A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 58 2013 Issue 3
DOI: 10.2478/amm-2013-0093

E. ZIÓŁKOWSKI*

ALGORITHM FOR BURDEN CALCULATION FOR FOUNDRY FURNACES USING CHARGE MATERIALS WITH AN UNCERTAIN COMPOSITION

ALGORYTM STEROWANIA PROCESEM NAMIAROWANIA WSADU DO PIECÓW ODLEWNICZYCH Z ZASTOSOWANIEM MATERIAŁÓW O NIEPRECYZYJNYM SKŁADZIE CHEMICZNYM

Calculation of charge burden to foundry furnaces by computing the proportions of particular charge materials is a most complicated task as a variety of technological aspects have to be considered. For practical and economic reasons, this problem is typically solved using computer-based optimisation methods, the main criterion being the optimal amount of charge materials related to the lowest costs of the burden. The problem is further complicated when the chemical composition of the charge materials is not accurately defined. So far the calculations of the charge burden were performed in order to work out the detailed melt procedure, which was to be modified and corrected by the trial and error method in subsequent melt processes.

An algorithm has been developed for use in calculating the charge burden depending on the target chemical composition of the casting alloy. Of particular importance is the application of the algorithm when the process conditions are changeable.

Keywords: burden calculation, melting optimization, control weighting of charge materials

Wyznaczanie namiaru wsadu do pieców odlewniczych, metodą obliczeń udziału poszczególnych materiałów wsadowych jest zadaniem złożonym z powodu znacznej liczby założeń technologicznych. Ze względów merytorycznych, praktycznych i ekonomicznych dąży się takiego zadania za pomocą komputerowych metod optymalizacyjnych, w których uwzględnia się kryterium optymalnej ilości materiałów przy najniższym koszcie całkowitym namiaru. Problem złożoności zadań jest tym większy im bardziej skład chemiczny materiałów wsadowych jest nieprecyzyjny. Dotychczas obliczanie namiaru wsadu było zazwyczaj realizowane wyłącznie na potrzeby przygotowania instrukcji wytopu, którą korygowano wynikami uzyskanymi metodą prób i błędów w kolejnych wytopach.

W artykule przedstawiono algorytm wyznaczania namiaru wsadu zestawianego w sposób zależny od zapotrzebowania na określony skład chemiczny produkowanego stopu odlewniczego. Szczególną uwagę zwrócono na możliwość efektywnego działania algorytmu w zmiennych warunkach technologicznych.

1. Introduction

Special efforts to optimise the costs of manufacturing of casting alloys prompts the introduction of novel IT solutions to determine the charge burden, i.e. to calculate the proportions of individual charge materials.

Calculation of the charge burden at the lowest possible costs taking into account a variety of charge materials with unspecified chemical composition becomes a formidable task. This difficulty is the consequence of the chemical composition of the charge materials being fuzzy and of incorrect weighting of particular components. Because of these inaccuracies, the proportions of particular chemical elements in the molten alloy may deviate from the desired value despite applying optimal calculation procedures. Attempts are made, therefore, to take corrective measures by using computer-controlled weighting and dosing units. This problem can be solved through applying the Author's algorithm for controlling the charge component weighting process.

2. Optimisation of charge burden to foundry furnaces

Semi-automatic or automatic control of weighting the charge components in the melting units is implemented only in those foundry plants which use charge materials with precisely defined parameters, such as chemical composition and level of disintegration. Because of most rigorous preparation procedures, such components are costly and hence their use is limited, for economic reasons. Commercially available charge materials, such as various grades of scrap steel and iron, come in form of single bits and have a chemical composition that is not precisely determined. All the same, they are widely used in foundry plants because of their low price.

Imprecise chemical composition of charge materials vastly complicates the calculation of the charge burden. Mathematical models of calculating the charge burden at the lowest cost and assuming the specified chemical composition of the charge materials are presented in the Author's works [1-2]. Various variants of the method used to determine the optimal

* AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, FACULTY OF FOUNDRY ENGINEERING, REYMONTA ST. 23, 30-059 KRAKÓW, POLAND

economically viable charge whose chemical composition may be uncertain are outlined in [3]. Finding the initial charge burden in the weighting process consists in finding their proportions xj such that the objective function written as:

$$burden\ cost = \sum_{j=1}^{N} c_j q_j x_j \quad (1)$$

should reach its minimum, for the following constraints being imposed:

$$\begin{cases} \underline{A}_i^w \cdot m_w \leqslant \sum_{j=1}^{N} \mathbf{A}_{ij} q_j x_j \leqslant \overline{A}_i^w \cdot m_w \\ 0 \leqslant \underline{x}_j \leqslant x_j \leqslant \overline{x}_j \leqslant m_w \\ \sum_{j=1}^{N} q_j x_j = m_w \\ i = 1, 2, \ldots, M \\ j = 1, 2, \ldots, N \end{cases} \quad (2)$$

where:

c_j	–	unit price of the j-th charge component (may be given in PLN/kg),
q_j	–	equal to 1 is the j-th charge component should be included in the calculation procedure, otherwise it is equal to 0,
x_j	–	mass or percentage fraction of the j-th component in the charge(expressed in kg or %),
$\underline{A}_i^w$, $\overline{A}_i^w$	–	lower and upper level of content of the i-th element in the charge material (%),
m_w	–	mass of the charge (in kg or equal to 100%),
$\mathbf{A}_{ij}$	–	matrix of content of the i-th element in the j-th charge component (%),
$\underline{x}_j \overline{x}_j$	–	lower and upper limit of content of the j-th component in the charge material (in kg or %),
M	–	the number of chemical elements taken into account in the charge burden calculations,
N	–	number of charge materials taken into account in the charge burden calculations.

The value x_j for which the objective function (1) reaches its minimum under the given constraints can be determined by a selected method of linear programming as both the objective function (1) and the equations and inequalities making up the system of constraints are expressed as linear functions.

Should the system of constraints (2) be contradictory, the set of the values of x_j cannot be determined. This contradictory nature may be attributable to either incorrect assumption of the proportions of particular components of the charge material or to the use of charge materials taken into account in the calculations (3). The possibility of contradictory assumptions and hence the lack of solution to the optimisation problem is a major obstacle in development of an automatic system for calculating the charge burden for foundry furnaces.

3. Algorithm for charge burden calculation

Let us first assume that in the optimisation problem involving the search for an optimal, economically viable charge burden, where the minimal value of the objective function (1) is to be determined, the system of constraints (2) is not contradictory, so the computed fractions x_j will become the input data in the start procedure for the system of weighting devices. High-precision weighting of charge materials, in accordance with the determined optimal burden calculation guarantees the desired chemical composition of the charge, yet in the foundry engineering practice some deviations can be encountered due to:

- variations in the level of disintegration of charge materials
- differences in precision levels during the weighting and dosage of particular charge components
- operators' errors

In order to eliminate the effects associated with imprecise weighting of the charge materials, an iterative charging algorithm is proposed:

Step 1. Work out a list of charge materials taken into account in the calculation procedure and arranged in the specific order: starting from materials with the largest mass of a single bit to those with the bits of the smaller mass. In further considerations we assume that q_i =1 for all considered charge materials.

Step 2. Develop a mathematical model of the optimisation problem involving the charge burden calculation (1)-(2)

Step 3. Determine the optimal economically viable charge burden, in other words find the theoretical values x_j ($j = 1, 2....N$) expressing the proportions of individual charge components.

Step 4. Set the value of the index l =1.

Step 5. Weight the l-th material and registers its content equal to x_i.

Step 6. Reformulate the optimisation process to yield:

Find the values of x_j to obtain the minimal value of the objective function:

$$burden\ cost = \sum_{j=1}^{N} c_j x_j \quad (3)$$

under the constraints:

$$\begin{cases} \underline{A}_i^w \cdot m_w \leqslant \sum_{j=1}^{N} \mathbf{A}_{ij} x_j \leqslant \overline{A}_i^w \cdot m_w \\ 0 \leqslant \underline{x}_j \leqslant x_j \leqslant \overline{x}_j \leqslant m_w \\ \sum_{j=1}^{N} x_j = m_w \\ x_1 = x_1^r \\ \vdots \\ x_l = x_l^r \\ i = 1, 2, \ldots, M \\ j = 1, 2, \ldots, N \end{cases} \quad (4)$$

Step 7. Solve the optimisation problem formulated in Step 6.

Step 8. Assume that $l = l + 1$. If $l \leqslant N$, then go back to Step 5, otherwise go to Step 9.

Step 9. Finish the charge weighting procedure.

An assumption is made that the charge material where the level of uncertainty involved in the weighting precision is the highest should be weighted first, and then the optimal proportion of the remaining components is established for thus weighted amount of the first material. Weighting each subsequent material leads to optimisation of the proportion of the remaining charge components.

The algorithm can control the system of charge material weighting provided that the calculations executed in Step 3 and Step 7 should yield the optimal charge burden; otherwise the algorithm should be interrupted, the weighting process should be stopped and the emergency procedure activated.

As the contradictory character of constraints cannot be wholly eliminated in practical applications and then the optimal charge burden cannot be determined, an alternative approach should be adopted to minimise the number of emergency conditions. One of the following operations is thus recommended:

1. Interrupt the preparation of the currently loaded charge portion and after emptying the charging unit, re-start the weighing process. This approach, however, has to be carefully programmed not only in the IT system but also in drives and controllers controlling the operation of dosing devices and transport units. The procedure of interruption of the weighting process and commencing the operation of charge re-load should be provided in those situations when the incorrect chemical composition of the charge cannot be modified through changing the parameters of the next charge batches to alter the composition of the molten alloy through mixing.
2. Finish the preparation of the current charge batch, working on the assumption that:
   a) finding the proportion of the next-in-line charge materials will be the effect of solving the minimisation problem whereby the deviation of the actual chemical composition of the prepared batch portion from the desired one should be minimised.
   b) Incorrect composition of the previous batch portion or portions would result in the change of the predetermined chemical composition of the new batch portion. One has to predict the number of subsequent batch portions which will be mixed after melting. Mixing of molten metal portions made from subsequent charge batches can be performed, in a defined range, in electric furnaces or in tank cupolas.

The procedure set forth in section 2a should be implemented in accordance with the thus formulated minimisation problem:

– find such proportions of the charge components x_s ($s = l + 1, \ldots N$) where l is the ordinal number of currently weighted charge so as to minimise the objective function given as:

$$\left[\sum_{j=1}^{N} \mathbf{A}_{ij} x_j - \frac{(\overline{A}_i^w - \underline{A}_i^w) \cdot m_w}{2}\right]^2 \rightarrow minimum \qquad (5)$$

under the following constraints:

$$\begin{cases} 0 \leqslant \underline{x}_s \leqslant x_s \leqslant \overline{x}_s \leqslant m_w \\ \sum_{j=1}^{N} x_j = m_w \\ x_1 = x_1^r \\ \vdots \\ x_l = x_l^r \\ i = 1, 2, \ldots, M \\ j = 1, 2, \ldots, N \end{cases} \qquad (6)$$

On account of the quadratic form of the objective function (5) and the linear system of constraints (6), the optimisation problem (5)-(6) can be solved by a selected method of quadratic programming, such as the Wolfe's method [3].

Solving the problem defined in section 2b consists in creating a mathematical model (similar to that recalled when solving the problem (3)-(4)) in which the values $\underline{A}_i^w$ and $\overline{A}_i^w$ should be modified accordingly such that mixture of the specified number of portions of molten metal should provide the desired chemical composition of the foundry alloy. The number of charge portions which can be mixed is dependent on such factors as furnace capacity, retention time of the molten metal and mixing intensity.

4. Summing-up

The proposed algorithm for controlling the charge burden to foundry furnaces can be implemented in any programming language to enable the design and fabrication of the IT system supporting the automatic or semi-automatic system for weighing and dosing of the charge components. Application of the method to determine the optimal charge burden from charge materials of uncertain chemical composition may help minimise the costs of molten alloy production. The developed algorithm for charge burden control allows for the use of an automatic gantry crane, so far used only in those foundry plants where the charge materials and their compositions were precisely controlled and managed accordingly.

REFERENCES

[1] E. Ziółkowski, Mathematical programming methods using in optimisation of melting in foundry furnaces, Modelowanie i optymalizacja. Metody i zastosowania, pod red. Janusza Kacprzyka, Jana Węglarza. Warszawa: Akademicka Oficyna Wydawnicza EXIT, 2002 (in Polish).

[2] E. Ziółkowski, Algorithms of furnace charge burden optimisation in foundries. Archives of Metallurgy and Materials/Polish Academy of Sciences. Committee of Metallurgy. Institute of Metallurgy and Materials Science; ISSN 1733-3490, **52**, 3, 487-495 (2007).

[3] E. Ziółkowski, Modelling the burden calculations for the foundry furnaces considering charge materials with fuzzy parameters. Kraków: AGH Uczelniane Wydawnictwa Naukowo-Dydaktyczne, 2007. ISSN 0867-6631, 169 (in Polish).

This article was first presented at the VI International Conference "DEVELOPMENT TRENDS IN MECHANIZATION OF FOUNDRY PROCESSES", Inwałd, 5-7.09.2013

Received: 20 January 2013.