Measurement 44 (2011) 738–742

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

# Temperature effects of imperfectly formed metal-ingots in high temperature fixed point crucibles

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ARTICLE INFO

*Article history:*
Received 27 June 2010
Received in revised form 2 December 2010
Accepted 7 January 2011
Available online 13 January 2011

*Keywords:*
Thermal modeling
High temperature fixed points
Eutectics

ABSTRACT

This paper investigates, through thermal modeling the effect on the radiance temperature of imperfectly filled thermometric fixed points. A two dimensional axisymmetric thermal model was established and the effect on the radiance temperature of various ingot imperfections such as voids and cracks in different places and of different dimensions in the ingot structure was calculated. It was found that the radiance temperature of the fixed point is quite tolerant to even relatively large flaws in the ingot structure. Only when flaws of significant dimensions near the radiating back wall were introduced was the overall radiance temperature significantly affected.



## 1. Introduction

The CCT-WG5 (Consultative Committee of Thermometry – working group on radiation thermometry) has instigated a programme of research with the aim of establishing high temperature fixed points as routine temperature standards above 1100 °C by 2012 [1]. These high temperature fixed points (HTFPs) are based on ingots of metal–carbon eutectics, metal–carbide eutectics or peritectics cast in graphite crucibles [2]. However, the casting process is not straightforward and can result in imperfect filling of the crucible, in particular forming an ingot with holes or voids. Part of the CCT-WG5 research plan is to seek to understand the effects such imperfect filling might have on the resultant temperature. This is not possible to determine experimentally so a numerical thermal model of non-contact thermometry cells has been established to help understand this effect. Different models have been constructed simulating the presence of both voids or holes and "cracks" in the ingot. A crack in the ingot is potentially a major flaw allowing direct communication of the thermal radiation from the crucible wall to the blackbody tube.

These models were implemented using finite volume software and the areal average of the back wall temperature calculated whilst the fixed point was raised from a fully frozen to a fully molten state. Furnace effects have been neglected, that is the crucible alone has been simulated. Two dimensional axisymmetric simulations have been performed for the following scenarios:

- Holes in the ingot adjacent to the crucible wall with the dimensions 1.5 mm and 3 mm width and 1 mm and 2.5 mm depth were simulated. The position of the hole was varied along the crucible wall.
- Cracks of 1.5 mm and 3 mm width allowing direct line of sight of the hot outer crucible wall to the blackbody wall were modeled in turn. The position of the cracks was varied.

This paper describes the results of the simulations, in particular the effect of imperfectly formed ingots on the duration and quality of the melt profile.

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0263-2241/$ - see front matter 
doi:10.1016/j.measurement.2011.01.003

## 2. Construction and implementation of thermal model

The thermal model was implemented using the software package FLUENT 6.1. FLUENT is a general purpose computational fluid dynamics (CFD) package based on the finite volume method. The subject of study is divided into a finite set of control volumes and the general equations for mass, momentum and energy conservation are simplified into algebraic equations and then solved to give individual values in each volume.

To simulate these fixed points two dimensional axisymmetric models have been constructed. The fixed-point modeled was of a typical NPL design [3]. These are constructed from high purity graphite and filled with an ingot of the metal–carbon mixture. In brief the outer crucible was 40 mm long and 24 mm of outer diameter. The crucible walls, including a thin sacrificial inner sleeve of graphite were 5 mm thick. The blackbody reentrant well was 7 mm outside diameter with a 3 mm blackbody internal diameter with a length of 27 mm and a 120° cone at the apex. The internal diameter of the crucible, where the ingot was cast, was 16 mm. The fixed-point modeled here was the Re–C point (2747 K) but the results are applicable in general. A photograph of one of these fixed-points is shown in Fig. 1 in [4].

The important thermophysical properties were; graphite emissivity 0.86, Re–C emissivity 0.35, thermal conductivity of graphite 36.5 $W\,m^{-1}\,K^{-1}$, the thermal conductivity of Re around the melting point 55 $W\,m^{-1}\,K^{-1}$. The uncertainty of graphite emissivity and thermal conductivity values is studied in references [5] and [6]. For the purposes of the model Re–C is assumed to have the same thermal properties as pure Re.

The boundary conditions were set with a uniform temperature of the outside wall of the crucible i.e. it did not experience any temperature gradients. The outside world at the fixed point aperture was simulated with a baffle at room temperature looking directly to the back wall of the crucible.

The numerical experimentation was performed as follows. The initial condition was that the crucible was held 7 K below the melting point. A temperature step function above the melting point was then implemented by raising the outside graphite wall to 20 K above the melting point. The areal average of the temperature of the back wall was then calculated during the simulated melting process.

The holes and cracks described in the introduction were implemented and modeled in turn. A typical numerical grid, showing the different positions of the holes and cracks inside the ingot, is given in Fig. 1.

## 3. Results

### 3.1. Results with the holes

The holes given in Table 1 were modeled at four different locations around the ingot. The holes were always assumed to be on the outside wall of the ingot facing the outside graphite wall, as shown in Fig. 1. These were designated $(x, y)$ (see Fig. 2), where $x$ designates the location of the hole and $y$ identifies its dimension.

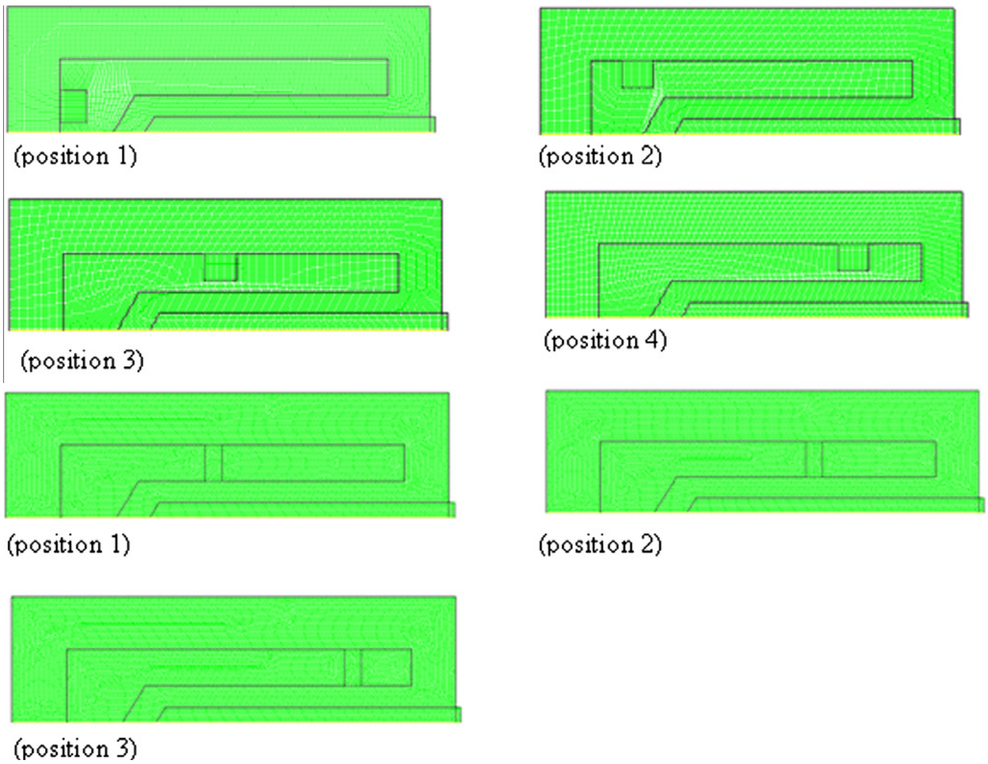


**Fig. 1.** The different positions of the holes and cracks inside the ingot.