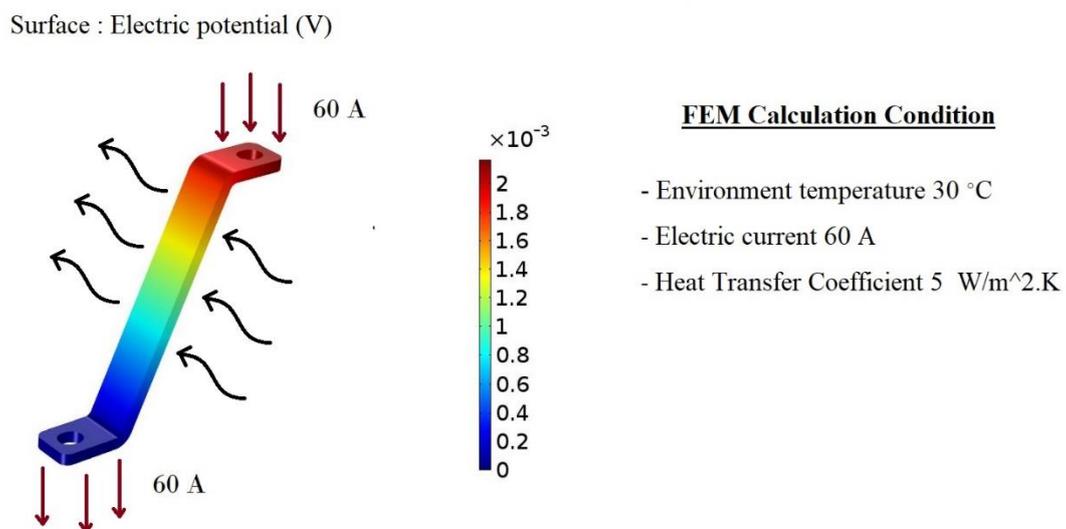


Figure 7. Condition for FEM calculation

Table 1. Electric resistance of Z Busbar

	<i>AL 3 mm</i>	<i>CU 3 mm</i>	<i>AL 2 mm</i>	<i>CU 2 mm</i>
<i>Electric resistance</i>	6.10997E-05	3.58811E-05	9.29615E-05	5.45909E-05

(b) Weighting parameters and comparison of result

All consideration aspects lead to a comparison of results. The evaluation scores are multiplied with the weighting percentage.

Table 2. Comparison of evaluation scores with weighting percentage

<i>Consideration aspect</i> <i>Weighting</i>	<i>percentage</i>	<i>Evaluation Score</i>		<i>Weighting calculation</i>	
		Aluminium	Copper	Aluminium	Copper
Thermal conductivity	30%	2.5	1	0.75	0.3
Electical conductivity	20%	3	5	0.6	1
Mechanical strength	10%	3.5	5	0.35	0.5
Material cost	40%	5	1	2	0.4
Total scores 100%	100%	14	12	3.7	2.2

(c) Manufacturing method

Regarding the manufacturing method of positive bus bar and Z bar, the information of Laser Cutting Machine (Laser CNC) is provided. According to the gathered information, Laser Cutting Machine (Laser CNC) / shearing machine technique is chosen to be the appropriate methods. This is mainly because this method has the ability to cut aluminium without distorting the material shape with short production time.

Concerning positive bus bar and Z bar, this research provides four aspects of consideration for the material selection, which are thermal conductivity aspect, mechanical strength aspect, density aspect and material cost aspect. The information regarding each aspect is supplied. In addition, the thermal simulation and conductivity simulation were also conducted in the FEM software. Then each material alternative is evaluated and scored in these four consideration aspects with the decision matrix tool. According to the result, aluminium receives the best total scores; therefore, it is chosen as the material for positive bus bar and Z bar. Regarding the manufacturing method of positive bus bar and Z bar, this research selects Laser Cutting Machine (Laser CNC) / shearing machine process to produce positive bus bar and Z bar.

5.2 Upper Battery Mount

In this topic, plastic selection guide from Quadrant Engineering Plastic Products is used as a guideline to select plastic type for the upper battery mount and its production method.

(a) Material Selection

Regarding to limit resource material for battery mount prototype, there are 2 possible material which are ABS and acrylic in this research. The guideline provides the information of plastic properties that should be concerned for plastic selection. Additional information of the plastic properties from other resources is also supplied.

Regarding the cooling connector of the new concept battery, the design criteria are provided following:

- **Thermal resistance** The heat deflection temperature value (HDT 1.8 MPa standard) and the maximum continuous service temperature value must be more than 50°C due to the battery design constraint.
- **Chemical resistance** The cooling connector material must be resistant to the coolant in the cooling system. However, the cooling fluid in the new concept battery is not yet specified, and the choosing of the cooling fluid is also beyond the scope of this thesis.

The prices of raw plastics can vary according to the different factors such as ingredients, additives, time, manufacturers, and quantities.

(b) Manufacturing method

There are several manufacturing methods of plastic parts such as injection moulding, die casting, sand casting, and machining. However, the injection moulding is concerned as the most popular plastic fabrication method. Plastic components with thin-walled are generally produced by this method. Complex shapes with good dimensional accuracy can be expected from the injection moulding. However, the cost of the tool and equipment is relatively high.

Table 3. Recommended manufacturing methods for different part shapes by Quadrant Engineering Plastic Products

<i>Plastic shape</i>	<i>Manufacturing method</i>
Long lengths Smaller sections Rod, plate and tube	Extrusion
Large stock shapes (heavy sections) Rod, plate and tube Near net shapes Custom cast parts	Casting
Various shapes in advanced engineering materials Rod, disc, plate and tube	Compression moulding
Plastic shape Small shapes and thin walls in advanced engineering materials High volumes (more than 10000 parts)	Injection moulding

Concerning the battery mount, the plastic selection guide from Quadrant Engineering Plastic Products is used as a guideline. The information regarding the selection factors is further provided, and the design criteria of battery mount is also discussed. These design criteria are used as the input variable into the plastic material database, which results in more than thousand of usable material options. Further evaluation is conducted by using the decision matrix tool to choose the suitable material alternative. Seventy-two plastic alternatives with available price and properties information are evaluated further with the decision matrix method. The selection criteria used in this evaluation are material price, material strength, heat deflection temperature, thermal expansion and water absorption, which are based on the plastic selection guide. According to the result from the decision matrix tool, ABS receives the best total score, which is chosen as the material. Regarding the manufacturing method, brief information of injection moulding is provided as the suitable manufacturing method. For the battery mount, there is

another possibility to produce this component. Firstly, the battery mount can be manufactured by plastic CNC milling process of ABS which the number of plastic choices is limited.

5.3 Negative bus bar

Regarding to the negative terminal of battery cell is Nickel based material which has to be attached with negative busbar. In this case, compatibility issue is the main parameter that need to be considered. Consequently, Nickel is the best optional material for producing negative busbar. However, nickel cost is very high and nickel processing is quite difficult. In order to reduce production cost, this research study alternative material that have similar property as nickel.

(a) Material Selection

This research design to use 2 components for producing negative busbar and nickel plate is fixed material for the first component. copper and aluminium are chosen as optional material for the second component. Therefore, this research uses the selection criteria for second component of negative busbar same as Positive Bus Bar and Z bar.

(b) Manufacturing method

For lower battery mount and negative busbar, there are 2 possible optional jointing technique which are spot welding and laser welding technique.



Figure 8. Spot welding and Laser welding technique

Table 4. Welding result for Negative busbar

<i>Material</i>	<i>Cycle time</i>	<i>Voltage</i>	<i>Result</i>	<i>Cost (Baht/kg)</i>
(a) Ni+Cu	5 sec	6	Attached well	223.95
(b) Al+Cu	5 sec	8	Can bear pressure only X and Y	42.7
(c) Ni+Al	5 sec	8	Attached well	193.45

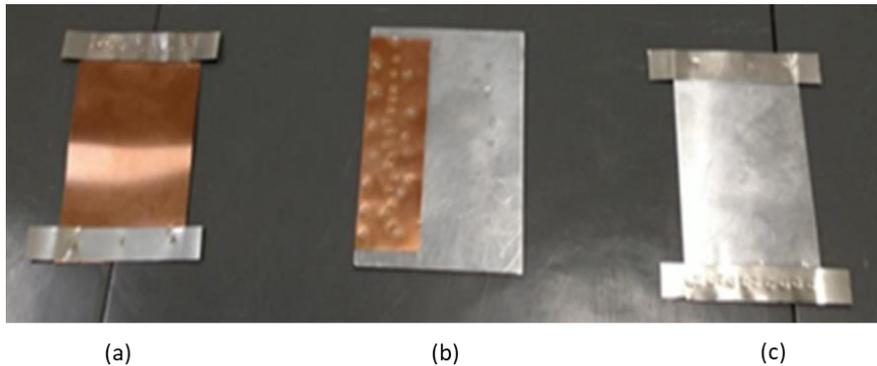


Figure 9. Sample result of spot welding for negative bus bar

Concerning negative busbar, the information is provided in four aspects of consideration for the material selection, which are material compatibility aspect, electrical conductivity aspect, density aspect and material cost aspect. However, the material compatibility issue dominates the material selection of the negative busbar. Negative nickel busbar is attached to the negative terminal of battery cell, while negative aluminium-busbar is attached to negative nickel-busbar. According to the gathered information, the nickel and aluminium are chosen as the negative-busbar material. Regarding the manufacturing method of the negative busbar, brief information of Laser Cutting Machine (Laser CNC)/ shearing machine is provided.

6. Conclusion

This research is expected to able evaluate various alternatives for materials and assembly techniques of battery pack, and some sample costs are presented. A methodology that choose the most proper alternative on the basis of this analysis is presented. The methodology also consider the impacts of choice-alternatives along multiple dimensions. This research studies each component of the new concept battery, and the information regarding the material selection and the manufacturing method selection is gathered and provided in this research. Moreover, the decision matrix is utilized as the decision aid tool in order to choose the appropriate material. Meanwhile, the selection of the manufacturing method is based on the gathered information. This research is expected to distribute knowledge of battery pack development for small electric cars leading to increased business opportunities. And it can be used as a guide for automotive industry in familiar field for the maximum benefit to consumers and manufacturer as well.

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