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A CONTEMPORARY REVIEW OF THE ADVANCEMENTS IN JOINING TECHNOLOGIES FOR BATTERY APPLICATIONS

SODOBEN LITERATURNI PREGLED UPORABE NAPREDNIH POSTOPKOV SPAJANJA ZA IZDELAVO BATERIJ

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The joining of multilayered foils to a conductive tab necessitates a joining process in the battery, which is an important storage device in renewable-energy sectors. Cell, module, and pack are the three levels of pouch cell joining in a battery pack. The joining of multi-layered dissimilar conductive materials is necessary for battery-pack fabrication. Mostly copper (Cu) and aluminium (Al) are used in battery-pack applications. The Cu and Al are characterized as high thermally and electrically conductive materials. However, obtaining a quality Cu-Al weld using conventional methods is hard and the durability of the weldments is uncertain. In general, the development of intermetallic compounds (IMCs) during welding is a major challenge for the joining of dissimilar materials due to the differences in the chemical and physical properties. This review addresses the battery packs and challenges involved in joining the conductive tabs. In addition, this review provides an insight into the suitability of various joining processes and explores their suitability for the joining of battery packs.

Keywords: friction-melt bonding, renewable energy storage, Li-ion battery, welding; joining, friction-stir spot welding, resistance welding, laser-beam welding, ultrasonic welding

Spajanje večplastnih folij na prevodne ploščice je nujen postopek pri izdelavi baterij, ki so pomembne naprave za shranjevanje električne energije na področju obnovljive energije. Celica, modul in paket so tri ravni baterijskega sklopa, shranjeni v enovito celoto. Medsebojno spajanje več plasti materialov z različno prevodnostjo je nujno za uspešno izdelavo baterijskega sklopa. V glavnem se uporabljata za baterijske sklope dva materiala: baker (Cu) in aluminij (Al). Oba materiala imata odlično toplotno in električno prevodnost vendar je za izdelavo kakovostnega Cu-Al zvara uporaba konvencionalnih postopkov težavna in trajnost zvarov slaba oz. nezanesljiva. V glavnem je pri tem problem nastajanje intermetalnih spojin zaradi razlik v kemijskih in fizikalnih lastnosti. Avtorji opisujejo glavne izzive in probleme s katerimi se srečujejo izdelovalci baterijskih sklopov zaradi spajanja prevodnih priključkov. Poleg tega pregled literature ponuja vpogled o primernosti uporabe različnih postopkov spajanja baterijskih sklopov.

Ključne besede: spajanje v talini s pomočjo trenja, shranjevanje obnovljive energije, litij-ionske baterije; varjenje, spajanje, točkovno varjenje s pomočjo trenja med vrtenjem obremenjenega trna, uporovno varjenje, lasersko varjenje, ultrazvočno varjenje

1 INTRODUCTION TO Li-ION BATTERY PACKS AND JOINTS

The production of electricity through renewable energy is a global demand. On the other hand, the requirement of energy storage is essential. Rechargeable storage devices are the key players in storing the produced renewable energy. Most storage devices are made from lithium (Li) ion batteries for renewable and portable energy needs. The packing efficiency of the pouch cell battery packs are the highest among the categories in Li-ion batteries. These batteries are categorized as prismatic, cylindrical and pouch cells.[1] Conductive foil tabs that are attached to the electrodes are used to position the cylindrical pouch cells. The pouch-cell arrangement contains levels like pack, module and cell. The level of cell configuration contains Li cathode and graphite anode foils that are filled with electrolytes. The Li foil is positioned over aluminum (Al) and copper (Cu) collectors that are joined to the tab. At the module level, the cells are joined and at the pack level, modules are joined.[2] The configuration and characteristics of Li-ion battery packs are presented **in Table 1**. The above-mentioned joints require the welding of multi-layered Cu and Al for battery packs, as mentioned in **Figure 1**. Considering the cost effectiveness and quality of the weld, the automated welding methods are preferred for battery packs. As in the case of mechanical joining, it provides better strength and ease of disassembly; however, it increases the weight of the battery pack and these joints are susceptible to corrosion. Joint preparation using resistance welding (RW) produces quality weldments. Besides, employing RW over conductive materials like Cu and Al needs a high electric current and more time to prepare the joints. This leads to an excessive heat input, causing intrinsic, localized fusion and creates extensive deformation.[3] Laser beam welding (LBW) involves a low heat input but causes melting of more materials to be joined, which may lead to cracks, due to solidification and the development of undesirable intermetallic compounds while dis-

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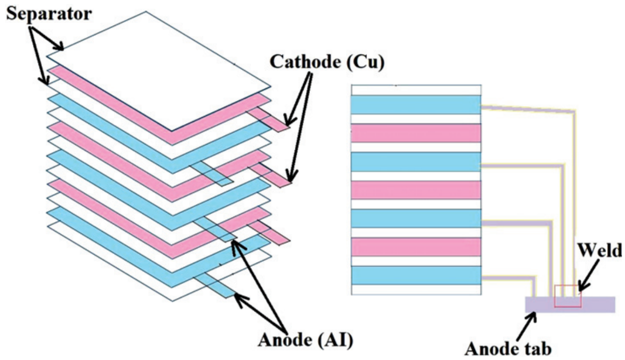

Figure 1: Configuration of cell level battery welded to anode tab (Redrawn from reference [30])

similar joining.[4] Friction-melt bonding (FMB) is one of the alternatives to the multi-layered welding of Cu and Al in battery packs. FMB is a variant of the friction-stir spot welding (FSSW) process that produces a spot – lap welding. FMB uses a non-consumable tool that produces the joints by plasticizing the region with frictional heat because of the forging pressure. FMB involves stages like initial rotation, plunging and retracting. The joints produced have excellent mechanical properties with very thin intermetallic layers.[5,6]

2 CHALLENGES INVOLVED IN BATTERY PACK DESIGN

This section deals with the various complexities involved in the fabrication of battery packs, such as the challenges with respect to mechanical loading, electromechanical, thermal and metallurgical influences are discussed in a brief note.

2.1 Mechanical aspects

Mechanical phenomena play a crucial part in battery-module functioning, as well as safety standards. The modules in a battery are subjected to dynamic loading and vibrations while in operation. Additionally, the pre-stressing of the battery interconnection joints because of the interconnecting by joining may visibly impair the dynamic responsiveness of the complete battery back.[7] When being charged and discharged, lithium-ion batteries typically exhibit dynamic behaviour in the structure. This effect may last forever, attributed to the irreversible expansion of the electrodes and pressure difference in the cell.[8] It is essential to take electromechanical effects into account since the mechanical connections between batteries and conductors serve both structural and electrical purposes by transferring current to or from the cells. In structural applications, fatigue is a well-known issue that can be troublesome, however it can also lead to an increase in electrical resistance. The fatigue life is predicted using the impedance of specimens throughout the fatigue tests, where the interaction between impedance and fatigue failure is separated from one of the factors, such aas variation in the length of the specimen.[9] Thermal aspects: materials with different thermal expansions at the joint interface produce heat that cause inhomogeneous thermal expansion. This leads to shear loading and may cause fracture in the prepared joint. This shear loading ultimately affects the contact interface and connection resistance.[10]

2.2 Metallurgical aspects

It is well known that joints that are available in electric contacts and integrated circuits experience corrosion, the degradation of material qualities and functionality.

Table 1: Configuration of Li-ion cell structure and type of joining methods employed in battery packs

Li-ion cell structure	Li-ion configuration		Characteristics	Type of joint
	Cell	Pack		
Cylindrical type			Packing density: Poor Individual cell capacity: Poor Cost: Low Casing: Hard	Wire bonding Mechanical fastening
Prismatic type			Packing density: High Individual cell capacity: High Cost: Expensive Casing: Hard	Mostly Mechanical fastening Laser welding Resistance welding
Pouch type			Packing density: High Individual cell capacity: High Cost: Inexpensive Casing: Soft	Ultrasonic welding Mechanical fastening

Here, atmospheric, localised, pitting, and galvanic corrosion are the most well-known and obvious forms. In-depth research into fretting in microelectronics and electronic connections revealed that it can be seen in practically all regularly used conductor materials, such as copper, aluminium, or nickel, and that it has a noticeable impact on connection resistance.[10] In mechanically linked electrical connections, metal-to-metal contacts are where the more significant process of degradation takes place. Direct effects of intermetallic compounds, such as those between copper and aluminium, include a reduction in mechanical strength and an increase in electrical connection resistance. During joining, the formation is both conceivable and frequently controllable. Furthermore, power and temperature during operation can promote diffusion and hence enable uninhibited creation.[11]

3 ESSENTIAL CRITERIONS FOR BATTERY-PACK JOINING

To analyse the possibility of joining the interconnections of the battery, interdisciplinary requirements must be investigated. The four major categories to be considered as per Das et al.,[12] for the battery-pack joining are shown in **Table 2**.

Table 2: Essential criteria to be considered for battery-pack joining

Major category	Essential criterions
Mechanical aspects	-Interconnection to be intact -Vibrational damage to be avoided during joining -Better fatigue life
Thermal aspects	-Low electrical resistance at joint interface -Creep resistance
Metallurgical aspects	-Less corrosive -Ability to join dissimilar materials
Economic aspects	-Durability -Easy to produce in bulk

4 PROBLEMS ASSOCIATED WITH VARIOUS BATTERY-PACK JOINING TECHNOLOGIES

The various problems with respect to battery-pack joining methods are discussed below and the challenges as well as the benefits with respect to battery-pack joining technologies are depicted in **Table 3**.

4.1 Mechanical fastening (MF)

Mechanical joining can be divided into two groups: integral joints and fasteners. Nuts, bolts, screws are all types of fasteners. Seams, snap-fits, are examples of integral joints. Therefore, the primary benefit of mechanical connecting is its simplicity in disassembling for upkeep and repair. Additionally, mechanical joining is often done without heat, with the possible exception of a few unique circumstances. However, additional mass to cell pack, corrosion issues and intensive labour are the key challenges of mechanical fastening.[13]

4.2 Resistance welding (RW)

The localized heating and fusion at the joint interface is obtained by the electrical resistance. Resistance welding is a faster process, and it can be easily automated. On dealing with battery-pack joints, employing resistance welding is challenging because of its non-suitability for highly conductive materials. Moreover, dissimilar metals are difficult to join. In the case of battery joints, large weld nuggets are essential, which is also difficult in resistance welding.[14] In the case of the resistance welding of dissimilar alloys, the formation of a thin intermetallic layer must be taken into consideration. However, the intermetallic layer's formation can be restricted by controlling the heat input.

4.3 Projection welding (PW)

It is a type of spot welding that provides a good joint for battery tabs. The projection joints increase the current density, which causes heat generation. Also, the welding of thicker slabs is possible, whereas, weldability is poor for highly conductive multi-layered materials and dissimilar materials.[14]

4.4 Laser-beam welding (LBW)

It is a non-contact joining process, which is capable of joining multiple pieces of materials. The weld is created as the material is rapidly heated by the powerful laser beam, usually in milliseconds. Laser welding has been used widely for joining battery packs, owing to its various benefits, such as a high speed, precise welding process that produces less distortion. Laser welding is challenging in materials like Cu and Al due to high reflectivity and thermal conductivity. Most often a poor metallurgical bond between Cu and Al limits this laser welding, as it produces weld defects like intermetallic brittle phases.[15,16]

4.5 Ultrasonic welding (UW)

In the process of ultrasonic metal welding, a high-frequency ultrasonic energy is utilised to form solid-state connections by generating oscillating shears between two sheets that are pressed together. The primary benefit of ultrasonic welding is suitable for dissimilar materials, and it is capable of joining stacks of multiple thin sheets and foils. As the working temperature of this welding is low and even if it provides sound welding on materials like Cu and Al. The drawback of ultrasonic welding is that this process is only suitable for thin sheets, and it is sensitive to surface conditions. It is also difficult to join high-strength materials using the method.[17]

Table 3: Challenges involved in battery pack joint technologies

S. No.	Type of joining technology in battery application	Benefits	Challenges
1	Mechanical fastening[13]	-Higher joint strength -Easier assembly/disassembly -No requirement for heat source	-Additional mass to cell pack -Corrosion issues -Work intensive
2	Resistance welding[13]	-Faster process -Easy to automate	-Not suitable for highly conductive materi-als -Difficult to weld dissimilar materials -Large weld nuggets are not possible, as it is essential for battery packs. Large welds help to reduce electrical resistance
3.	Projection welding[10]	-Welding of thicker slabs are possible	-Poor weldability for highly conductive dis-similar materials
4.	Laser-beam welding[15,16]	-Less distortion -Highly precise process -High speed, non-contact process	-Producing large joint area is difficult -Material reflectivity -Necessity for shielding gas
5.	Ultrasonic welding[18]	-Suitable for conductive materials and thin sheet metals -Dissimilar materials can be joined -Solid-state process	-Restricted to lap joints -Sticking of sonotrode (electrode) -Sensitive to surface conditions

5 EMERGING JOINING METHODS FOR BATTERY CONDUCTIVE TABS

The alternative joining methods used for battery applications are joining by forming technologies and friction-assisted welding processes.

5.1 Joining by forming technologies

This process involves plastic deformation of at least one of the combining materials. Impact welding, roll bonding are some of the solid-state methods involved in joining by forming technologies. Recently, Pragana et al.[19] fabricated Cu-Al by partial cutting and bending with a compression form-fit process. This technology enables the joining of dissimilar materials, irrespective of their high conductivity. Moreover, the problem associated with these forming technologies are the difficulty of joining more than two or three layers of sheet metal and thr accessibility of the parts is difficult.

5.2 Friction-based joining processes

It is a solid-state method being adopted to join battery tabs using frictional heat. The main advantage of this process is dissimilar materials like Cu and Al can be joined without the formation of brittle intermetallic layers. Mypati et al.,[20] welded a Cu-Al cell tab successfully. However, the left out exit hole is the major drawback of this process. The various friction-based joining processes that are found to be suitable for battery-tab joining processes are friction-assisted joining, friction spot joining, friction riveting, friction lap welding [20–24]

5.3 Friction melt bonding

FMB is a novel joining technology that takes advantage of the substantial temperature variations between the materials to be bonded. **Figure 2** shows a diagram of this process. One plate is placed on top of the other and fixed together in FMB. The top surface of the plate is forced against a rotating flat cylindrical tool, which generates heat through friction and creates a deformation. The frictional heat generated raises the temperature of the top plate to near the melting point of the bottom plate. As a result, both the top and bottom plates melt and react locally, forming an intermetallic layer. The tool moves on the surface of the top plate to form a continuous weld seam with prolific weld quality and with minimal welding defects.[25–28]

5.4 Refill friction-stir spot welding (RFSSW)

RFSSW is one of the solid-state techniques used for joining thin layers in batteries. It forms a spot weld without melting the materials, with better quality of the weld. This technique has a tool with a probe, adjustable shoulder and clamp ring, as shown **Figure 3**. RFSSW is one

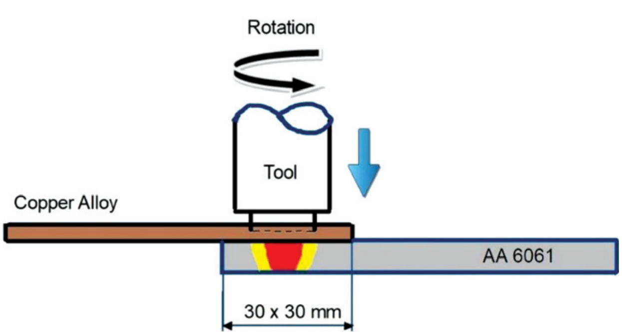

Figure 2: Schematic setup of friction melt bonding

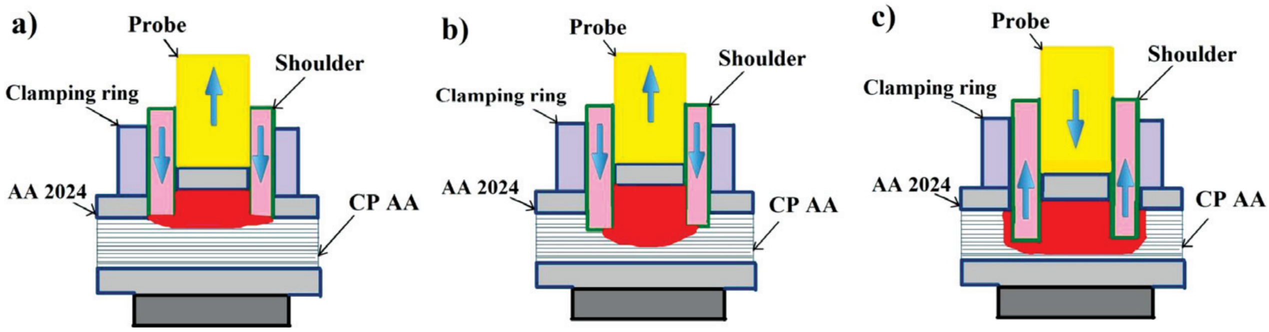

Figure 3: Schematic representation of process sequence involved in Refill friction stir spot welding (Redrawn from reference [30])

of the solid-state welding techniques that evolved from friction-stir welding. Tool traverse on the materials to be welded is not associated in this process. So, it forms a spot weld without melting the materials with better quality on the weld properties. This technique has a rotating probe, adjustable shoulder and clamp ring, as shown **Figure 3**. RFSSW takes place in four stages: 1) the tool moves to the top surface of the plate and rotation starts to generate frictional heat to make the materials sufficiently soft. 2) Shoulder is plunged to the top plate to retract the materials to form a gap through which flow of the displaced material takes place. 3) Rotating tool is used to return retracted the material to the top surface, leading to consolidation of the weld and the welding process is finished [29-30]

6 NECESSITY FOR AN ALTERNATIVE JOINING TECHNOLOGY

Batteries made of Li-ion are used in most renewable-energy storage devices, and the cells are categorised as pouch, prismatic, or cylindrical.[1] The pouch cell has the highest packaging efficiency (95%) compared with battery packs. Its great efficiency is due to its design, which uses conductive foil-tabs soldered to electrodes instead of metallic cylinders and a glass-to-metal electric feed through.[2] Figure 1 depicts the procedure of combining a battery pack with a pouch cell design. As a result, the connecting of many layers is critical in the fabrication of batteries. For both financial and quality concerns, the cell welding process must be highly automated. Although mechanical connecting offers the best strength and simplicity of disassembly, it also adds more pieces and mass to the cell, making it more prone to corrosion.[13] To join stacked Cu and Al to a conducting tab in battery pouches, welding methods are required.[10] However, these approaches have drawbacks that prevent them from being widely used in battery manufacturing.[16]

7 DISCUSSION ON JOINING TECHNOLOGIES FOR BATTERY PACKS

MF stands out because it joins simply by imparting force, which produces little heat. Furthermore, the connection resistance as well as the scatter range were recorded to be low. However, this method involves additional parts which increases the weight and manufacturing complexity while also limiting automation. The loosening of connections was recorded. Based on the above considerations, MF cannot be a suitable method for manufacturing battery packs. RW is a low-cost process that has been used in industry. However, stabilising the process is challenging due to various influencing parameters. Moreover, if the process is regulated for a particular welding operation, preserving quality is possible. As a result, it is suitable for a regulated welding activity with a lot of cycles, like making battery modules. Resistance spot welding is also a good choice for either type of weld task because it naturally has the benefit of welding locally at the joining surfaces. LBW produces a low condensation resistance, low scattering, and produces excellent weld strength. Furthermore, the heat input was the lowest among all the presented process technologies. This offered the possibility to extend LBW as an automated method. However, LBW is a costlier process due to the requirement for a shielding gas, tool and alignment of joints. A high-quality weld depends on the chosen processing window. In joining the interconnector to the cell, it is essential that LBW must completely melt throughout the interconnector. In the case of large prismatic cells, LBW must be employed to weld a large volume of material. For battery-pack joining applications, the LBW and RW are suitable. On considering the economic aspects, less environmental impact and process stability RW technology is convenient. Ultra-sonic welding is a solid-state process supported with self-tool and it is well suited for joining conductive metals. Moreover, heat generation during the process was found to be inferior, particularly for battery-pack joining. Additionally, connection resistance is high when compared to welding techniques. As a result, UW may be regarded as unsuitable for cylindrical battery cell welding, but suitable for pouch and cylindrical cell interconnection. Welding using forming technique is practically not suitable for connecting cylindrical cells due to the penetration takes place in the battery cell. However, it can be used to connect the pouch cell and prismatic when the tabs are located externally in the former case. Interconnection busbars are an alternative for this method. Softening of aluminium is the major challenge that leads to the issues and should be investigated thoroughly for the particular application. Therefore, welding using forming technologies seems to be a workable strategy provided that the joining partners are reachable and that application-related difficulties are resolved. Friction based welding has not been widely used in battery interconnections. However, it appears to be advantageous from a metallurgical standpoint, as the formation of an intermetallic is unavoidable, particularly in dissimilar material combinations. Friction-based welding produces less heat than fusion welding. However, it has not been investigated whether frictional heat can damage battery cells. It is unclear whether welding can cause thermal or physical damage to the cells. Clamping the joining partners can be difficult if the battery-connector joint designs become difficult. Some of the benefits of utilizing friction-based joining processes are shorter joining time, energy efficient, better joint strength, shorter installation time and suitable for dissimilar joints. At this point, it is possible to conclude that the technology has the potential to be used in battery interconnections, but additional research is required.

8 CONCLUSION

This review allows for a comprehensive idea about employing various joining technologies, allowing durable joints with low connection resistances.

When comparing battery welding-joining technologies it is clear that adapting to a technology is dependent not on connection resistance but also depends on the joining task.

Ultrasonic welding was found to be suitable for joining pouch cells.

Laser welding can be used to join cylindrical cells. Moreover, it may be less effective for large cells with geometrically large interconnectors. Also, la aser requires an entire melting of the connector regardless of its size.

Resistance welding is flexible for all battery-cell types as the joining happens locally.

Friction-based welding is observed to be beneficial owing to the shorter joining time, energy efficient, better joint strength, and suitability for dissimilar materials.

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6 REFERENCES

[1] M. Palanisamy, V. P. Parikh, M. H. Parekh, V. G. Pol, Lithium metal battery pouch cell assembly and prototype demonstration using tailored polypropylene separator, Energy Technology, 8 (**2020**) 6, 2000094, https://doi.org/10.1002/ente.202000094

[2] J. Y. Yong, V. K. Ramachandaramurthy, K. M. Tan, N. Mithulananthan, A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects, Renewable Sustainable Energy Reviews, 49 (**2015**), 365–385, https://doi.org/10.1016/j.rser.2015.04.130

[3] M. Piott, A. Werber, L. Schleuss, N. Doynov, R. Ossenbrink, V. G. Michailov, A study of the heat transfer mechanism in resistance spot welding of aluminum alloys AA5182 and AA6014. International Journal of Advanced Manufacturing Technology, 111 (**2020**), 263–271, https://doi.org/10.1007/s00170-020-05650-x

[4] S. Katayama, Introduction: fundamentals of laser welding. In: Handbook of Laser Welding Technologies, Woodhead Publishing, UK, 2013, 3–16. https://doi.org/10.1533/9780857098771.1.3.

[5] U. Suhuddin, V. Fischer, F. Kroeff, J. F. dos Santos, Microstructure and mechanical properties of friction spot welds of dissimilar AA5754 Al and AZ31 Mg alloys, Material Science and Engineering A, 590 (**2014**), 384–389, https://doi.org/10.1016/j.msea.2013.10.057.

[6] Y. Chen, H. Deng, H. Liu, T. Zhang, S. Li, S. Wang, C. Chen, A novel strategy for the reliable joining of Ti6Al4V/2A12-T4 dissimilar alloys via friction melt-bonded spot welding, Materials Letters., 253 (**2019**), 306–309, https://doi.org/10.1016/j.matlet.2019.06.089

[7] L. Shui, F. Chen, A. Garg, X. Peng, N. Bao, J. Zhang, Design optimization of battery pack enclosure for electric vehicle, Structural and Multidisciplinary Optimization volume, 58 (**2018**) 1, 331–347, https://doi.org/10.1007/s00158-018-1901-y

[8] J. H. Lee, H. M. Lee, S. Ahn, Battery dimensional changes occurring during charge/discharge cycles - Thin rectangular lithium ion and polymer cells, Journal of Power Sources, 119–121 (**2003**), 833–837, https://doi.org/10.1016/S0378-7753(03)00281-7

[9] P. Starke, F. Walther, D. Eifler, PHYBAL – A new method for lifetime prediction based on strain, temperature and electrical measurements, International Journal of Fatigue, 28 (**2006**) 9, 1028–1036, https://doi.org/10.1016/j.ijfatigue.2005.07.050

[10] M. F. R. Zwicker, M. Moghadam, W. Zhang, C. V. Nielsen, Automotive battery pack manufacturing –a review of battery to tab joining. Journal of Advanced Joining Processes, 1 (**2020**), 100017, https://doi.org/10.1016/j.jajp.2020.100017

[11] R. S. Timsit, (2013), Electrical Contacts: Scientific Fundamentals. In: Wang, Q.J., Chung, YW. (eds) Encyclopedia of Tribology. Springer, Boston, MA. 2013, 3–112, https://doi.org/10.1007/978-0-387-92897-5_429

[12] A. Das, D. Li, D. Williams, D. Greenwood, Joining Technologies for Automotive Battery Systems Manufacturing, World Electric Vehicle Journal, 9 (**2018**) 2, 1–13, https://doi.org/10.3390/wevj9020022

[13] S. Lee, T. H. Kim , S. J. Hu, W. W. Cai, J. A. Abell. Joining technologies for automotive lithium-ion battery manufacturing - a review, ASME 2010 International Manufacturing Science and Engineering Conference, 1 (2010), 541–549, https://doi.org/10.1115/MSEC2010-34168

[14] M. J. Brand, P. A. Schmidt, M. F. Zaeh, A. Jossen, Welding techniques for battery cells and resulting electrical contact resistances, Journal of Energy Storage, 1 (**2015**), 7–14, https://doi.org/10.1016/j.est.2015.04.001

[15] J. Helm, A. Schulz, A. Olowinsky, A. Dohrn, R. Poprawe, Laser welding of laser-structured copper connectors for battery applications and power electronics, Welding in the world, 64 (**2020**), 611–622, https://doi.org/10.1007/s40194-020-00849-8

[16] J. Helm, I. Dietz von Bayer, A. Olowinsky, A. Gillner, Influence of the surface properties of the connector material on the reliable and reproducible contacting of battery cells with a laser beam welding process, Welding in the world, 63 (**2019**), 1221–1228, https://doi.org/10.1007/s40194-019-00727-y

[17] A. Das, T. R. Ashwin, A. Barai, Modelling and characterisation of ultrasonic joints for Li-ion batteries to evaluate the impact on electri-

cal resistance and temperature raise, Journal of Energy Storage, 22 (**2019**), 239–248, https://doi.org/10.1016/j.est.2019.02.017

[18] M. E. McGovern, T. J. Rinker, R. C. Sekol, Assessment of ultrasonic welds using pulsed infrared thermography, Journal of Non-destructive Diagnostics and Prognostics of Engineering Systems, 2 (**2019**) 1, 1–9, https://doi.org/10.1115/1.4042260

[19] J. P. M. Pragana, R. J. S. Baptista, I. M. F. Bragança, C. M. A. Silva, L. M. Alves, P. A. F. Martins, Manufacturing hybrid busbars through joining by forming, Journal of Material Processing Technology, 279 (**2020**), 116574, https://doi.org/10.1016/j.jmatprotec.2019.116574

[20] O. Mypati, D. Mishra, S. Sahu, S. K. Pal, P. Srirangam, A study on electrical and electrochemical characteristics of friction stir welded lithium-ion battery tabs for electric vehicles, Journal of Electronic Materials, 49 (2020), 72–87, https://doi.org/10.1007/s11664-019-07711-8

[21] F. Lambiase, F. Balle, L. A. Blaga, F. Liu, S. T. Amancio-Filho, Friction-based processes for hybrid multi-material joining, Composite Structures, 266 (**2021**), 113828, https://doi.org/10.1016/j.compstruct.2021.113828

[22] N. Nguyen, D. Kim, H. Y. Kim, Assessment of the failure load for an AA6061-T6 friction stir spot welding joint. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 225 (**2011**) 1746–1756, https://doi.org/10.1177/0954405411405911

[23] M. M. El-Sayed, A. Y. Shash, M. Abd-Rabou, M. G. ElSherbiny, Welding and processing of metallic materials by using friction stir technique: A review. Journal of Advanced Joining Processes, 3 (2021), 100059, https://doi.org/10.1016/j.jajp.2021.100059

[24] I. Dinaharan, E. T. Akinlabi, Influence of the tool rotational speed on the microstructure and joint strength of friction-stir spot-welded pure copper, Materiali in tehnologije / Materials and technology, 50 (**2016**) 5, 791–796, https://doi:10.17222/mit.2015.301

[25] T. Sapanathan, N. J. Mena, I. Sabirov, M. A. Monclús, J. M. M. Aldareguía, P. Xia, L. Zhao, A. Simar, A new physical simulation tool to predict the interface of dissimilar aluminum to steel welds performed by friction melt bonding, Journal of Materials Science & Technology, 35 (**2019**), 2048–2057, https://doi.org/10.1016/j.jmst.2019.05.004

[26] N. J. Mena, P. J. Jacques, L. Dinga, N. Gauquelin, D. Schryvers, H. Idrissi, F. Delannay, A. Simar, Enhancement of toughness of Al-to-steel Friction Melt Bonded welds via metallic interlayers, Materials Science & Engineering A, 740–741 (**2019**), 274–284, https://doi.org/10.1016/j.msea.2018.10.101

[27] Y. Chen, H. Deng, H. Liu, T. Zhang, S. Li, S. Wang, C. Chen, A novel strategy for the reliable joining of Ti6Al4V/2A12-T4 dissimilar alloys via friction melt-bonded spot welding, Materials Letters, 253 (**2019**), 306–309, https://doi.org/10.1016/j.matlet.2019.06.089

[28] S. Crucifix, C. V. D. Rest, N. J. Mena, P. J. Jacques, A. Simar, Modelling thermal cycles and intermetallic growth during friction melt bonding of ULC steel to aluminium alloy 2024-T3,

[29] Science and Technology of Welding and Joining, 20 (**2015**), 319–324, https://doi.org/10.1179/1362171815Y.0000000020

[30] D. Gera, B. Fu, F. H. R. Uceu, Suhuddin, A. Plaine, N. Alcantara, J. F. dos Santos, B. Klusemann, Microstructure, mechanical and functional properties of refill friction stir spot welds on multilayered aluminum foils for battery application, Journal of Materials Research and Technology, 13 (**2021**), 2272–2286, https://doi.org/10.1016/j.jmrt.2021.06.017.

[31] A. Kubit, R. Kluz, T. Trzepieciński, D.Wydrzyński, W. Bochnowski, Analysis of the mechanical properties and of micrographs of refill friction stir spot welded 7075-T6 aluminium sheets. Achieves of Civil and Mechanical Engineering, 8 (**2018**), 235–244, https://doi.org/10.1016/j.acme.2017.07.005