NEXUS

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Material choice for the Accumulator Container

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Early considerations for material selection based on the regulation:

EV 5.5.5

TSACs must be constructed of steel or aluminium. With the following requirements:

• The bottom of the TSAC must be at least 1.25mm thick if made from steel or 3.2mm if made from aluminium.

• The internal and external vertical walls, covers, and lids must be at least 0.9mm thick if made from steel or 2.3mm if made from aluminium.

T 9.3.1

Critical components themselves and their mountings must be able to withstand the following accelerations:

• 40g in the longitudinal direction (forward/aft)

• 40g in the lateral direction (left/right)

• 20g in the vertical direction (up/down)

Introduction

This study will analyse an early design of the accumulator container, testing different aluminium alloys for the structure. This design is based on the current configuration of the battery segments and cells layout. For that reason, the overall dimensions may change slightly, maintaining general proportions and not impacting too much the conclusions derived from these tests. The image below shows this version of the cell's layout and the container where it sits (figure 1).

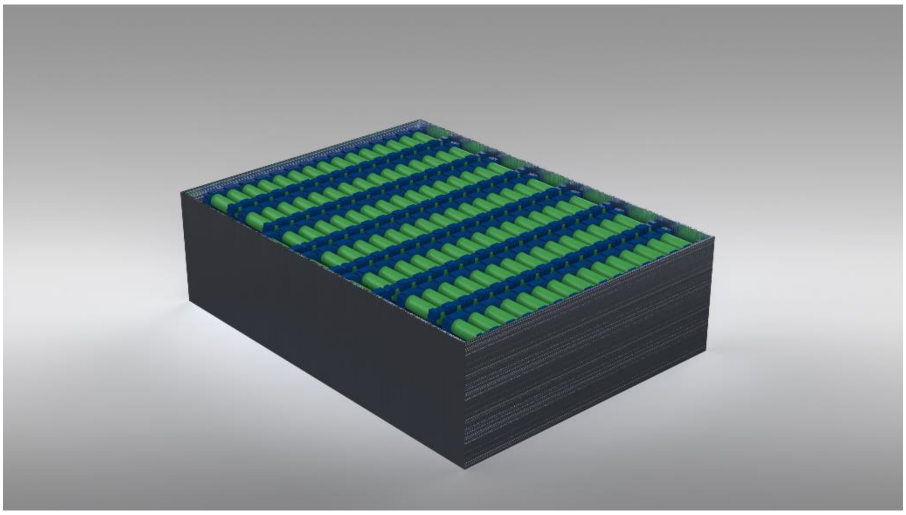


FIGURE 1 - CELL CONFIGURATION AND CONTAINER

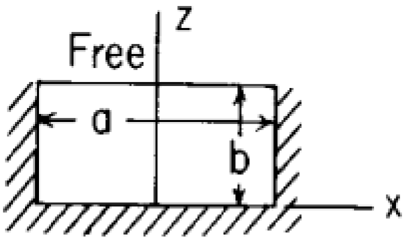
TIG welding for aluminium

The first step is to study the general requirements for aluminium welding, to understand if it´s a viable option, having in consideration production of the parts on top of the structural integrity of the container. With some research on the various types of aluminium, some alloy series stand out as good candidates for their mechanical properties and welding capabilities. To further confirm this, ANSYs is used to filter all aluminium alloys that have good or great welding capabilities. Using the highest level of the database (level 3), 200 results were given that still needed to be compared.

Material comparison and analytical calculations

To achieve this, extensive research was conducted on plate bending theories. The main conclusions and formulas used in this specific case can be found in **[1]** and **[2].**

On the first book, it can be found formulas for calculating stress in different points of a rectangular plate for different boundary conditions. Our specific case is a plate with three fixed edges and a free one (one wall of the container). Because the choice of material is dependent on the maximum stress, the point where that occurs is the one were interested in **(At x = 0 and z = 0)**. An illustration of the case study can be seen below.



The stress formula is the following:

$$\sigma = \frac{\beta q b^2}{t^2} \; (1)$$

Where

q is the pressure applied evenly on the plate

b is the height of the plate

t is the thickness of the plate

β is a parameter obtained empirically for each coefficient of a/b.

For this case, a/b is 3,5 (calculated with the general dimensions of the accumulator found ahead) which isn't present the given tables so β had to be extrapolated trough a third order polynomial.

Given the yield strength of each alloy, this formula allowed the calculation for the minimal thickness of the plate. This permitted the calculation of the flexural rigidity of the plate (D), trough the equation (2).

$$D = \frac{Et^3}{12(1-\nu^2)} \; (2)$$

Where

E is the Young´s Module

t is the thickness of the plate

ν is Poisson´s ratio

At last, it´s possible to calculate the deflection the plates suffer through the formulas and tables found in [2]. The maximum deflection occurs at x = 0 and z = b. The formula for the calculation is the following:

$$w = \alpha \frac{Fa^4}{D} \; (3)$$

Where

α is a parameter similarly calculated as β

F is the uniformly applied force

a is the length of the plate

D is the flexural rigidity

With all the needed properties, three criteria were devised to compare the different aluminium:

- Stiffness limited design (M1)
- Strength limited design (M2)
- Thickness limited design (M3)

These criteria are useful trough the maximization of M. The bigger the factor M the better the material. If the 3 M-factors are multiplied, the best material overall can be determined.

Equations for M:

$$M_1 = \frac{E^{1/3}}{C_m \rho} \ (4)$$

$$M_2 = \frac{{\sigma_y}^{1/2}}{C_m \rho} \ (5)$$

$$M_3 = \ {\sigma_y}^{1/2} \ (6)$$

Where

C_m is the cost per kg

ρ is the density

σ_y is yield strength

An Excel was created to automatically calculate all the properties and compare the materials.

With a first design for the cell modules and the weight of each cell, we can calculate the weight of all the components and the overall size the container must have.

The total mass for the cells is:

$$47g \times 690 = 32{,}43\ kg$$

With the density of PC ($1160\ kg/m^3$) used for the cells supports and their volume ($3778{,}56\ mm^3$) the mass becomes:

$$3778{,}56 \times 10^{-9} \times 2 \times 690 = 6{,}044\ kg$$

The total mass calculated is multiplied by a safety factor of 1,5 to consider the rest of the components that are not yet projected.

$$TotalMass = 57{,}712\ kg$$

The first design for the container with aluminium can be seen below with its integration in the chassis. It measures $558 \times 415 \times 160\ mm$.

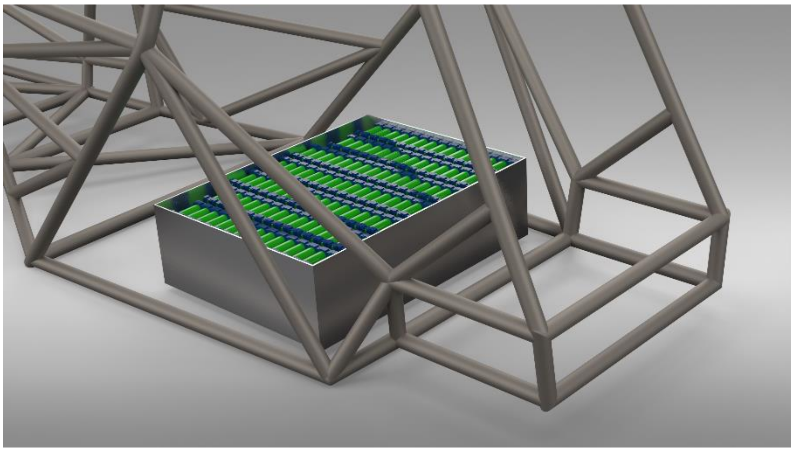


FIGURE 2 - ACCUMULATOR INTEGRATION

From this the relation a/b is obtained as well as the load applied by the mass inside the container.

The main conclusion is that **Al6013 T6** is the best material for the purpose. These calculations were conducted for 3 plates: the front, side and bottom plate.

Finite Element Simulations of the Container

Having chosen the best material for the application and the respective thickness of each wall, the CAD model for the accumulator container was adapted and simulations were run. The objective was to first validate the values calculated analytically and add the extra complexity of between walls interactions. The analytical models only allowed simple calculations on singular plates; however, the container has the walls attached to each other, interacting and adding strength through geometry features.

We can conclude that the analytical procedure gives the confidence that the material chosen is adequate, but FEM simulations are the primary tool to achieve a final design for the accumulator container.

A simplified simulation of the container with all the loads applied at once, concluded that the yield strength was never achieved with a safety factor of 1,3. The deformation was higher than expected with 9 mm at maximum load. It´s important to considerer this design has no structural reinforcement, meaning the results can be improved trough refinement of the design. A representation of the simulation can be seen in figure 3.

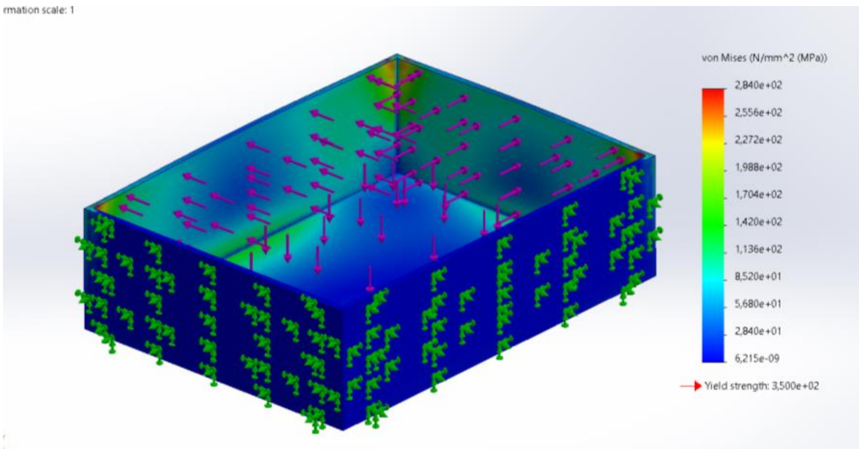


FIGURE 3 - SIMULATION RESULTS

The primary goal was achieved which was to validate the analytical calculations

Filler Metal

Another important aspect when considering welding is the correct choice for the filler metal. For that reason, a chart **[3]** was consulted and for the aluminium chosen there are some options:

- Al 4043
- Al 4943
- Al 5183
- Al 5356
- Al 5554
- Al 5556
- Al 5654

Final Conclusions

To conclude this study, the best material for the accumulator container is Aluminium 6013 T6 because of its strength and weight and being weldable. The container may suffer slight changes in dimension and will be reinforced structurally.

Bibliography

[1] W. C. Young and R. G. Budynas, Roark's Formulas for Stress and Strain, 8th ed. New York, NY, USA: McGraw-Hill Education, 2011.

[2] S. Timoshenko and S. Woinowsky-Krieger, Theory of Plates and Shells, 2nd ed. New York, NY, USA: McGraw-Hill Education, 1959.

[3] Hobart Brothers LLC, *Aluminum Selection Chart*, Troy, OH, USA.