
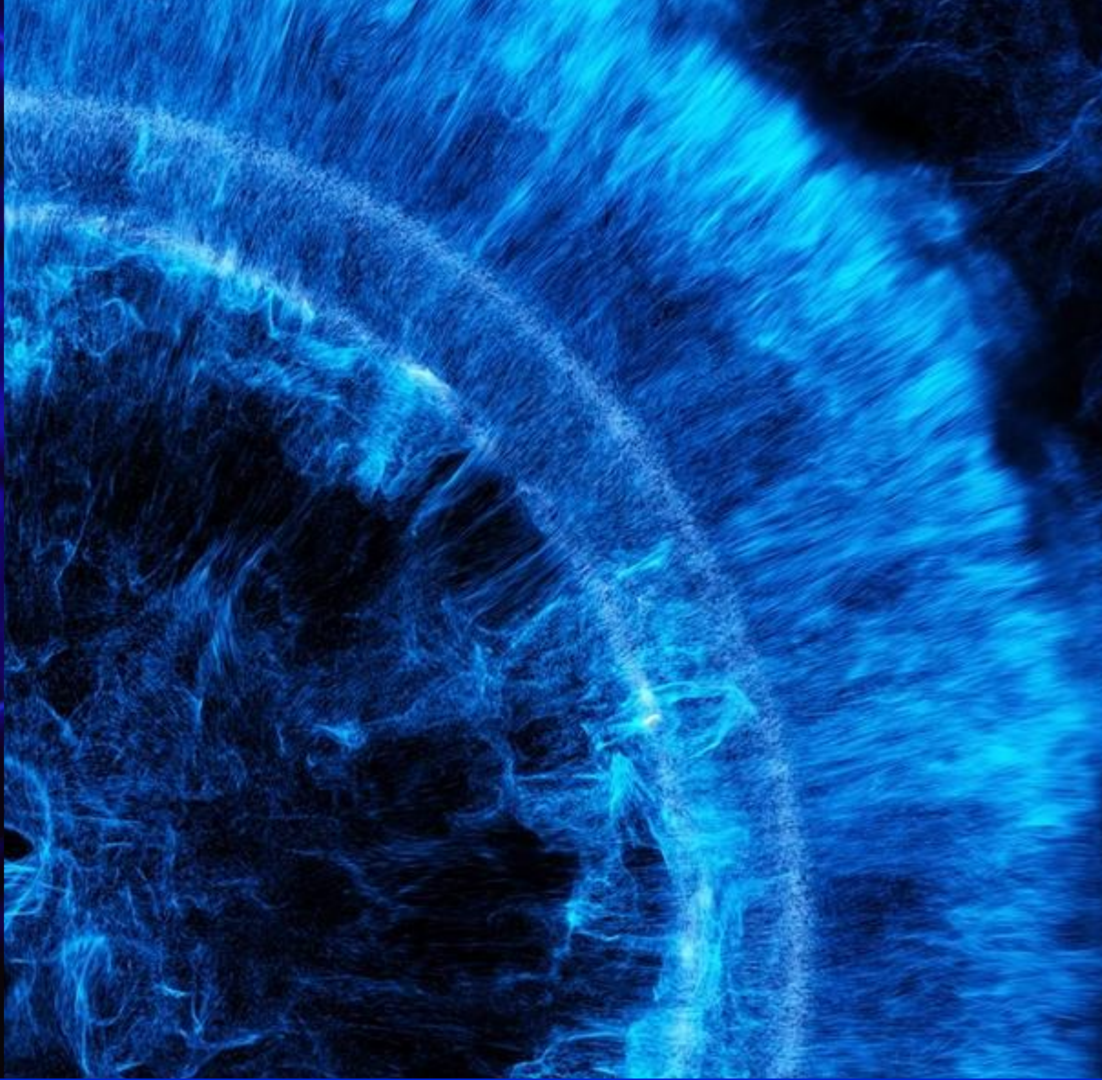

IMPROVING PROCESS DESIGN USING COMPUTATIONAL MODELLING

LUCIDEON
providing material solutions

INTRODUCTION

Parametric Multiphysics Analysis uses computational modelling to simulate the different aspects of physical systems and predict the effect of their interactions. This powerful tool can be applied to products and processes in many fields of engineering, manufacturing, and scientific research to accelerate their development and optimisation.

This case study focuses on the development of an improved electrode system for an innovation ceramic process technology, Flash sintering, which applies an electric current to a sample as it is heating to accelerate sintering, bringing both cost and time savings, and improving material properties.

The analysis was carried out by Lucideon Limited under the “Midlands Advanced Ceramics for Industry 4.0” programme as part of the programme’s activities to expand the application of mathematical modelling to ceramic manufacturing processes.

THE CHALLENGE

In Flash sintering the electric current is applied through electrodes in contact with the sample within the furnace hot zone. This requires a material that can withstand the heat, conduct electricity efficiently and not oxidise. The assembly of the feed through and the electrodes is known as the powerbar. Platinum is the material of choice due to its exceptional properties.

However, its cost is high, which poses a significant barrier to adoption as the technology scales up in size. Inconel, a cheaper nickel alloy, can be used for some of the length outside of the furnace hot zone, but the heat from the current flowing

through the Platinum rod could lead to Inconel reaching its melting point, resulting in failure. The challenge was to optimise the powerbar design for cost and performance through a combination of platinum and Inconel components.

WHAT WE DELIVERED

The powerbar design was optimised using COMSOL Multiphysics, particularly the Electric Currents, Heat Transfer in Solids and Fluids, and the Electromagnetic Heating modules.

Parametric thermal analysis of the entire furnace chamber determined the dimensions of the platinum rod that can used.

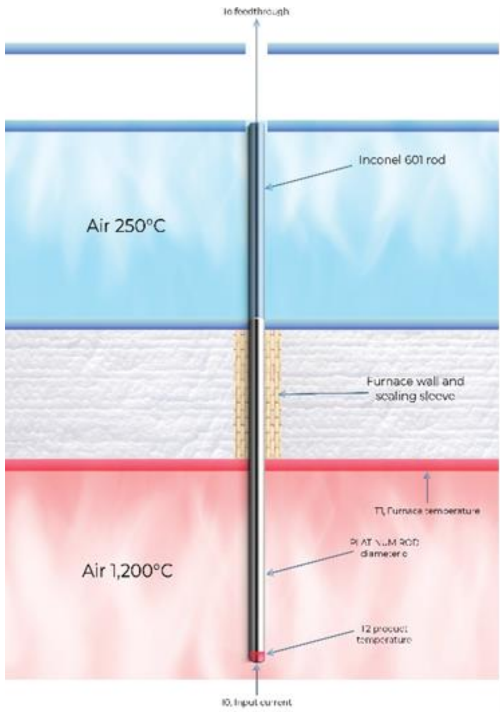

Figure 1 - Furnace Model Cross-Section

Figure 1 shows a cross-section of the furnace with key parameters. To reduce computational complexity, the furnace is assumed cylindrical, a widely accepted approximation. The Multiphysics simulation was iterated for a combination of input parameters including furnace temperature, specimen temperature, platinum rod dimensions and input current, as shown in Table 1. The whole rod was assumed to be made of platinum at this stage.

Overall, DIW is most suitable for manufacturing components quickly with broad tolerances for resolution and surface finish. DIW is especially suitable for parts containing internal lattice structures due to the gap bridging ability of the extrudate.

In the second stage of the analysis, the objective is to minimise the amount of platinum used, with the Inconel being used to make up the remainder. The location of the specimen is fixed at the centre of the kiln, meaning the overall length of the powerbar is fixed.

Table 1 – Model Input Parameters

Input Parameter	Range
T1 – Furnace temperature	800 – 1200°C (100°C steps)
T2 – Specimen temperature	1200 – 1700°C (100°C steps)
I0 – Input Current	0 – 100A (10A steps)
d - Platinum rod diameter	4 – 6mm (1mm steps)

Table 2 – Follow-on Model Input Parameters

Input Parameter	Range
T1 – Furnace temperature	1200°C - fixed
T2 – Product temperature	1700°C - fixed
I0 - Current	80A - fixed
d Pt - Platinum rod diameter	6mm - fixed
d In – Inconel rod diameter	9.525mm - fixed

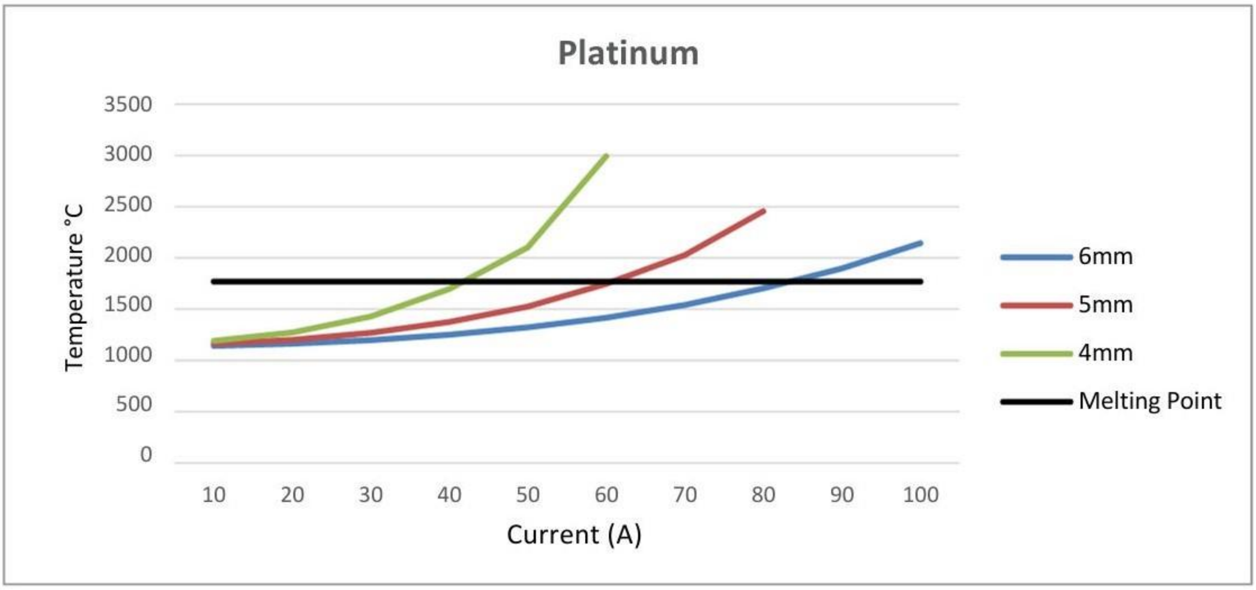

Figure 2 - Temperature (°C) of Pla num Rod, vs Current (A) for d=4,5,6 (mm)

The results showed that the maximum temperature in the platinum rod for all values of d was below the melting point of platinum at the maxi- mum temperatures of T1 and T2 provided the current I0 remains below 40A. As the current increases, the platinum rod approaches its melt-ing point, as shown in Figure 2.

Thus, increasing the length of the Platinum rod will decrease the length of Inconel proportionally. The second parametric model varied the ratio of Platinum to Inconel in the powerbar assembly, to optimise cost and performance. The results for the previous study were used to determine the most conservative values for the next study, and the updated parameters are shown in Table 2.

The optimum powerbar design was found to have 62% of its length in platinum and 38% in Inconel as shown in Figure 3. This is the shortest length of Platinum required to maintain the inconel rod temperature safely below melting point.

Considering platinum is roughly 1000 times more expensive than Inconel, the Pt% of the powerbar correlates directly to cost, meaning the savings presented here were around 38%.

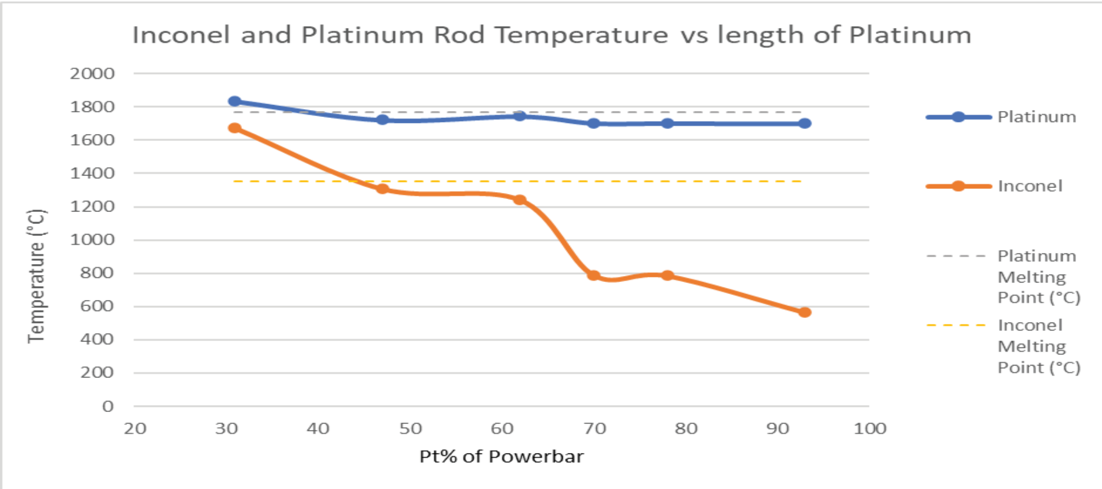

Figure 3 - Inconel and Platinum Rod Temperature vs % of length of

VALUE TO THE CLIENT

This case study demonstrates the benefits of using parametric computational modelling in optimising the design of a flash sintering furnace.

By using this approach, different parameters were systematically varied to optimise the powerbar composition against costs. This allowed the optimal design configuration to be quickly identified, saving time and resources compared to traditional trial-and-error methods.

It is also important to note that some assumptions were made during this analysis, and the most conservative case was always used.

One example is the specimen temperature, T1, which was set to a constant 1200°C. In reality, this value will fluctuate and is the subject of one of the workstreams of this programme, so that case studies such as these can use more detailed information, resulting in more accurate analysis, and greater savings.