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# Low-Pressure Die Casting of Aluminium Alloy Components for Electric Vehicle Battery Enclosures

**Jaime Lazaro-Nebreda*, Erdem Karakulak, Pavel Shurkin, Geoff Scamans**

BCAST, Brunel University London, Uxbridge, UB8 3PH, UK

*E-mail: jaime.lazaronebreda@brunel.ac.uk

**Abstract.** The production of battery boxes for electric vehicles typically relies on extrusions joined by welding, riveting, or adhesives, with minimal use of casting components due to their lower performance and higher defect rates. This study aims to enhance the structure and properties of battery box corner nodes, making them more reliable and viable for broader use in electric vehicle manufacturing. We employed Low-pressure Die Casting to produce the corner nodes, replacing previous sand-casting method known for higher porosity. A new die design, developed in collaboration with our industrial partner, allows for the simultaneous casting of four corner nodes, reducing die filling turbulence and improving casting integrity. Additionally, we used electric heating for the die and furnace to lower $CO_2$ emissions compared to traditional gas burning heating methods. Advanced characterization techniques, including X-ray tomography and Profilometry-based indentation plastometry (PIP), were used to evaluate the internal structure and properties of the castings. Our findings indicate excellent mould filling with minimal porosity defects and good mechanical properties, though with some variability. This variability correlates with the presence of porosity within the casting structure, demonstrating a clear relationship between local defects and local mechanical properties. This research contributes to the development of optimized castings with reduced weight and low rejection rates, enhancing the potential for aluminium alloy cast components in electric vehicles.

## 1. Introduction

With the growing demand for electric vehicles (EV), the industry must adapt and re-design new parts of the vehicle structure [1]. This presents new challenges but also gives new opportunities to explore ideas on manufacturing methods. One of the main new parts of this new type of vehicles is the frame where the battery is placed, i.e., the battery enclosure. It consists of a big rectangular "box" to be located at the bottom of the car. Therefore, it must be strong enough to resist the weight of the rest of the car and withstand the associated forces during operation. At the same time, it is preferable to use a relatively lightweight material, such as aluminium, to avoid excessively increasing the overall weight of the vehicle while maintaining good mechanical performance [2].

There are different methods to manufacture and assemble battery enclosures: using long extruded profiles bent into "U" shape; using straight extrusions joined by rivets or welds; or using straight extrusions for the sides with four corner nodes made by casting, as shown in Figure 1.

The latter method allows for independent manufacturing of each component, providing better control and facilitating disassembly for repair or recycling.

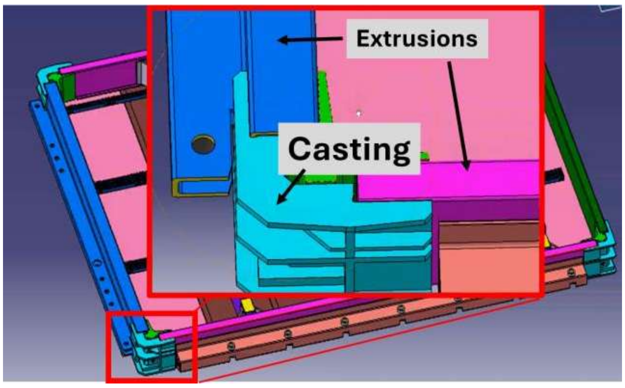


**Figure 1.** Example of an EV battery enclosure manufactured using Aluminium cast corner nodes.

Due to their more complex shapes, corner nodes are best manufactured by casting. This simplifies the process and allows for greater control over final assembly requirements. However, despite the potential of aluminium cast alloys to further reduce the weight of the battery enclosure, a major drawback of these alloys is their inferior and more variable mechanical properties compared to wrought alloys [3].

One of the main reasons for this lower performance is the presence of defects such as porosity and oxides. These defects originate either during the melt handling, due to inadequate degassing [4], or during the mould filling, because of turbulent melt flow and air entrapment [5].

Typically, due to the low demand, these components are easily manufactured using gravity sand casting, which offers good shape control at relatively low cost. However, this technique is known to produce significantly more porosity and structural inhomogeneities than other casting methods. Moreover, the need to produce a new sand mould for each casting introduces variability in performance and productivity [5].

This study explores the use of Low Pressure Die Casting (LPDC) as a more consistent technique for producing the corner nodes for battery enclosures. LPDC provides better control over mould filling [6, 7], reducing turbulent flow and air entrapment, and allows improved control of the solidification process. In collaboration with an industrial partner, we designed a new die to cast all four nodes in a single operation and produced an initial batch of castings. These castings were then evaluated for external and internal integrity, as well as mechanical properties, providing a comprehensive overview of the production-structure-properties relationship to guide improvements in future castings.

## 2. Experimental procedure

*2.1 Low Pressure Die Casting (LPDC) equipment preparation*

The study was conducted using the Low Pressure Die Casting Equipment (Figure 2a) located at the Advanced Manufacturing Casting Centre at Brunel University London.

Figure 2b shows a diagram of the new die, which allows producing the four corner nodes at the same time (2 for front and 2 for rear) and avoid problems associated with previous designs. To begin, the nodes were positioned in a way that would allow better melt filling, prevent turbulences, and a simpler extraction. MAGMA software was used in the process of optimizing the die design and the simulation of the filling process and solidification. Once the die was manufactured and installed, the first components were produced (Figure 2c). Final adjustments on casting parameters were done with the assistance of the foundry company *Sarginsons Industries Ltd.* (Coventry, UK) to ensure good mould filling and avoid surface defects (example of bad casting in Figure 2d).

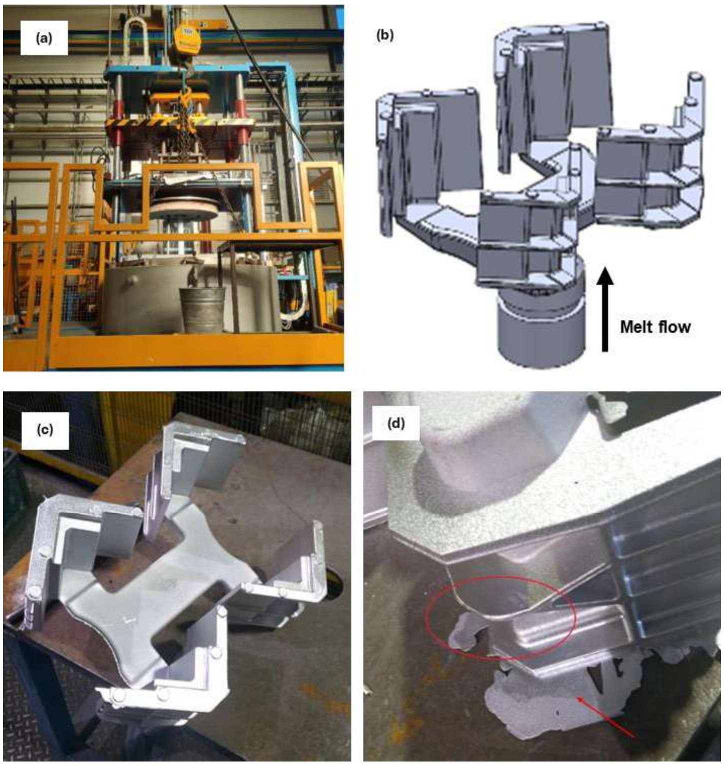


**Figure 2.** (a) LPDC equipment, (b) new die design, (c) 1st components, (d) example of poor filling.

*2.2 Melt preparation, degassing and casting*

The LPDC furnace was fed with around 500 kg ingots of an aluminium cast alloy (Al-9.5Si-0.5Mg-0.1Fe). Ingots were melted at 720 °C using the furnace electric heating elements. 80ppm of Sr was added to the melt just before degassing using Al-10Sr master alloy rods. Degassing was performed for 15 minutes using a FOSECO 90mm unit, with Argon gas injected at 15 L/min and a rotor speed of 600 rpm. Coveral 1524 Flux was incorporated into the vortex to help with the cleaning process. The degassing process was monitored, before and after, by standard Reduced Pressure Test (RPT) [8] and by direct hydrogen probe measurements (Alspek-H; [4]). After degassing, melt dross was removed and 0.1wt.% of AlTi5B1 was carefully added to the melt for grain refinement.

While degassing, the die was heated using an in-house electric heating system to replace the previous gas burning heating system. This allowed a better die temperature control and reduced the power consumption and $CO_2$ emissions.

The casting process was done according to the parameters obtained during the initial trials in collaboration with *Sarginsons Industries Ltd.* during the commissioning of the new die.

*2.3 Characterization techniques*
The overall integrity of the castings was assessed using X-ray computed tomography equipment. Standard optical microscopy was employed to analyse the material's microstructure. Mechanical properties in the as-cast condition were evaluated by machining tensile bars from the castings and testing them in accordance with ASTM-E8. Additionally, this study explored the use of Profilometry-based Indentation Plastometry (PIP).

PIP is a novel, non-destructive, technique that derives tensile test stress-strain curves by analysing the 3D profile of residual indents, i.e. simulates the sample behaviour in tension. It involves three main steps: sphere/ball shape indentation, profilometry and inverse finite element modelling. It enables rapid (~3min) characterization of mechanical properties in the region surrounding the indent, allowing for the detection of local property variations along the sample. Further details of the technique can be found online [9, 10].

## 3. Results

*3.1 Degassing and melt quality*
Figure 3 shows the results from degassing, presenting the internal aspect of the porosity of RPT samples solidified under 80mbar, before and after the degassing process. The density index (DI), indicating melt quality [8], changed from 14% to 5% after degassing, while hydrogen content varied from 0.25ml/100g to 0.12ml/100g. Despite the reduction, these values are still considered high. It is well known that rotary degassing is not fully effective at removing all oxide inclusions from the melt. It primarily targets dissolved gases and relies on the use of fluxes to address the oxides. Moreover, if not carefully controlled, the process can degrade melt quality by introducing turbulence, which may lead to further oxide formation [11].

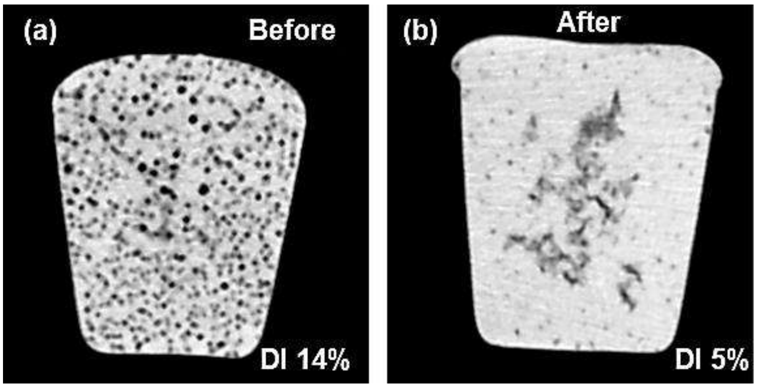


**Figure 3.** RPT cross sections (a) before and (b) after degassing.

In a foundry environment, repeated degassing cycles would have been required to achieve lower values. Alternative approaches to clean the melt more effectively include using advanced physical treatments, such as ultrasounds [12] or high shear melt conditioning (HSMC) [4].

In this study, the partially degassed melt was used directly, allowing for a better understanding of its impact on the casting integrity and mechanical properties. The high-density index observed after degassing provides clear evidence of a significant presence of oxide bi-films in the melt, which is also visible in the cross section of the RPT sample in Figure 3c. The combination of these oxides with residual dissolved hydrogen can lead to the formation of porosity (specially inflated oxide bi-films) during the solidification stage [13].

*3.2 Internal macro-structure of the castings*

The appearance of the castings under X-ray inspection is shown in Figure 4a. Tomography cross sections at different positions were evaluated, with selected examples presented in Figure 4b. The castings exhibited good internal filling, with most porosity concentrated near the bottom inlet gating system, consistent with other studies [6]. The overall porosity level across the entire castings remained below 1%, which is particularly notable given the suboptimal melt quality after degassing. This highlights one of the key advantages of LPDC over other techniques.

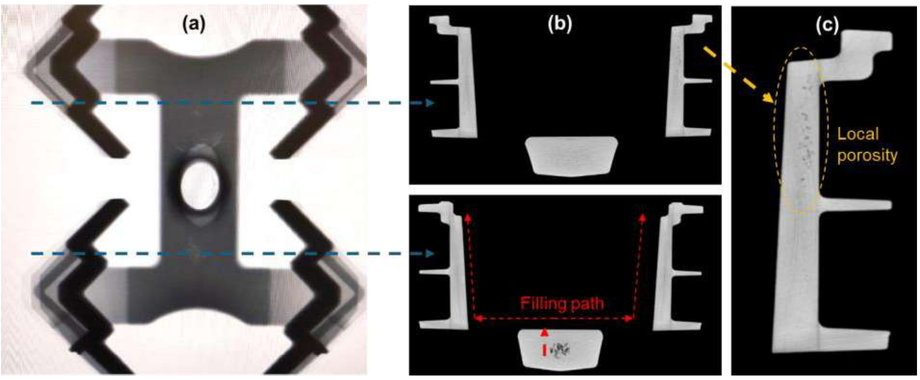


**Figure 4.** (a) Aspect of the casting under X-rays, highlighting the porosity at the inlet. (b) virtual cross sections at two positions showing the good die filling. (c) closer look at the local porosity.

According to Campbell's casting principles [5], achieving good melt quality is the first essential step. However, it is equally important to minimise air entrapment and reduce turbulence during mould filling, both of which are effectively addressed by LPDC. This better control of the filling process limits the drag of existing oxides in the melt and the formation of new ones, which are known to significantly degrade casting quality. When comparing the four nodes, no significant variation in macrostructure was observed, indicating good casting symmetry. Closer inspection revealed localised regions with porosity (Figure 4c), which is expected to play a critical role by acting as stress concentrator and reduce ductility and strength on those regions.

*3.3 Microstructure*

After X-ray examination, selected samples were cut at specific positions (Figure 5a). Local porosity was assessed by optical microscopy (Figure 5b), after which PIP indentations were performed along the entire cut sections at 10 mm intervals (Figure 5c).

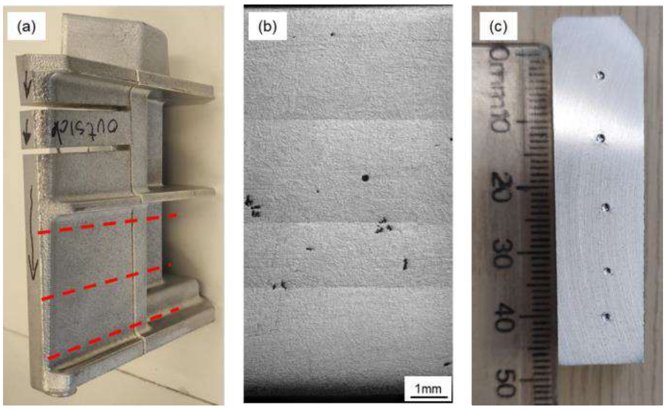


**Figure 5.** Sample preparation (a) cutting; (b) flat section; (c) optical microscopy; (d) PIP mapping.

Porosity, measured from images like in Figure 5b, ranged from 0.1% to 0.6%, with pore lengths up to 300 μm. Only rounded gas pores were observed, with no signs of shrinkage or oxide bi-films. However, the presence of hydrogen in the melt causes oxide bi-films to inflate during solidification. Therefore, the observed porosity indirectly indicates the presence of oxide bi-films

*3.4 Mechanical properties*

Figure 6a presents the yield strength (YS) and ultimate tensile strength (UTS) versus elongation, comparing results from tensile testing and PIP analysis. The results indicate good mechanical performance, though with noticeable differences and a high variability, especially in elongation. Recent studies [14] have proposed elongation as a metric for melt quality before casting, which aligns with the degassing results discussed before.

PIP values overestimated YS by 13%, UTS by 18%, and elongation by a factor of 3 to 6 compared to real tensile tests. This overestimation arises from the nature of the PIP method. Figure 6b shows example stress-strain curves from both methods. PIP evaluates a small, relatively "defect-free" region [10], whereas standard tensile tests involve larger specimens, increasing the likelihood of encountering defects such as porosity or oxide bi-films. As a result, tensile bars will tend to fail at these weaker regions much earlier than a defect-free component, leading to significantly lower elongation and UTS.

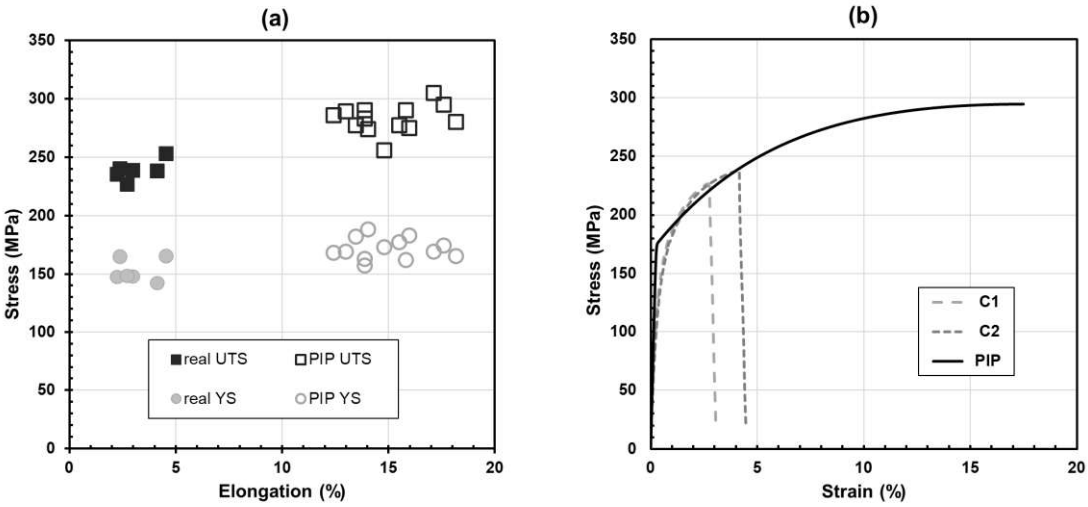


**Figure 6.** Comparison of PIP and tensile tests (a) YS and UTS versus Elongation, (b) stress-strain curves

*3.5 Correlation between mechanical properties and local porosity*

The variability observed in PIP mechanical properties in Figure 6, particularly in elongation, is attributed to microstructural inhomogeneities and the presence of local defects. Although PIP is intended to estimate the bulk properties of a defect-free material, its accuracy can still be affected by porosity [15]. Porosity can distort the indentation profile, introducing uncertainty into the inverse simulation process and consequently the estimated stress-strain curves.

On the other hand, the variability in elongation in real tests is also linked to defects but over a larger volume. Recent studies [16,17] have demonstrated that it is possible to use X-ray tomography to predict both fracture location and mechanical properties of tensile bars by assessing the location and concentration of the defects (pores, oxides) before testing.

Figure 7 presents a comparative overview of elongation versus porosity obtained from both PIP analysis and tensile testing. The plot highlights the differences between local and bulk porosity and their respective impacts on mechanical performance. A logarithmic trend line fitted to the data confirms the findings of a previous study by the authors [16] and aligns with more recent investigations [17], while also extending the critical local strain model analysis [16] to much lower porosity levels than previously reported.

According to the quality index proposed by Tyriakiouglu [18], the potential elongation for the material exhibiting a yield strength of 170 MPa is approximately 25%. This value aligns well with the extrapolated end of the trend line in Figure 7, representing a defect-free condition. This comparison clearly illustrates how even small amounts of porosity can drastically reduce mechanical performance, emphasizing the importance of melt quality and defect control in casting processes.

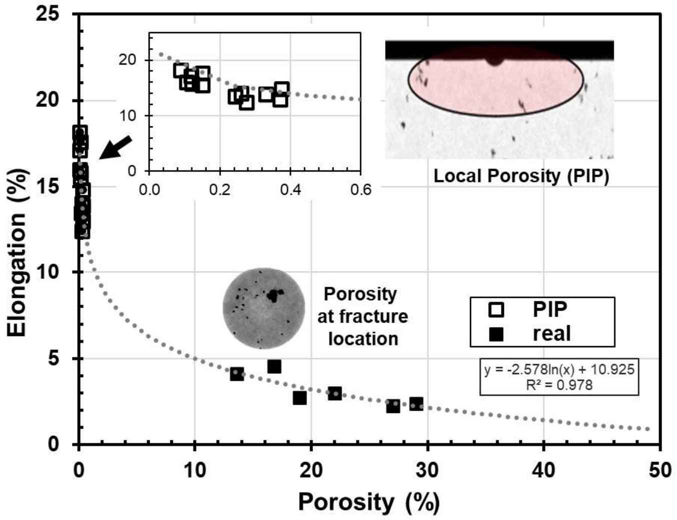


**Figure 7.** Variation of local elongation with local porosity in different positions inside the castings

## 4. Summary and Conclusions

This study confirms that Low Pressure Die Casting (LPDC) is a valid and effective technique for producing aluminium corner nodes for EV battery boxes. The newly developed die design enables the simultaneous casting of four nodes, achieving good mould filling, symmetry, and low porosity.

The resulting components exhibit good mechanical properties, although some variability was observed. This variability is attributed to local microstructural inhomogeneities and the presence of defects. The correlation between defect content and mechanical properties aligns well with previous research, reinforcing the importance of melt quality.

PIP provides complementary results to standard tensile testing, offering insight into the expected behaviour of the material in regions free of, or with very low fractions of, defects. Moreover, the use of adequate tools for component characterisation—such as PIP, microscopy, and tomography—can greatly aid in understanding and predicting mechanical performance.

Finally, the study highlights opportunities for further improvement, particularly through the optimisation of the degassing process to reduce residual bi-films and enhance consistency.

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