

Plutonium Casting Modelling – Beyond the Present

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Casting modelling has become widely used for various industrial applications. In general, modelling techniques such as Computation Fluid Dynamics (CFD), Finite Element (FE) and Meso-Scale (MS) modelling are utilised as a research tool to aid optimisation of manufacturing processes; therefore, it has become a powerful ally. These techniques have helped to better understand the complexities and natural behaviour of molten metal flow, assess turbulence generated during mould filling, helped to develop an in-depth understanding of the complex interactions between molten metal flow and mould material, predict casting defects, segregation, thermal stress behaviour and assess the average cooling rate experienced during the casting processes, which all have a profound effect on the metallurgical properties of the casting being produced.

Casting plutonium alloys is both complex, time-consuming affair involving multiple stages, these include; Vacuum Induction Melting (VIM) and annealing. By their very nature, studies involving plutonium alloys are inherently difficult and therefore, future studies are likely to be limited due to a number of factors which include; high associated costs and health and safety considerations. As such, development of the plutonium casting processes has been limited and the fundamental casting process design has seen little improvements in the last 20 years. The casting and homogenisation processes are simple by design, gravity VIM casting and isothermal annealing however; when considering the number of complex metallurgical and physical phenomena that occur, some of which occur simultaneously, developing a validated process model encompasses all the phenomena, becomes a true challenge.

Modelling the heating cycle of the casting process is currently beyond the capability of the modelling software used (Keysights ProCAST), as it involves modelling the complex interactions in the form of eddy currents and hence, several thermal examinations using the non-active area casting furnace were conducted. Numerous thermocouples were attached to the various components inside the furnace and the temperatures were recorded as a function of time. It was concluded that prior to pouring being initiated the majority of components inside the furnace reached a thermal steady-state. These steady-state temperatures as a function of mould temperature are plotted in Figure 1.

In developing the initial thermal flow FE model the steady-state temperatures associated with each component were extracted and used as a starting point. The simulated results from the initial thermal flow FE model were compared to thermocouple data obtained from actual castings. Thermocouple data revealed that the casting experiences an average cooling rate of between 3 – 3.5°C per minute through the $\epsilon + \delta$ mixed-phase region. Results from the FE model showed an average cooling rate of 3.2°C/ minute and these can be found in Figure 2.

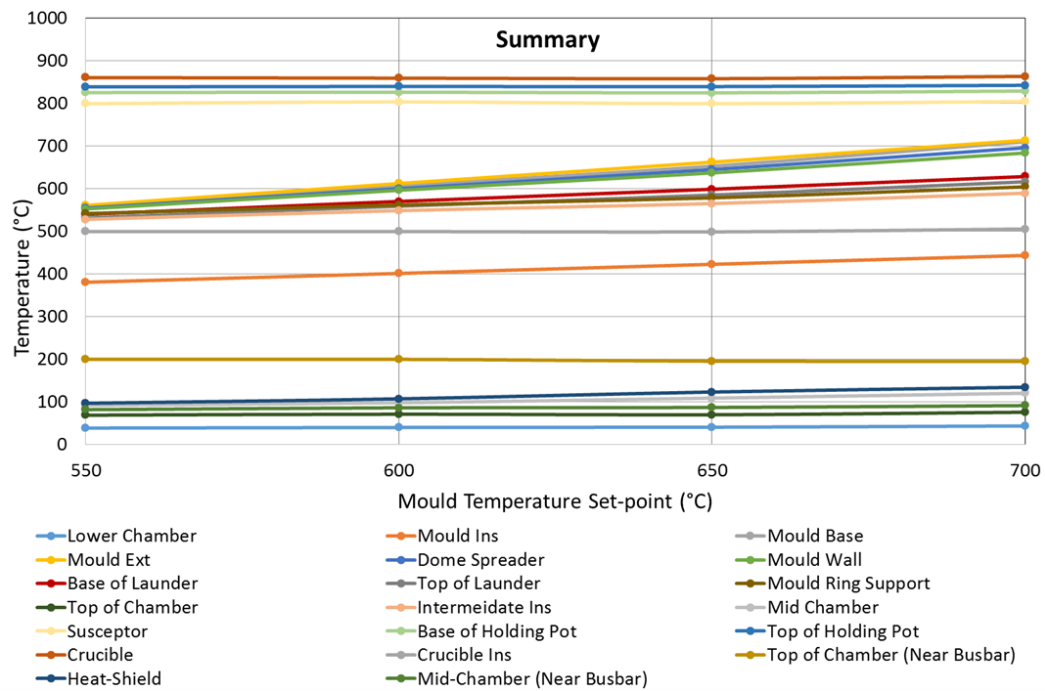


Figure 1: A summary of the thermal examinations carried out using the non-active area furnace for various heating cycles.

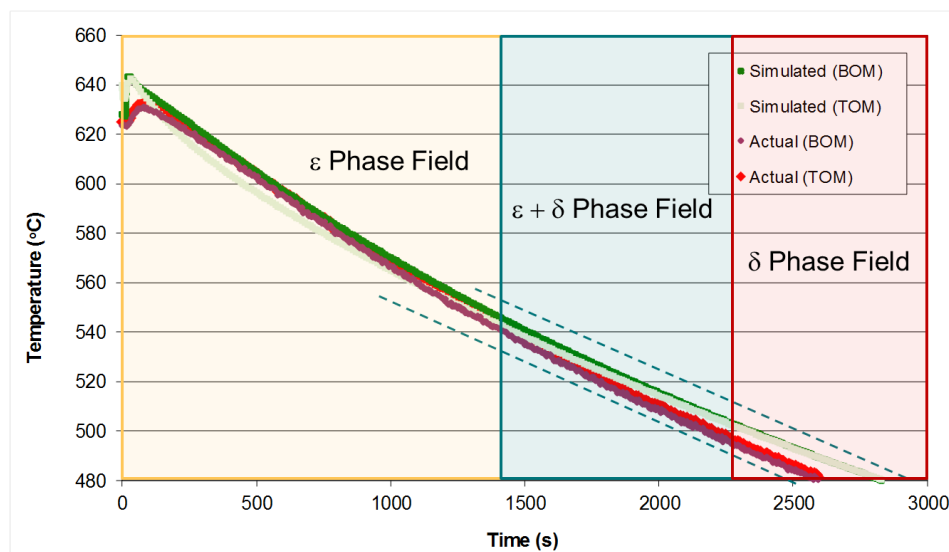


Figure 2: shows the process thermocouple data for plutonium alloy castings compared against nodal temperatures found at a similar thermocouple location from the model.

In conclusion, most of the physical phenomena can be modelled using commercially available software; the challenge of predicting the metallurgical phenomena i.e., grain size, segregation behaviour and solid-state phase transformation at the length scales of interest to engineers still remains. The thermal-flow FE model still requires further development and validation, a time-line for model development has been proposed, once validated this model will be utilised to guide future process improvements and aid in designing a future plutonium casting capability.