

# CIRCULAR ECONOMY OF FOUNDRY INDUSTRY 4.0

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**Abstract:** The use of mathematical models of control processes in foundry such as: K-test and Chemical spectral analysis is a good set of mathematics (thermal conductivity theory) and theoretical physics (first-order phase transition) are important elements for ensuring high quality castings in micro-foundries.

The idea of estimating the overheating of a liquid metal alloy based on the appearance of a curing process upon filling has been developed. These control processes combined with zone refining are an important opportunity to create a waste-free foundry in a circular economy in Industry 4.0.

**Keywords:** CIRCULAR ECONOMY, FOUNDRY, INDUSTRY 4.0, CONDITION OF MICROSTRUCTURE

## 1. Introduction

The Industrial Revolution [1] is taking place without being interested in the enormous changes that are also causing concern for a huge number of people - not just jobs are disappearing, but entire industries are disappearing. This change requires a very good knowledge of the complete knowledge (profound changes in the education system) of the “meaning and personal orientation of each worker” [2]. The need for knowledge transfer in even the smallest family (micro-foundry) is considered in work [2] and is shown by net picture:

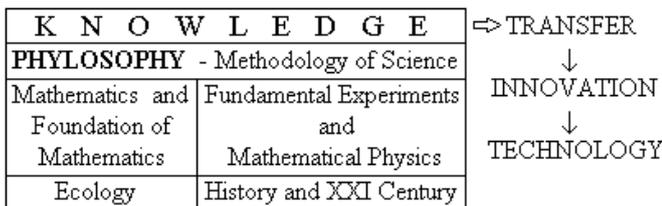


Fig. 1 Subject of Knowledge Transfer → Innovation → Technology [2].

The term ecology was coined by Greek philosophers Hippocrates and Aristotle in the study of nature. The term ecology was coined by Greek philosophers Hippocrates and Aristotle in the study of nature. The German scientist Ernst Haeckel in 1866y introduced the idea of ecology, which is today a very important interdisciplinary science and, but also the basis for an almost "revolutionary technological" policy [2].

Today it is still used, and the way of thinking is linear economy raw materials - production - product - product life - waste. An essential part of sustainable development is based on a circular economy [3 and 4]. In the foundry [5], castings are turned into waste after use, but in a circular economy they are transformed into raw materials - secondary materials (meals or alloys). For this reason, the European Commission has introduced 54 measures to create a circular economy. The use of secondary alloys is controlled by a K-test by monitoring the percentage of non-metallic impurities [5]. A mathematical model of solidification of castings in the form of K-test has been created. In Fig. 2 shows a general view of the non-stationary solidification temperature field in this test at one point in time.

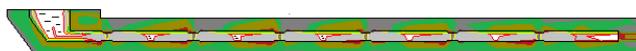


Fig. 2 Temperature field at some moment in in the time from Stefan-Schwartz 3D problem.

In the following Figure 3, we present the open thermodynamic system cast/mold through the finite element

method and only one isotherm to identify the solidification process. The open thermodynamic system is shown with:

Commonsense and parts with serial numbers

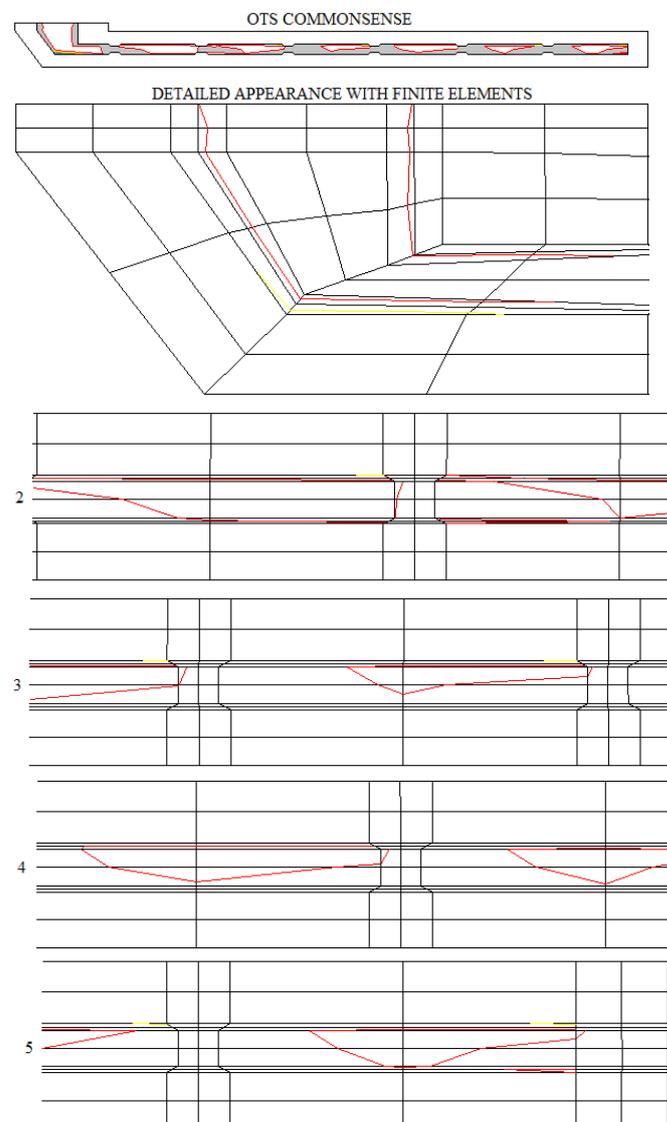


Fig. 3. Open thermodynamic cast/mold system K-test describe by Finite elements method. An isotherm (red color) only in the volume of cast. OTS commonsense and detailed appearance with Finite elements method.

The K-test form has protrusions that cause local vortices and help the concentration of unwanted impurities that is observed. Each subsequent melt-down for the use of end-of-life products is subject to a K-test [2, 5 ÷7].

The purpose of this work is to show the capabilities of the numerical description of the Stefan-Schwartz task of supporting and creating criteria for the circular use of secondary and fresh (primary) alloys in non-waste foundry by K-test & Chemical spectral analysis [2, 5 and 6].

### 2. Numerical Results of the Filling process of the cast of K-test and cast of Chemical Spectral Analysis

K-test is introduced on Figure 4 as follows: three identical consecutive time intervals, for the sake of clarity, the process is shown only in the casting, (but task is Stefan-Schwartz); follows the end of the filling: the cast in the mold for better system visibility and finally the full temperature field of the system:

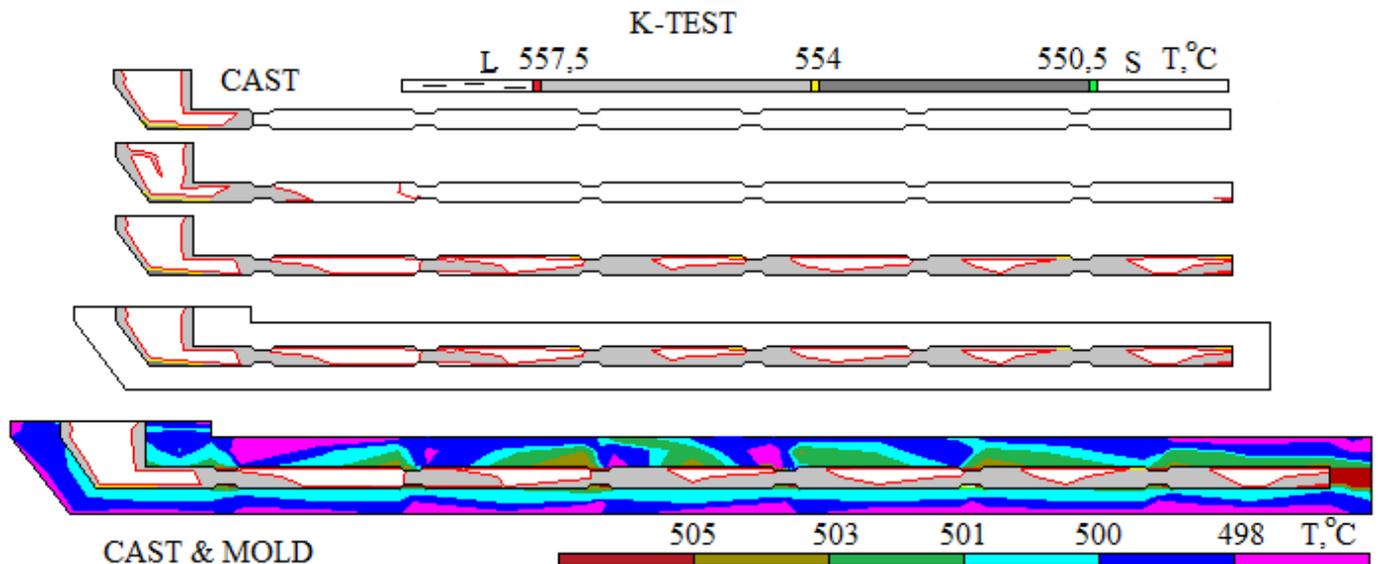


Fig. 4 Filling with liquids the mold of the K-test.

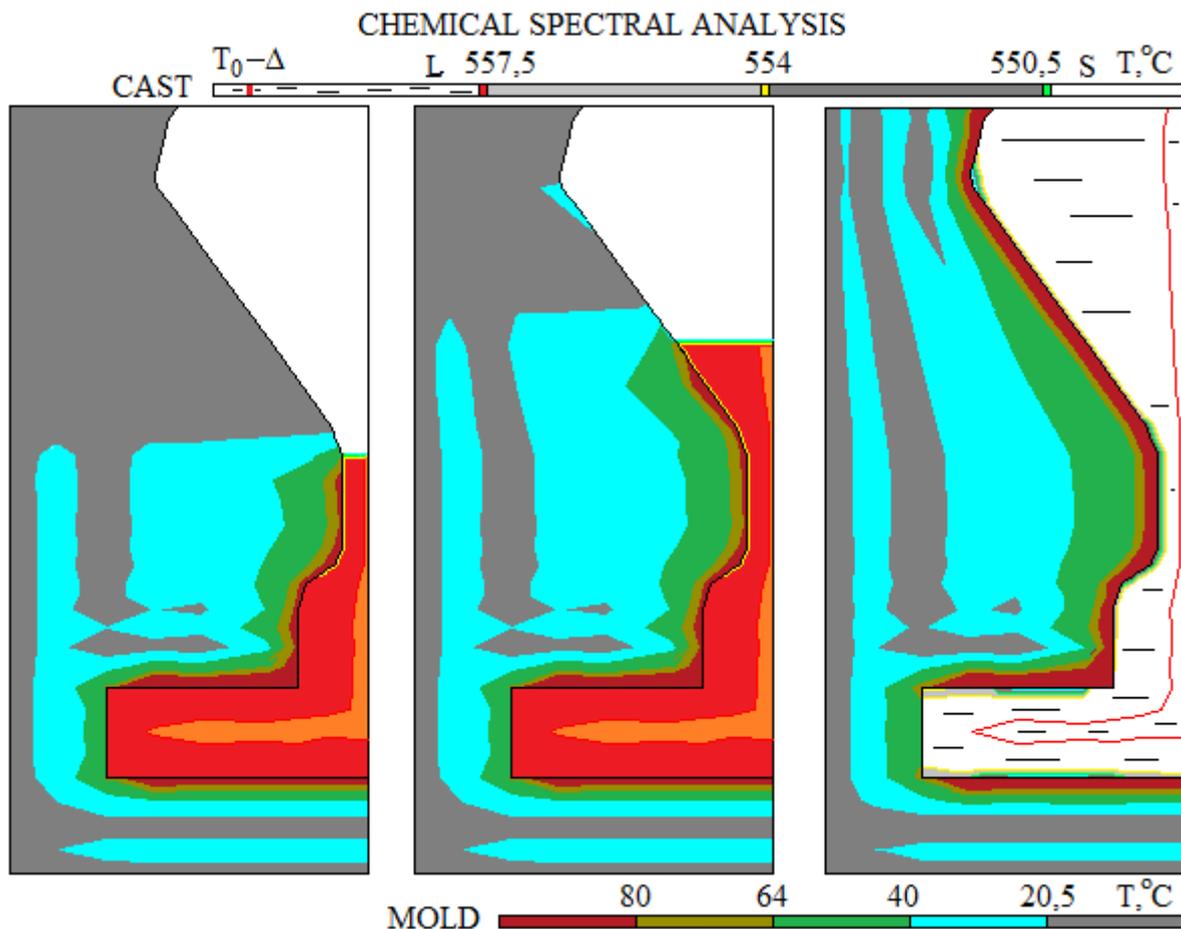


Fig. 5 Filling with liquid alloy the mold of the Chemical spectral analysis. These test is important: just before casting and overheating estimation ( $T_0-\Delta$ ) by solidifying the narrow portion of the channels between the overflow and the sample.

### 3. Overheating estimation by Chemical spectral analysis

To estimate the intensity of heat transfer in the cast/mold system in the chemical analysis, we propose that the value  $T_0 - \Delta$ , where  $T_0$  is the initial temperature of the liquid phase and  $\Delta$  is the tolerance. In the concrete case,  $T_0 = 664$  °C, and the melt isotherm shown is  $T = 660$  °C. Thus, at the end of the filling at  $\Delta = 4$  °C.

At the end of the filling, crystallization begins. Heat exchange is the maximum possible for the macro-scale process, which is very difficult to accomplish. Computational physics is expanding its capabilities here.

Parameters: initial melt temperature; the coefficients of heat transfer at the working and external surfaces of the mold are fundamental to the mathematical basis of foundry - the Stefan-Schwartz problem [2, 5÷7].

### 4. Ecology and Circular Economy

Waste-free foundry is naturally controlled by the processes demonstrated above. The K-test monitors the use of secondary alloys by the number of melts and concentrations of undesirable impurities. The chemical analysis is directly related to the microstructure of the castings. Summarizing the results of the two analyzes allows each foundry to create a specific database.

A very important process is also the melting zone as refining of the secondary alloys after the allowable number of melts. Thus, secondary alloys are an important source of raw material for both fresh metals and reclaimed primary alloys.

This combination of processes: K-test, Chemical spectral analysis and zone refining can also be applied to semiconductor materials, production of mono-crystal castings, etc. In 3D printer technology, a combination of the processes presented is also used. Similar possibilities for applications are in micro-casting technologies.

Precision software is very convenient for high-tech micro-foundries. With the help of computational mathematics and mathematical physics, the direction for digitalization is also in the polar. What is more, creating smart factories without people [1, 2, 3, 4, 5, 6, 7].

### 5. Conclusions

The mathematical models of the K-test and the Chemical Spectral Analysis allow us to determine the initial temperature conditions for each technological casting process.

The combination of the K-test, the chemical spectral analysis and the zone refining allow us to analyze and create a circular economy on a small geography scale, i.e. of interest to the micro-foundries.

### 6. Reference

1. K. Schwab, The fourth industrial revolution, Hermes, Plovdiv, 2016. (In Bulgarian) ISBN 978-954-26-1630-6
2. S. Bushev, Knowledge transfer Industry 4, International scientific journal, INDUSTRY 4.0, 51-54, year I, ISSUE 1/2016. ISSN (PRINT) 2543-8582
3. <https://ec.europa.eu> › ... › *Към кръгова икономика*
4. <https://www.europarl.europa.eu> › news › priorities › *namaliavane-na-otpadtsite*
5. A. S. Maneva, Thesis of PhD Investigating the structure and properties of castings from sub-eutectic aluminum alloys depending on the ratio of primary and secondary, Bulgarian academy sciences, Institute of metal science equipment and technologies with center of hydro- and aerodynamics, Sofia, 2013. (In Bulgarian)
6. S. Bushev, Thesis of PhD Controllability problems of crystallization process in casting, Technical University – Sofia, 1993.
7. S. Bushev, Full Use of Mathematics – Foundry, International Scientific Journal "Industry 4.0", 183-186, year II, ISSUE 4/2017, ISSN 2543-8582