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AGT – Aligned Graphite Technology

Demonstration for use in electric vehicles

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Zusammenfassung

Im Rahmen des Projekts "AGT - Aligned Graphite Technology - Demonstration for use in electric vehicles" (AGT - Ausgerichtete Graphit-Technologie - Demonstration für den Einsatz in Elektrofahrzeugen) wollte Battrion die technologische Bereitschaft und die Vorteile von AGT für eine breite Anwendung in Nutzfahrzeugen und Fahrzeugen des öffentlichen Nahverkehrs aufzeigen, indem es schnellladende VDA-Batteriemodule baute und diese in einer entsprechenden Umgebung testete. Dieses Projekt wurde in Zusammenarbeit mit einem Zellhersteller mit Sitz in Singapur durchgeführt.

Zu Beginn des Projekts stellte Battrion umfangreiche Ressourcen für die Prozessentwicklung bereit, um drei (3) verschiedene Graphitmaterialsysteme zu entwickeln, wobei ein Graphittyp von seinem Partner, dem Zellhersteller, und zwei Graphitvarianten von Battrion selbst vorgeschlagen wurden. Das Prozessentwicklungsteam stellte nicht ausgerichtete, konventionelle Elektroden "REG" und mit Battrion's Technologie ausgerichteten negativen Elektroden "AGT" erfolgreich her und charakterisierte diese. Das Hauptaugenmerk des Projekts lag auf dem Einsatz einer bestimmten Graphitvariante, einem weniger prozessiertem Naturgraphit, der im Battrion-Materialsystem als RM0662 bezeichnet wird. Dieser spezielle Graphittyp ist für EV-Anwendungen unkonventionell, bietet aber Vorteile wie deutlich geringere Kosten und einen kleineren CO_2-Fußabdruck im Vergleich zu den anderen im Projekt untersuchten Graphitvarianten, die den EV-Standards näherkommen bzw. in EVs verwendet werden. Aufgrund des beobachteten komplexen rheologischen Verhaltens wurde die Verwendung dieses Graphittyps jedoch eingestellt. Es wurde ein alternatives Material identifiziert, woraufhin die Projektarbeit wieder aufgenommen wurde.

In der zentralen Phase des Projekts lag der Schwerpunkt auf den von Battrion vorgeschlagenen Graphitvarianten, nämlich den Materialien RM0730 und RM0731. Battrion fertigte und lieferte nicht ausgerichtete "REG" und ausgerichtete Elektroden mit AGT aus diesen Materialsystemen. Nach Erhalt stellte der Zellhersteller Knopfzellen und grossformatige EV-Zellen her und charakterisierte diese. Bedauerlicherweise blieben die ersten Ergebnisse der Zellen deutlich hinter den Erwartungen zurück und stimmten nicht mit den internen Ergebnissen von Battrion aus kleineren Zellen überein.

Battrion und der Zellhersteller identifizierten einen Performance-Unterschied bei den jeweiligen regulären, d.h. nicht ausgerichteten Elektroden, die Battrion und der Zellhersteller unabhängig voneinander hergestellt hatten. Es wurde beschlossen, dass zuerst eine Leistungsparität bei den regulären Elektroden erzielt werden muss, bevor ausgerichtete Elektroden untersucht werden. Nachfolgende Zelltests bestätigten den Unterschied, insbesondere, da die regulären Anoden des Zellherstellers eine bessere Zykluslebensdauer und Ladeleistung aufwiesen als die regulären Anoden von Battrion. Eine eingehende Analyse ergab, dass beide Unternehmen zwar denselben Graphit verwendet hatten, aber unterschiedliche Dichten und Bindemittel eingesetzt worden waren. Insbesondere wurde festgestellt, dass die Dichte der Elektrode beim Zellhersteller niedriger war (und nicht den vereinbarten Spezifikationen entsprach), was sich in einer höheren Porosität der Elektrode und einer besseren Ladeleistung niederschlug. Für eine Fortsetzung des Projekts war es von entscheidender Bedeutung, die exakt gleichen Materialien für die Paste zu verwenden wie der Zellpartner in Singapur. Diese Forderung stiess jedoch aufgrund von Bedenken hinsichtlich des geistigen Eigentums auf Widerstand, so dass Battrion trotz mehrerer Versuche keine ähnliche Anoden-Performance erzielen konnte. Die einzige praktikable Option für die Fortführung des Projekts war die Implementierung der Aligned Graphite® Technologie von Battrion im Forschungs- und Entwicklungslabor des Zellherstellers in Singapur. Dadurch hätten sowohl "REG" als auch "AGT" Anoden unter denselben Bedingungen und aus derselben Paste hergestellt werden können.

Bedauerlicherweise wurde das Projekt aufgrund der Schließung von Battrion gestoppt. Battrion musste bei seiner letzten Finanzierungsrunde im Juli Rückschläge hinnehmen. Infolgedessen sah sich das Unternehmen gezwungen, ein Insolvenzverfahren einzuleiten. Am 25. August 2023 wurde der Insolvenzantrag vom Gericht Luzern formell anerkannt.

Résumé

Dans le cadre du projet "AGT - Aligned Graphite Technology - Demonstration for use in electric vehicles" (Technologie de graphite alignée - Démonstration pour une utilisation dans les véhicules électriques), Battrion a voulu démontrer l'état de préparation technologique et les avantages de l'AGT pour une application à grande échelle dans les véhicules commerciaux et les véhicules de transport public, en construisant des modules de batterie VDA à charge rapide et en les testant dans un environnement approprié. Ce projet a été mené en collaboration avec un fabricant de cellules dont le siège social se trouve à Singapour.

Au début du projet, Battrion a consacré d'importantes ressources au développement de processus afin de mettre au point trois (3) systèmes différents de matériaux en graphite, dont un type de graphite proposé par son partenaire, le fabricant de cellules, et deux variantes de graphite proposées par Battrion lui-même. L'équipe de développement des processus a réussi à fabriquer et à caractériser des électrodes conventionnelles non alignées "REG" et des électrodes négatives alignées "AGT" avec la technologie de Battrion. Le projet s'est concentré sur l'utilisation d'une variante particulière de graphite, un graphite naturel moins traité, appelé RM0662 dans le système de matériaux Battrion. Ce type particulier de graphite n'est pas conventionnel pour les applications EV, mais il présente des avantages tels qu'un coût nettement inférieur et une empreinte carbone plus faible par rapport aux autres variantes de graphite étudiées dans le projet, qui se rapprochent des normes EV ou qui sont utilisées dans les EV. Cependant, en raison du comportement rhéologique complexe observé, l'utilisation de ce type de graphite a été abandonnée. Un matériau alternatif a été identifié, à la suite de quoi le projet a été relancé.

Au cours de la phase centrale du projet, l'accent a été mis sur les variantes de graphite proposées par Battrion, à savoir les matériaux RM0730 et RM0731. Battrion a fabriqué et fourni des électrodes "REG" non alignées et des électrodes alignées avec AGT à partir de ces systèmes de matériaux. Après réception, le fabricant de piles a fabriqué et caractérisé des piles boutons et des piles EV de grand format. Malheureusement, les premiers résultats des cellules étaient nettement inférieurs aux attentes et ne correspondaient pas aux résultats internes de Battrion obtenus à partir de cellules plus petites.

Battrion et le fabricant de cellules ont identifié une différence de performance entre les électrodes régulières, c'est-à-dire non alignées, que Battrion et le fabricant de cellules avaient fabriquées indépendamment, et ont décidé qu'il fallait d'abord obtenir une parité de performance avec les électrodes régulières avant d'étudier les électrodes alignées. Les tests de cellules ultérieurs ont confirmé la différence, notamment parce que les anodes régulières du fabricant de cellules présentaient une meilleure durée de vie du cycle et une meilleure performance de charge que les anodes régulières de Battrion. Une analyse approfondie a révélé que, bien que les deux entreprises aient utilisé le même graphite, des densités et des liants différents avaient été utilisés. Il a notamment été constaté que la densité de l'électrode était plus faible chez le fabricant de cellules (et ne correspondait pas aux spécifications convenues), ce qui se traduisait par une porosité plus élevée de l'électrode et une meilleure performance de charge. Pour que le projet puisse se poursuivre, il était essentiel d'utiliser exactement les mêmes matériaux pour la pâte que le partenaire cellulaire de Singapour. Cette exigence s'est toutefois heurtée à une résistance

en raison de préoccupations liées à la propriété intellectuelle, de sorte que Battrion n'a pas pu obtenir des performances d'anode similaires malgré plusieurs essais.

Die einzige praktikable Option für die Fortführung des Projekts war die Implementierung der Aligned Graphite® Technologie von Battrion im Forschungs- und Entwicklungslabor des Zellherstellers in Singapur. Dadurch hätten sowohl “REG“ als auch “AGT“ Anoden unter denselben Bedingungen und aus derselben Paste hergestellt werden können.
Bedauerlicherweise wurde das Projekt aufgrund der Schließung von Battrion gestoppt. Battrion musste bei seiner letzten Finanzierungsrunde im Juli Rückschläge hinnehmen. Infolgedessen sah sich das Unternehmen gezwungen, ein Insolvenzverfahren einzuleiten. Am 25. August 2023 wurde der Insolvenzantrag vom Gericht Luzern formell anerkannt.

Summary

In the project “*AGT – Aligned Graphite Technology- Demonstration for use in electric vehicles*” Battrion’s objective was to showcase the technological readiness and benefits of AGT for widespread adoption in commercial and public transport vehicles by building fast-charging VDA battery modules and testing them in a relevant environment. This project was executed in partnership with a cell manufacturer, headquartered in Singapore.

At the project inception, Battrion allocated substantial process development resources to develop three (3) different graphite material systems, with one graphite type proposed by its cell manufacturer partner and two graphite variants proposed by Battrion itself. The process development team successfully synthesized and characterized conventional electrodes "REG" and aligned negative electrodes “AGT” the latter featuring Battrion Aligned Graphite® technology. The primary project focus centered on employing a specific graphite variant which was a less processed natural graphite, identified as RM0662 in Battrion material system. This particular graphite type is unconventional for EV applications but would offer advantages such as significantly reduced costs and a smaller CO_2-footprint compared to the other graphite variants explored in the project which are closer to the EV standards or are actually being utilized for EVs. However, due to observed complex rheological behaviors, the utilization of this less processed graphite type was ceased. An alternative material was identified, prompting project work to resume.

During the project's central phase, focus shifted to the other Battrion's proposed graphite variants, namely RM0730 and RM0731 materials. Battrion manufactured and delivered regular and aligned electrodes using these material systems. Upon receipt, the cell manufacturer fabricated and assessed coin cells and large-format EV cells. Regrettably, initial cell results fell significantly short of expectations and were inconsistent with Battrion's in-house results from smaller-scale cells.

Recognizing the disparity in performance between the respective regular electrodes, Battrion and the cell partner decided that achieving similar cell results from regular electrodes manufactured by their respective facilities was of paramount importance. A meaningful application of AGT hinged on this performance parity, which was absent due to the performance gap. Subsequent cell tests confirmed this gap, with the cell manufacturer's regular anodes demonstrating better cycle life and charge performance than those of Battrion's regular anodes. An in-depth analysis revealed that while both companies had used the same graphite, differing densities and binders were employed. In particular, the cell partner’s electrode’s density was discovered to be lower (not satisfying the agreed specifications, but thus translating in higher electrode porosity and better charge performance). It became vital for Battrion to start

from the same materials as the cell partner in Singapore. However, this request was met with resistance due to intellectual property concerns, preventing Battrion from achieving similar anode performance despite multiple trials.

The sole viable option for the project's continuation was implementing Battrion's Aligned Graphite® Technology at the cell partners' Singapore R&D lab. This would have enabled both regular and aligned anodes to be produced under the same conditions and from the same slurry.

Regrettably, the project was halted due to Battrion business closing. Battrion faced setbacks during its most recent financing round in July, culminating in an unfavorable outcome. Consequently, the company was compelled to initiate insolvency proceedings. On August 25, 2023, the insolvency filing was formally acknowledged by Luzern Court.

Contents

Abbreviations

AGT = Aligned Graphite Technology

EV = Electric Vehicle

ICE = Internal Combustion Engines

LIB = Lithium-Ion Battery

MDU = Magnetic Dryer Unit

REG = Regular (Non-aligned)

SFOE = Swiss Federal Office of Energy

VDA = Verband der Automobilindustrie (German Association of the Automotive Industry)

1. Introduction

This document serves as final report related to the project “AGT – Aligned Graphite Technology – Demonstration für Einsatz in e-Fahrzeugen” that Battrion started in Jan 2022 with the support of Swiss Federal Office of Energy. In the context of this project, Battrion goal was to build and certify a VDA module featuring AGT technology, as proof of concept for subsequent implementation in the transportation industry.

1.1 Meet Battrion

Established in 2015 as a spin-off company from ETH University (Zurich), Battrion AG is a privately owned company incorporated in Luzern. Today, Battrion team includes 15 people and operates a facility in Dübendorf, Zurich, including 660 m^2 office and laboratory space and 180 m^2 production space.

Battrion technology has been developed around the research activity of its founders, who transformed the root-cause of performance and lifetime limitations of lithium-ion batteries in a unique business opportunity. More precisely, the fast charging performance of modern lithium ion batteries is hampered by the negative electrode (anode) microstructure. Battrion designs, builds and markets its innovative anode fabrication technology – the *Aligned Graphite® Technology* (*AGT)* – that modifies the orientation of the anode graphite particles and reduce anode resistance. Since the development of AGT, Battrion has been working with many relevant stakeholders in the battery field, including battery coating lines manufacturers, battery suppliers, automotive OEMs.

1.2 Background information and current situation

1.2.1 A primer on Batteries

Based on their utilization, batteries are classified as **primary batteries** or **secondary batteries**. Primary batteries are designed to be used until exhausted, then discarded. In contrast, secondary batteries can have their chemical reactions reversed by applying electric current to the cell. This regenerates the original chemical reactants, so these batteries can be recharged multiple times. **Lithium-Ion Batteries (LIB)** are the most popular example of secondary batteries. Since their introduction in the late 1990s they became market leader due higher energy density, which translates in lower weight and smaller volume for any given application (**Figure 1**); improved safety and resistance to overcharge; fast charge and discharge performance.

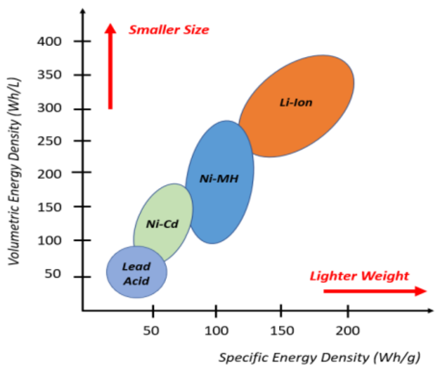

Figure 1: Lithium Ion batteries compared to other secondary batteries

Today, due to these technical reasons and the significant cost reduction achieved in the last years (made possible by large investments in manufacturing plants which enabled economies of scale), LIBs are the highest performing batteries on the market today and are considered the key energy storage technology of the 21st century. They are found in countless applications, such as mobile phones, tablets, laptops, cordless power tools, drones, e-bikes and the strongly growing electric vehicle (EV) segment.

The most important performance aspects of batteries are energy density and power density, as well as charging/discharging speed. From a battery manufacturer's perspective these parameters can be traded against each other: batteries can either be designed to hold a lot of charge (high energy density) but take and release that charge slowly (low power density), or they can be designed to be fast to charge and discharge at the cost of lower capacity. This trade-off is governed by the fundamental principles that govern the physics of LIBs. More precisely, fast-charging of today's LIBs is limited by the negative electrode.

Over 95% of all lithium ion batteries use graphite as active material in the negative electrode. However, the structure of the graphite electrodes utilized in today's LIBs is characterized by long and tortuous transport paths which severely limits the cell charging and discharging speed. The more flake-shape is the graphite, the longer is the lithium ion transport path, the slower is the battery charging and discharging performance (**Figure 1**)

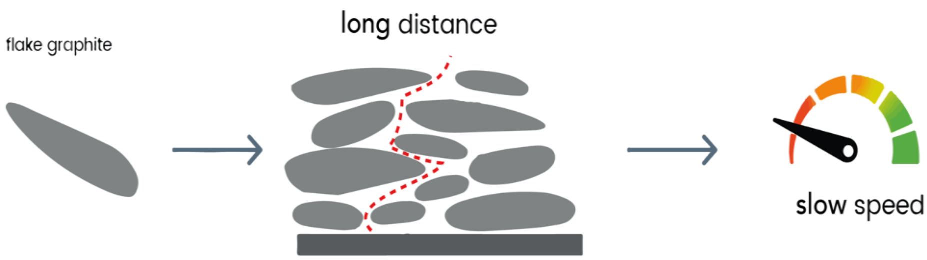

Figure 1: tortuous charge path through a conventional anode with random arrangement of graphite flakes

To overcome this issue, graphite utilized today in the EV batteries tend to be more spherical and is obtained through a very energy-intensive and wasteful industrial process called spheronization. During the production of graphite for LIBs from natural sources, ca. 50% of the raw material is lost, leaving behind huge environmental footprint (**Figure 2**). LIB performance is also a major limitation for the adoption of new key technologies such as electric vehicles (EVs).

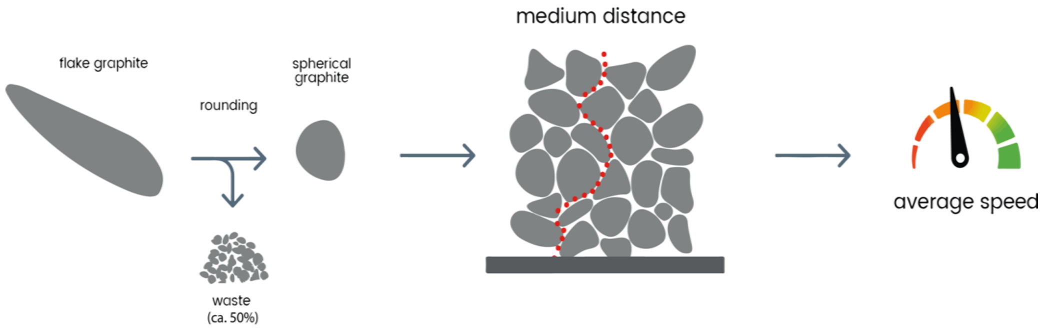

Figure 2: Use of spherical graphite particles to reduce the lithium-ions travelling distance through the graphite layer

On the one hand EVs offer the possibility for sustainable transportation, but on the other hand is a cause for concern (range anxiety) and limited adoption (due to slow charging). Only by matching or surpassing the criteria set forth by ICE powered cars in terms of safety, costs, user convenience and performance will EVs make a difference in the transportation landscape and can thus help achieve the goal of a climate neutral economy.

1.3 Purpose of the project

Battrion has developed and patented the Aligned Graphite® Technology (AGT) – an efficient and scalable new platform technology for the production of high performing electrodes that are integrated into LIB cells. The technology is able to control the microscopic orientation of the graphite particles in the negative electrodes. This minimizes the distance that lithium ions must travel during charging or discharging, increases battery cells charging and discharging speed and reduces heat generation while retaining energy density and life time (**Figure 3**).

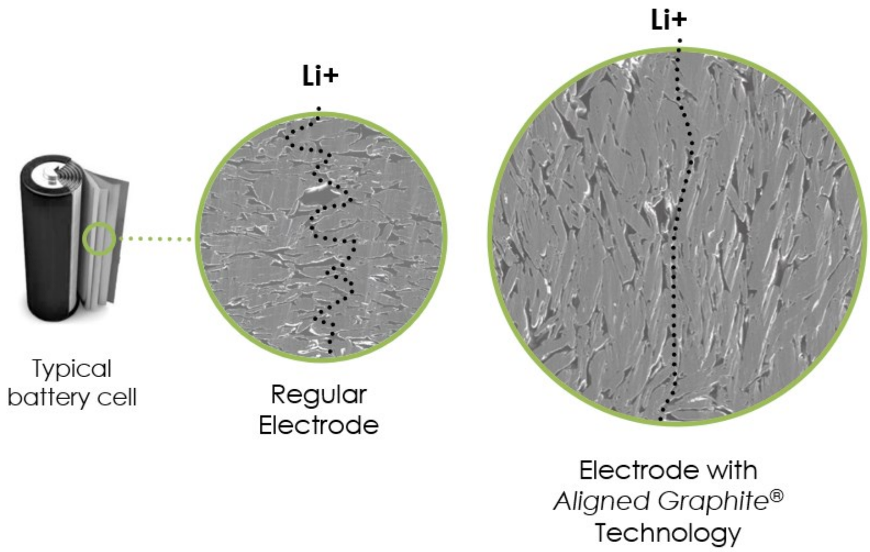

Figure 3: Graphite particles aligned in a AGT electrode (SEM pictures)

By using flake graphite for the production of LIBs, Battrion's technology brings costs down and allows for a reduction in the environmental impact of cell production that relies on the use of spherical graphite. Furthermore, Battrion's technology is fully compatible with current LIB manufacturing processes, aqueous and non-aqueous binder systems, as well as next generation materials such as carbon/silicon composites. The impact of the aligned graphite technology on cell performance include higher charging rates, lower costs, and longer lifetime.

With this project, Battrion and its cell partner aimed at demonstrating the readiness of Aligned Graphite® Technology for use in battery pack of electric commercial and public transportation vehicles, such as E-Truck and E-Bus.

1.4 Objectives

More specifically, Battrion's objective was to build fast-charging VDA (*Verband des Automobilindustrie*) battery modules and showcase the readiness of its technology for widespread adoption in commercial and public transport vehicles.

To achieve this goal, a number of tasks were planned, namely: *(1) Raw Materials Selection on the Anode Side; (2) Anode Process Development and Manufacturing; (3) Cell Construction and Testing; (4) Module Construction and Safety Certification; (5) Battery Pack Construction and Safety Certification.*

From a production perspective Battrion role was to manufacture all regular (REG) and aligned (AGT) anodes required throughout the project (conceptually, from the cell development until the VDA certification stage).

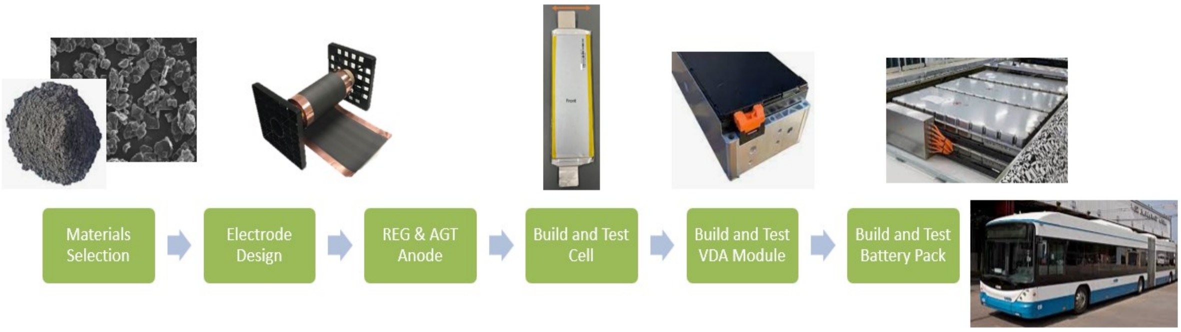

Figure 4: main tasks from material selection to battery pack build and test

2. Description of facility

Graphite flakes alignment within the negative electrode is achieved by the application of a force field as part of roll-to-roll electrode manufacturing process that promote the formation of an aligned microstructure of the coating constituents. Battrion particularly aims at enabling fast, permanent and high yield alignment and to this goal has developed the AGT platform (

Figure 5). The core part is a piece of equipment that produces a special magnetic field to allow alignment of the graphite particles within the slurry. This piece is called "Alignment Unit" (AU) and is placed inside the dryers of the coating line. The number of alignment units required depends on several properties, such as: coating line speed, drying parameters, slurry viscosity.

Figure 5: Battrion's inhouse coating line at the top, magnetic AU at the bottom

Looking at the entire manufacturing process, Lithium-ion cell production can be divided into three main stages: electrode manufacturing, cell assembly, and cell finishing. While Battrion took care of the negative electrode production from the slurry manufacturing to the calendering (slurry, coating, calendering or pressing), the remainder of the processes were planned to take place at the production facility of our cell partner, namely: cathode slurry preparation, cathode coating, cathode calendering, cell assembly, cell finishing (

Figure 6) and subsequent assembly of cells into modules and modules into battery packs.

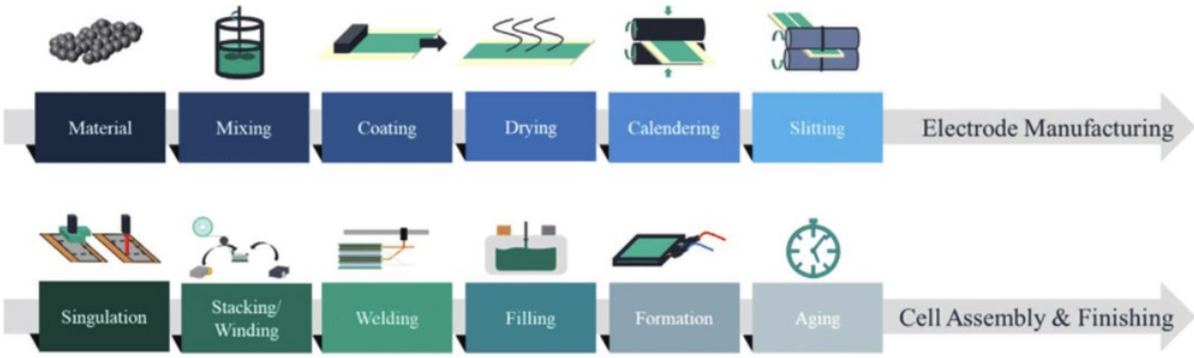

Figure 6: Overview of the production processes of a Lithium-Ion cell

3. Procedures and methodology

3.1 Electrode manufacturing and characterization

Negative electrode (also referred to as anodes or webs) were fabricated at Battrion using standard operating procedures to ensure repeatability. Generally speaking, the electrode manufacturing process involves several steps including (i) the mixing of different components to produce a slurry that is (ii) coated onto a Cu current collector and (iii) dried. The web is then (iv) pressed and (v) characterized (**Figure 7**).

Figure 7: Anode Fabrication Process at Battrion

Hereafter, details about how these steps are implemented at Battrion are disclosed:

i) *Mixing and slurry preparation:* an anode slurry is composed of several materials that can be graphite, viscosity modifier (carboxyl methyl cellulose, CMC), binder (styrene butadiene rubber, SBR). These components are mixed in a planetary mixer following a precise recipe. The CMC and SBR amounts are iteratively selected and adjusted to typically obtained a shear thinning type of rheology and good coating adhesion to the current collector. These development steps must be performed for each graphite type. The slurry production step is completed with its characterization, that is the evaluation of its rheology, total solid contents, dynamic viscosity. These metrics are used as quality gate prior to proceeding to the following step, i.e. the coating and drying.

ii) *Slurry coating and drying*: the produced slurry is coated onto a Cu foil using a reverse comma coater technology. At this stage Several process parameters such as coating loading and oven temperature requires to be adjusted. Following the slurry application Battrion aligned technology can be enabled or disabled to produce an AGT or REG coating, respectively. The coated film is then dried by passing through a series of ovens. A second pass is required to coat the second side of the electrode.

iii) *Pressing:* The coated film is then pressed to achieve the desired coating density. Note that in case of a new material it is required to construct a calibration figure that relates the coating density to the actual material spring back. The spring back corresponds to the material decompression of the coated film typically measured 24 hours post pressing.

iv) *Characterization:* As last step, the produced coating is characterized using standardized methods. Among these the peel force relates to the adhesion quality of the coating onto the current collector and the McMullin number relates to the coating tortuosity. The latter parameter is a key metric to evaluate alignment efficiency using Battrion's align graphite technology.

The above steps were applied to several graphite materials, each of them identified with a specific identification number in Battrion's material system: RM0662 (less-processed graphite), RM030 (artificial graphite, Chinese Supplier), RM0731 (artificial graphite, US Supplier), RM0742 (artificial graphite, Chinese Supplier). These graphite's were selected based on foreseen performance potential, e.g., cycling stability and alignment performance. For each graphite, multiple AGT and REG electrodes were produced and the most promising were shipped to the cell manufacturer facility. To facilitate comparison from a cell electrochemical point of view, the slurry composition among the different graphite types was similar, in terms of type of CMC and binder for each graphite.

3.2 Cell manufacturing and performance assessment

Cell Build: these activities were carried out at the production facility of our cell partner. Large capacity cells (41Ah) are built with AGT and REG anode (all other parameters being equal). Cell consisted of 31/32 cathode/anode layers, with this geometry: 240 mm x 116 mm x 11.6 mm (Length x Width x Thickness). With the exception of the total energy (41Ah instead of 57Ah) the configuration chosen by the cell partner was representative of future VDA cell (e.g. mass loading / number of electrode layers and outer dimensions).

Cells Testing: after build, cells were subject to several tests, namely: Standard Capacity Testing, Direct current internal resistance (DCIR), Charge Rate Map, Quick Charge life at different Current Rates (1C/2C/3C), Discharge Rate Map.

Figure 8 shows the VDA cell jointly designed with the cell manufacturer for this project.

Figure 9 shows a common VDA Battery modules.

Due to confidentiality reasons, specifications of the VDA cell and battery modules cannot be disclosed in this report.

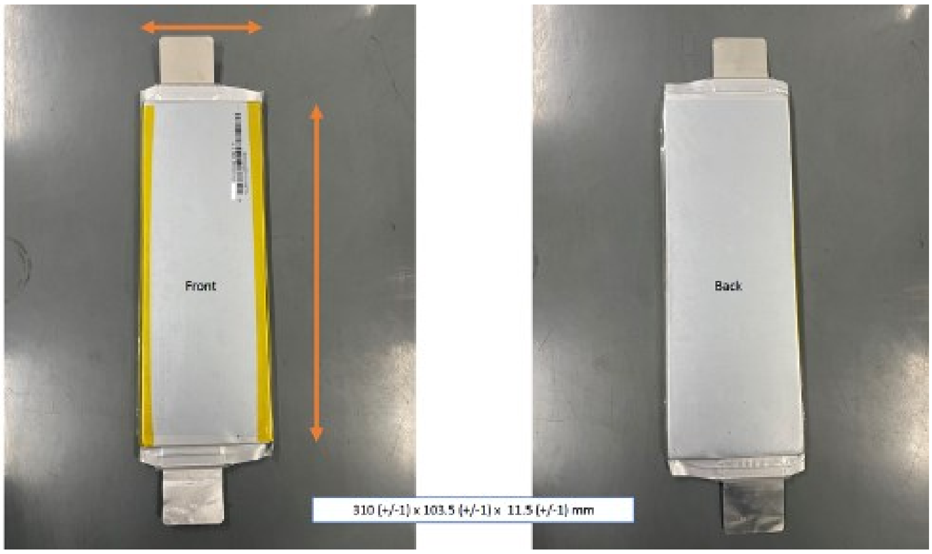

Figure 8: VDA Cell manufactured by the Cell Partner

Figure 9: VDA battery module

4. Activities and results

4.1 Project activities

Starting from January 2022, Battrion has focused its project efforts on scouting and selecting the cell manufacturing and testing partner (**Jan-Feb 2022**); pre-testing, selecting and sourcing suitable raw materials (**Mar-Apr 2022**). Based on current state of the art and Battrion's know-how at the project start, one artificial graphite materials (RM0730) and one natural / less-processed graphite material (RM0662) were selected by Battrion for anode manufacturing. Similarly, the cell manufacturer proposed an artificial graphite material extensively tested at their facility (RM0742). However, despite a significant level of effort, the development of a coating process for RM0662 (natural graphite) did not achieve the required quality and in July 2022 a decision was taken to put on hold any further development effort on RM0662, in order to focus on the other more promising alternatives. Thanks to the work carried out within another project, Battrion had the opportunity to evaluate another artificial graphite well known for long cycle life and competitive performance. Hence, in **Jul-22**, It was decided to replace RM0662 with this material, RM0731.

Following the anode development and manufacturing process described in Par. 3 twin-web consisting of REG and AGT electrodes were manufactured and shipped to cell partner until **Aug-22**. Five (5) REG + five (5) AGT large cells were made for each material, using a portion of the shipped electrodes. This first set of cells were tested based on a commonly agreed protocol and results presented and discussed with Battrion at the end of **Oct-22.**

Notably, in the same month Battrion and its cell partner were able to identify a potential partner (Swiss electric bus manufacturer) to test the technology in an electric mobility application. End Oct-22, Battrion, its cell partner and the bus manufacturer met at the bus manufacturer's premises to discuss the opportunities that Battrion technology could unlock in the public transportation space. Further discussions with the bus manufacturer were postponed to until after the VDA module completion.

The cell manufacturer was in charge of sourcing and shipping its material of choice RM0742. Due to logistics challenges and approval required from Chinese authorities (graphite for battery applications is an export-controlled material) the arrival of RM0742 at Battrion premises took much longer than anticipated (this material reached Battrion premises in Oct-22). By End **Nov-22** Battrion had successfully developed its first slurries and set of electrodes with this material.

After delivering the interim report to SFOE in **Dec-22**, Battrion received a sample of electrode coated by the partner (identified as WB0564), for characterization in Battrion's Labs. The request of this material was initiated by Battrion to ensure that the regular electrodes coated with the same graphite at both parties would have led to similar cell performance.

In **Jan-23**, Battrion shipped to a regular electrode (identified as WB0561) made with the same graphite (RM0742) for cell build to the cell partner. Cells were built in **Feb-23** and put under test between **Mar-23 and Jun-23**. This second round of tests showed that cells built with the partner electrode WB0564 outperformed cells built with Battrion electrode WB0561, both in terms of charge rate and cycle life.

The results collected from these tests triggered an investigation which confirmed that the two electrodes had substantial differences (in terms of chemistries and coating densities). The cell partner's electrode had a lower density than Battrion's electrode (1.52 g/ml instead of 1.65 g/ml), thus explaining the lower porosity and better ionic resistance. From a chemical perspective, the partner's electrode was developed with a PAA-CMC based slurry rather than an SBR-CMC based slurry and contained carbon black (1%wt). Carbon black (CB) is a commonly used conductive agent for battery electrodes, and does also find its application outside the battery industry to strengthen rubber in tires or as a pigment and UV stabilizer.

Battrion agreed to develop another slurry with the same level of carbon black found in the partner's slurry and targeted the lower density of the partner's electrode. The resulting electrode (WB0613) was ready to ship as of **Jun-23,** with the purpose of manufacturing and testing a new set of cells. However, after internal characterization, the shipment was aborted. Electrode WB0613 had similar loading and density of electrode WB0564, but the internal ionic resistance of this electrode was still significantly higher than the one of the partner's electrode WB0564. This could be deducted by comparing the MacMullin number of all electrodes. A new cell build-and-test activity would have confirmed the latest results. A summary of these characterization activities is presented in **Table 1**.

Given that the coating densities and degree of divergence were similar, Battrion attributed the difference in ionic resistance to the different chemistries (PAA vs SBR based slurry) and re-iterated its request to the partner to provide PAA / CMC / CB in order to replicate the partner's slurry at Battrion premises. Due to IP concerns, this request met strong resistance. The only viable option to move the project forward was to build and deploy customized alignment units at the partner's R&D line in Singapore. While this option was discussed with the partner, in parallel Battrion executed several process development runs at its facility in Dubendorf to optimize the alignment process for this material. These runs were executed using up to twelve (12) alignment units (3 sets x 4 alignment units with different disposition of magnets that create magnetic fields with different intensities) under different conditions (drying parameters, distance of the AU from the electrode, etc..).

Regrettably, the project was halted at this point due to the discontinuation of Battrion business.

	Received from Durapower in Dec-22	Shipped to Durapower in Jan-23	Ready to ship to Durapower Jun-23
Characteristic	**Durapower Sample Material ZH95C ID: WB0564**	**Battrion REG Material: ZH95C ID: WB0561-P16**	**Battrion REG Material: ZH95C ID: WB0613-P13**
Composition	**Gr / PAA / CMC / CB: 95.8 / 2.0 / 1.2 / 1.0**	**Gr / SBR / CMC / CB: 97.0 / 2.0 / 1.0 / 0.0**	**Gr / SBR / CMC / CB: 96.0 / 2.0 / 1.0 / 1.0**
Loading (mg/cm^2)	11.55	11.53	11.78
Density (g/mL)	**1.52**	**1.65**	**1.57**
Peel force (mN/mm)	3.6	2.2	9.0
DD-XRD (*) uncompressed web (-)	19.3	-	17.8
DD-XRD (*) pressed web (-)	17.1	15.9	15.9
MacMullin Number, Nm (-)	**15.6**	**25.1**	**23.2**

(*) DD means degree of divergence. It's a metric related to graphite microstructure arrangement in the coating. Low DD values signify "random" arrangement of graphite particles; high DD values signify presence of a preferential orientation of graphite particles (e.g., this is the case of AGT webs)

Table 1: Comparison of WB0564, WB0561 and WB0613

4.2 Anode Production and Characterization

A total of four (4) graphite materials were investigated two (2) of which were new to Battrion. At first several process engineering runs were necessary to produce slurry with good coatability properties and further downstream processes needed to be optimized such as drying and calendering. The process development of slurry based on natural graphite (RM0662) required more efforts to reach good overall process characteristics. The reason for such challenging material was the switch rheology caused by the platelet form of the graphite flake. Despite the identified process challenges that remained to be addressed, the natural graphite RM0662 was found to be a very promising material for the AGT technology, as the McMullin number improvement was found close to 60%. Due to budget and time constraints, Battrion halted the process development with this material in July 2022. As far as the other graphite materials, **Table 2** below provides a summary of the McMullin numbers measured for each REG and AGT electrodes built for cell manufacturing purposes. The % improvement shall be read as a proxy of the fast charge / discharge performance improvement.

Material	McMullin Number REG Anode	McMullin Number Aligned Anode	Improvement(%)
RM0742	29.9	21.1	30.0%
RM0730	26.6	21.3	20.0%
RM0731	40.9	21.4	50.0%

Table 2: McMullin Numbers associated to the 3 materials used by Battrion

In total 16 slurry development runs and 50 process development runs were executed within this project. Most of the slurry development runs were required to understand the challenging rheology of the less processed graphite (RM0662) while most of the process development runs were centered around RM0742 and RM0731 materials. Different parameters need to be defined before starting a process development run, such as type of magnetic fields, drying pattern, type of binders, use of conductive additives, etc. Considering all these parameters, a plethora of possible configurations was defined and explored, ultimately leading to the manufacturing of defect-free, high performing shippable electrodes.

	RM0742	RM0730	RM0731	RM0662	Total
Number of Slurry Development Runs	4	2	2	8	16
Number of Process Development Runs	25	5	18	2	50

4.3 Cell Manufacturing and Testing

In **Sep/Oct 2022** the partner manufactured and tested cells built with AGT & REG anodes provided by Battrion, coated with two materials (RM0730 and RM0731) and cells built with their RM0742 coated anodes (to be used as benchmark). Both in terms of charge rate map and quick charge cycle life, test results did not align to Battrion expectations. 3C/1C quick charge cycle life and discharge rate map were not completed due to poor performance in the preceding testing activity.

This first round of testing triggered investigations around the partner’s electrode coated with RM0742. A second round of testing was conducted between **Mar/Jun 2023**, centered around the comparison between REG RM0742 electrodes coated by Battrion and the partner.

QC cycle life details with this second set of cells demonstrate that the regular cells of the partner out-performed Battrion’s cells. Cells made with the partner’s electrodes shown a better performance, due to the lower density of the electrode and an optimized material system. Tests were stopped when the partner’s cells had accumulated approx. 800 cycles.

5. Outstanding Scope of Work

For sack of completeness, this paragraph outlines the activities that would have been required to bring the project to conclusion.

5.1 Manufacturing of Alignment Units for Cell partner R&D line

The partner hosts two identical small R&D lines in Singapore and China. Battrion and the partner agreed that, to overcome IP concerns, the best course of action was to build and install customized alignment units and produce electrodes starting from slurry materials from the partner's facitlity.
Estimate to Complete, including shipping and installation of Battrion hardware: 6-8 weeks.

5.2 Optimization of REG and AGT anodes at Partner

Process development activities were required to take place at the partner's site, with the goal of preparing both REG and AGT electrodes with RM0742 graphite. The ionic resistance of the REG electrode would be expected to be similar to the partner's standard electrodes used for production; the ionic resistance of the AGT electrode would be expected to be 25-30% lower than the REG electrode's one.
Estimate to complete: 2-3 weeks

5.3 Optimization of AGT anodes at Partner through cell testing

At this point, AGT and REG cells made with RM0742 materials had to be manufactured and tested. Multiple AGT electrodes could have been built and tested at once, in order to select the best parameters for production. *Estimate to complete, including cell testing: 6-8 weeks.*

5.4 Certification of REG and AGT VDA Module

At this point the partner would have produced enough REG and AGT electrode to build and test VDA modules. The cell partner would have provided the required facilities and certification expertise. A clear fast charge performance difference should have been demonstrated at this point.
Estimate to complete, including VDA modules testing: 8-12 weeks.

5.5 Certification of AGT Battery Pack for E-Bus application

At this point, Battery pack based on the E-Bus manufacturer requirements could have been assembled and bench-tested.
Estimate to complete, including Battery Pack testing: 8-12 weeks.

6. Lessons Learned and Conclusion

This project's pivotal takeaways include: (1) AGT technology benefits cell makers when regular electrodes' performance is on par between Battrion and the cell maker; (2) AGT isn't a universal, plug-and-play technology; rather, it demands specific fine-tuning contingent on material system, encompassing slurry composition, drying parameters, and magnetic field type and strength; (3) to prevent IP concerns and ensure, at the same time, identical slurry composition it is recommended that AGT is implemented directly at R&D line of the cells manufacturers; (4) utilizing less-processed graphite necessitates substantial adjustments to achieve rheological compatibility with other graphite types prior to mass production.

In conclusion, Battrion wishes to extend its appreciation to SFOE for the significant interest and economic support provided throughout the project's execution. A comprehensive breakdown of all project expenses can be found in the concluding section of this report.

1. Complete Cell Manufacturing and Testing Activities
2. Optimization of REG anodes at Battrion (to match performance of REG anodes manufactured by Durapower)
3. Optimization of AGT anodes at Battrion (to quantify the benefit of AGT technology)
4. Certification of REG and AGT VDA Module
5. Certification of AGT Battery Pack for E-Bus application: at this point, Battrion and Durapower will be ready to further scale up manufacturing and testing efforts to build a Battery pack based on Hess (the E-Bus manufacturer.