ALBATROSS

Advanced Light-weight BATteRy systems Optimized for fast charging, Safety, and Second-life applications

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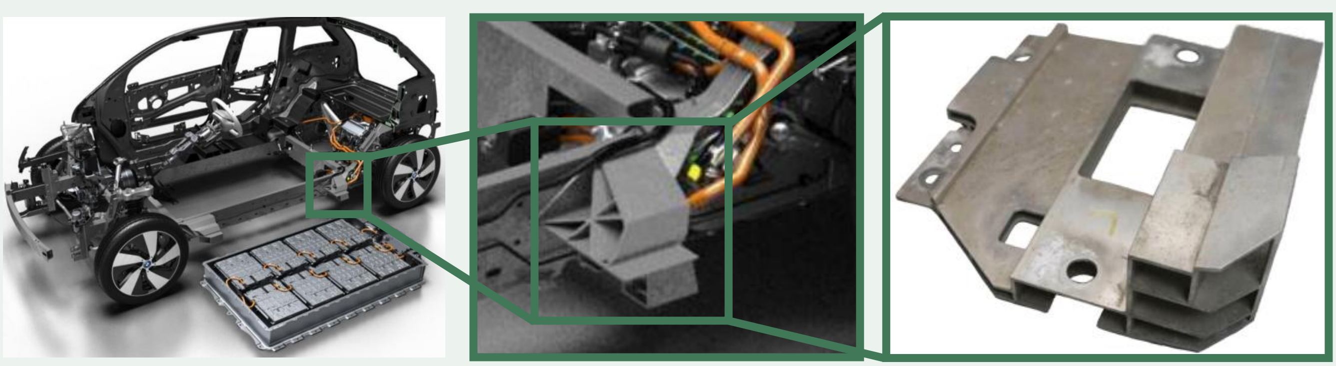
This newsletter aims to provide an in-depth look into the developments of the activities carried out for the different tasks of Work Package (WP) 3. We hope that you enjoy to read and know about them, as much as we have enjoyed working on them!

1. Aluminium Extruded Parts

In recent years, the automotive industry has made a major push to reduce vehicle weight due to the increased regulations and a strong consumer demand for fuel economy. Aluminium has become a material of choice for many applications, and in many cases, it has come to replace high-strength steel in the body structure.

Aluminium is used in an increasing number of applications. While in the 1990s, they were used primarily for bumper systems and door beams, currently steel and aluminium are used side-by-side in the automotive bodies of cars and pickup trucks. Aluminium alloys of the 6000 and 7000 series provide the high strength needed for safety critical, structural, and other types of applications.

Extruded aluminium components are mainly used in crash management, cross car beam, rockers, roof headers, subframes, trim & accessories, and battery box applications. In the BMW i3, aluminium is utilized for the crash protection structure and the one-piece rocker panel reinforcement.



(a) (b) (c)

Figure 1. a) Battery carrier of the BMW i3 with b) the location of the extruded aluminium one-piece rocker panel reinforcement and (c) a photograph of the respective part.

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Aluminium extrusion is a process by which aluminium alloy material is forced through a die with a specific cross-sectional profile. A powerful ram pushes the aluminium through the die, and it emerges from the die opening. When it does, it comes out in the same shape as the die and is pulled out along a runout table. In a summary, extrusion is a modern process in which aluminium billets are heated and pushed through a shaped die opening. The opening can be modified to create different shapes and sizes to fulfil a user's specific needs.

Even though mechanical and thermal requirements have to be fulfilled by the battery tray manufacturer, the main expectations regarding mechanical properties (static, dynamic, crash, and fatigue loads), assembly requirements, corrosion resistance, weight requirements, lifetime, geometrical constraints, and electrical and/or thermal conductivity have to be enlightened by OEM's. In this case, aluminium usage as a sub-component provides plenty of advantages particularly mechanical properties, weight reduction, recyclability, and higher corrosion resistance.

OEM's aim to increase the percentage of aluminium usage due to its 100% recyclability and sustainability.

Due to the nature of the extrusion process, the extrusion process speed is quite important to increase the productivity of serial production. The 6xxx series can provide higher production speed with adequate mechanical properties, whereas 7xxx series which have higher mechanical properties than 6xxx aluminium alloys can also be manufactured by extrusion.

Due to the lower production speed and complexity of the process, the 7xxx series are not commonly preferred for production in the extrusion lines and to be used as a sub-component of automotive parts.

6xxx are generally preferred in extrusion process and although they are relatively soft during extrusion (enabling high exit speeds), they can also be easily heat treated afterwards to gain considerable strength. The heat treatment in question is known as age hardening, and it exploits the most effective hardening mechanism in metals.

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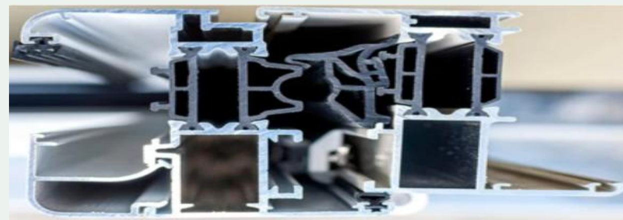
Apart from better extrudability and adequate mechanical properties, as a sub-component application of the aluminium extrusion in the EV battery box production, there are two main material selection criteria for the 6xxx alloy (AlMgSi) wrought alloy:

1. Comparison of the extrudability and yield strength of the extruded AlMgSi alloy

The 6xxx series (AlMgSi) extruded aluminium alloys that are widely used in the battery trays according to TS-EN 755-2 standard are:

- EN AW-6005 [AlSiMg]
- EN AW-6060 [AlMgSi]
- EN AW-6063 [AlMg0,7Si]
- EN AW-6082 [AlSi1MgMn]



Very small amounts of aluminium EN AW-6061 [AIMg1SiCu] and EN AW-6463 [AlMg0,7Si(B)] can also be used depending on the areas of application. When the alloys are compared according to their extrudability performance and adequate yield strength properties, the previous alloys can be used for automotive structural applications.

Computer-aided engineering (CAE) guidelines from OEM's help to define which materials are to be used in any automotive structural part. The yield strength of the alloy is one of the most crucial criteria for the alloy selection, due to the fact that adequate yield strength guarantees proper CAE results before physical validation tests are performed. In each production phase of the extrusion profiles, the tensile properties (yield strength, tensile strength, and elongation) are controlled according to the TS-EN 755-2 standard.

2. Comparison of the thermal conductivity of the extruded AlMgSi alloy:

The thermal conductivity of aluminium is about three times greater than that of steel. This makes aluminium an important material for both cooling and heating applications such as heat-exchangers, battery cooling and housing systems. Therefore, the thermal conductivity properties of the 6xxx wrought aluminium alloys are also crucial. According to the thermal conductivity values, EN AW 6061 has the lowest thermal conductivity value with 152 W/m.K and EN AW 6063 has the highest thermal conductivity value with 218 W/m.K, respectively.

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The thermal conductivity is quite important for the bottom plate application which can be seen in Figure 2, to provide support for the cooling performance of the whole modules. However, the profile must also have an adequate yield strength to have an adequate resistance for carrying the whole modules on the extruded profile. In these circumstances, the EN AW 6063 aluminium alloy provides the best solution, since it has the highest thermal conductivity combined with an adequate yield strength value, thus being the best choice for the bottom plate application.

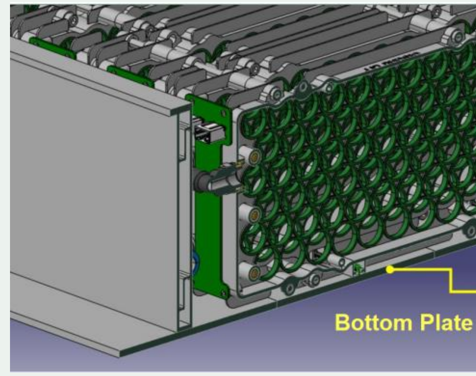

Figure 2. Schematic of the battery tray with demonstration of the bottom plate and modules.

Even though the material properties (yield strength and thermal conductivity) are one of the most substantial steps for the material selection, post processing like weldability must be considered before the alloy selection.

Upon the previous considerations, the bottom profiles have been planned to be manufactured with the EN AW 6063 alloy due to its better weldability performance through the FSW process and its improved ductility behaviour.

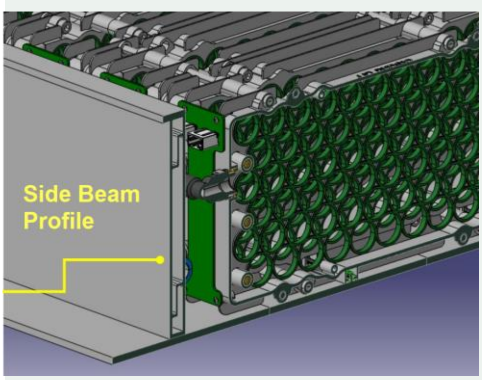

Figure 3. Schematic of the battery tray with demonstration of the side beam extruded profile.

For the side beam of the battery tray which can be seen in Figure 3, the EN AW 6082 alloy was selected for the production of these side profiles due to its enhanced mechanical properties and rigidity performance during a collision. The thermal conductivity of this alloy is also adequate according with the requirements of the battery tray design.

To achieve enhanced mechanical properties and crash performance, different trials have been carried out in extruded profiles of this alloy.

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Regarding the extrusion process, some main parameters like billet (aluminium raw material) temperature, extruded profile exit temperature, ram speed, and cooling method have critical importance to obtain the final mechanical properties.

During the developments of ALBATROSS, two different ram speed and billet temperature trials have been completed and microstructural improvements have been investigated. The values those parameters can be seen in Table 1.

Billet Temperature (°C)	Ram Speed (m/min)
470	2.5
490	3

Table 1. Extrusion parameters of the experimental trials.

For the aluminium alloys like EN AW 6082 that have higher tensile properties, the production speed can be lower than commercial alloys like EN AW 6063. Therefore, higher billet temperature can provide a higher production speed with adequate mechanical properties. In this case, a higher billet temperature allowed to achieve a successful production in the extrusion line. According to the microstructural analysis, higher billet temperature provides a thinner RX layer which improves the collision and energy absorption properties of the extrusion profiles.

Larger grain and thicker RX layer may cause deterioration of the energy absorption performance.

During the production phase of the side beam profile, which is produced with the EN AW 6082 alloy, a minimum 490°C billet temperature with as higher as possible ram speed (minimum 3 m/min.) will be used. The final geometry of the side beam and its extrusion process parameters will be validated via CAE analysis.

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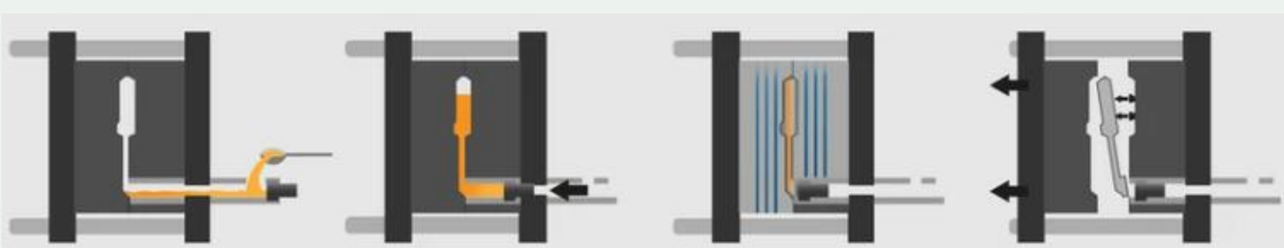
2. Aluminium High-Pressure Die Casted (HPDC) Parts

High-pressure die castings (HPDCs) produces lightweight alternative components by forcing molten metals into a mould at high speed and pressure. The automotive aluminium parts high-pressure die casting (HPDC) market has been segmented by application type, vehicle type, and geography. On the basis of application type, the market is segmented into body-in-white, chassis, transmission, and other components.

Approximately half of the world's total light metal production is obtained by high-pressure die casting (HPDC).

Although it is a proven technique for producing automotive components, there can be a high number of part rejections due to defects, porosities, and shrinkages. With the cooperation of the partners Fraunhofer IWS and Yeşilova, casting alloys (EN AC 46000, EN AC 44300, EN AC 43500) and extrusion alloys (EN AW 6063 and EN AW 6082) were used for coupon-based level parameter development studies of the laser welding.
According to the coupon-based laser welding trial results from the partner Fraunhofer IWS, the alloy type did not directly affect the weldability properties of the sample (weldability with EN AW 6063 and EN AW 6082 alloys). However, the most crucial point for the enhanced welding properties on behalf of the casting part is the metal quality and lower porosity level.

To improve the metal quality and hence obtain enhanced mechanical properties and better weldability, the degassing operation is widely preferred. After melting the alloys, the degassing process takes place to reduce the porosity formation. Therefore, metal quality improvement studies via different degassing parameters were performed to select to most suitable alloy for the casting node production.



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The efficiency of the currently applied degassing process and the change in the amount of hydrogen dissolved in the liquid metal with time in the holding furnaces after degassing was investigated by collecting RPT (reduced pressure test) samples.

These samples were taken from EN AC 46000 (A380), 46100, and 44300 (A413.0) alloys that were melted before and after degassing, and after 30 minutes and 1 hour after degassing in holding furnaces, under vacuum were cooled down and the formation and amount of porosity due to the gas content in the liquid metal was investigated. The resulting cross-sections for a EN AC 46000 alloy are presented in Figure 4.

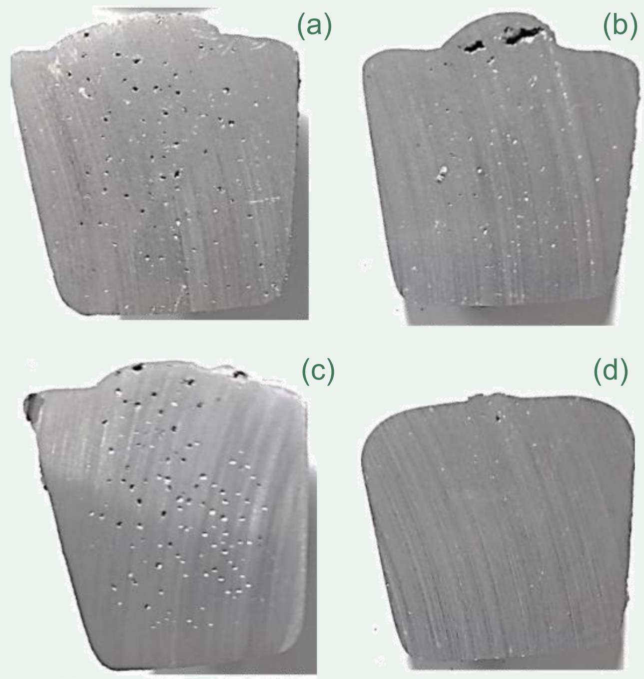

Figure 4. Photographs of the cross-sections of collected RPT samples for examination of degassing efficiency in EN AC 46000 alloy: a) before degassing, b) after degassing, c) 30 minutes later in transfer crucible and d) 60 minutes later in the transfer crucible.

The first alloy analysed was that of Figure 4. The temperature of the melting furnace was recorded as 722°C and during the transfer of the molten metal from the melting furnace to the transfer crucible, the molten metal temperature dropped to around 690°C. Samples were taken for the RPT and for the spectrometer analysis prior to degassing. The image of the cross-section of the sample taken before degassing and cooling under vacuum is given in Figure 7a. While a “dome” formation is observed on the sample, a large number of gas porosity is also observed in the sample section.

After 3 minutes of degassing and fluxing, the liquid metal temperature decreased to around 676°C. The cross-sectional image of the RPT sample taken after degassing is presented in Figure 7b.

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In addition to the homogeneously dispersed porosities that have decreased in size in the section, two large porosities can be observed in the "dome", which are formed together by the shrinkage and the gas content. When these two examples were examined, it was observed that the degassing process was insufficient, and the gaseousness of the liquid metal could not reach the desired ideal levels.

RPT samples were taken from the liquid metal which was kept at 640-645°C, after 30 minutes and 1 hour after its transfer to the holding furnace, and the sections were examined. The amount and dimensions of porosity in the RPT sample taken after 30 minutes are similar to the samples taken before and after degassing. However, a certain decrease was observed in the amount of porosity in the sample taken after 1 hour.

As a result of the examination of the RPT samples, it has been concluded that the hydrogen content before degassing is high in the EN AC 46000 alloy, which is melted by mixing with the leftover "chips" coming from the supplier and returning from the production in the factory, and that the applied degassing process is insufficient.

Similarly, RPT samples were collected for the EN AC 46100 alloy and their cross-sections were examined. It was concluded tht there is a “dome” formation on the RPT samples, as well as an increase in the observed porosity number and size. For the EN AC 44300 alloy, the degassing process was also inadequate, similar to the results obtained for the EN AC 46000 alloy.

Looking at the results, even though the current degassing process is insufficient, the welding trial results were acceptable. In this case, metal quality improvement analysis will be applied during the production phase of the casting nodes, and the production of the casted parts will be under control. The degassing parameters will be rearranged according to the determination results of the metal quality determination analysis.

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For the casting alloy selection, it is not possible to select the final alloy before having the metal quality and porosity level of the product. Since the casting nodes will be located in the battery tray and they will be welded to extrusion profiles, the welding performance is quite important because they will be chassis components and dynamic loads will be applied on both welding lines and casting nodes as well. In conclusion, three of them will be injected to investigate the metal quality and then according to the result of the metal quality and the Computer-Tomography (CT) scan results for the precise measurement of the porosity level, the final alloy selection will be completed.

3. Polymer-based Composite Parts

The ALBATROSS approach is to use thermoplastic composites (TPCs) to be applied in critical parts of the battery pack: top cover and side beam, with high potential light weighting.
TPCs are considered the next generation of composite materials with remarkable advantages over thermoset composites (TSCs), such as high ductility and toughness, and efficient, reliable, and easy-to-implement manufacturing routes able to meet the tight production times of mass production. Moreover, TPCs have a great recycling potential, which can be translated in reducing cost contributing to the circular economy system.

TPCs have a great recycling potential and the recent developments in CFRP thermoplastic-based processing appoints them as strategic candidates for multi-material design on the grounds of processing speed, recyclability, and reparability.

The requirements for lightweight are consequently translated downstream to different components of ALBATROSS. One of the key elements in the process has been identified as the battery case due to its inherent weight (278 kg for the BMW i3). In terms of composites, most of the very few market proposals focused on the replacement of the metal housing by polymer composite materials are again based on TSCs, a material with a low recycling potential that can be only reused as a filler. Thus, ALBATROSS represents a novel approach and solution.

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Considering the requirements and constraints established during WP1, two case studies had been clearly identified. This way, long fibre reinforced composites will be used for the component with higher mechanical properties, given the performance of this type of material. On the other hand, short fibre reinforced composites will be used in the component with less mechanical requirements.

Two Components	Mechanical Requirements	Reinforcement
Battery Cover	Low	Short
Hybrid Side Beam	High	Continuous

Composite materials are complex materials which can be integrated by a considerable range of elements. One of the most appealing aspects of these materials is that the full set of subcomponents which integrates them can be produced with unique properties fit for the purpose. To simplify, two main elements can be distinguished in composites: matrix and reinforcement.

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