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Scrap management by statistical evaluation of EAF process data

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Abstract

The electric arc furnace (EAF) is a process for melting steel scrap with electricity. In this paper a method for estimating scrap properties based on the evaluation of historical process data is discussed and a series of scrap management strategies based on the estimated properties are suggested. Data from four Swedish EAFs have been analysed and on-line software applications have been developed and installed at one steel plant. The results from this study show that it is possible to use partial least squares to provide accurate estimates of the levels of impurity (Cu, Sn, As) and alloy content (Cr, Ni, Mo) in scrap grades. The degree of explained variation (R^2) obtained in this study ranges between 40% and 70% for impurity elements and 70% and 100% for alloy elements. The mean prediction errors (RMSEE) are in some cases small enough to improve steel quality control in terms of chemical analysis. To ensure that the estimates remain consistent with scrap quality, it is suggested that the prediction models be updated on a regular basis.

Keywords: Steel industry; Electric arc furnace; Statistical analysis; Linear multivariable systems; Multivariate quality control; Optimisation problems

1. Introduction

Steel scrap is the most important raw material for electric steelmaking, contributing between 60% and 80% of total production costs. In addition, the degree of which the electric arc furnace (EAF) process may be controlled and optimised is limited by fluctuations in scrap quality. Therefore quick estimations of properties of different steel scrap grades are very important for improving the control and optimisation of the EAF process. Most countries have national classification systems for steel scrap, but there is also a European classification system that the EU-countries use for international scrap trade (Birat, Le Coq, Russo, Gonzales, & Laraudogoitia, 2002). Steel scrap is usually graded in terms of size distribution, chemistry, density, origin and processing method. Some meltshops have internal classification systems that further divide the standard scrap grades into subtypes, and also a number of internal scrap grades (scrap produced within the steel plant). However, the scrap grading systems are designed for commercial purposes and the variation in scrap properties within each scrap grade is high.

In general scrap properties may be divided into two main categories, physicochemical properties and process related properties. Physicochemical properties (chemical composition, density, specific surface area, size distribution, melting temperature, specific heat capacity, metallic/organic/oxidic content) are only dependent on the particular scrap grade and are best determined by controlled experiments in laboratories. Process related properties (yield coefficients, specific energy consumption, contribution to chemistry of steel and slag, contribution to basket and furnace filling degree, contribution to dust generation and off gas composition) depend on both the process conditions and the other materials in the scrap mix. Therefore, the process-related properties for the same scrap grade may vary considerably between different meltshops.

Chemical analysis, conductivity, metal content and size distribution may be measured or estimated for individual

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pieces of scrap and/or random samples but the fluctuation in scrap quality is often too large for these measurements to be representative for the whole population of a scrap lot on the scrap yard.

Experimental design methods have been proposed to set up a series of experimental heats that can then be used to estimate the scrap properties (Birat et al., 2002). However, because of the variation in process conditions and fluctuations in scrap quality each experiment would have to be repeated several times. The number of experiments needed to get estimations for all scrap grades can therefore be very high, depending on the number of scrap grades that are used, rendering this approach unsuitable.

An alternative to designed experiments is to firstly extract large quantities of data from process databases (Birat et al., 2002). Advanced statistical methods can then be used to analyse the combined effect of scrap mix and process conditions on the end conditions (chemical analysis of the liquid steel, energy consumption and metal yield). This is the approach investigated in this work.

The objective of this study is to estimate process related properties for several meltshops through the statistical evaluation of process data collected from the respective EAFs. Details of the participating meltshops are given in Table 1.

The strategy was to begin by developing prediction models for steel chemical analysis, specific electrical energy consumption and yield. By analysis of the regression coefficients of these models, it is shown in Section 6 that the mean of the desired scrap properties can be estimated for some scrap grades. Some scrap management software applications based on the estimated properties are then discussed in Section 7. Besides the applications mentioned in Section 7, better estimation of scrap properties will allow more detailed definition of initial conditions for various MPC applications based on dynamic process models for EAFs (Bekker, Craig, & Pistorius, 2000; Oosthuzen, Craig, & Pistorius, 2004).

2. Collection of process data

The first step is to consider which parameters may be relevant to the end conditions that are to be predicted. The parameters assumed to be relevant are listed in Table 2. Depending on the capabilities of the process logging systems of the meltshops, variables representing the parameters listed in Table 2 may or may not be available in the historical database.

2.1. Variable availability

In this section a brief overview of the considerations and important aspects of the data logging and availability of variables representing the relevant process parameters is discussed. A summary of the available data at the four participating meltshops is presented in Table 3. Table 3

Table 1
Participating meltshops

Meltshop name	Location	No of heats	Products
Ovako Steel AB	Hofors, Sweden	3716	Bearing steels
Fundia Special Bar AB	Smedjebacken, sweden	3837	Long products (low alloyed)
Sandvik Materials Technology	Sandviken, Sweden	3085	Stainless and speciality steels
Fundia Armering AS	Mo I Rana, Norway	969	Reinforcement bars (carbon grades)

Table 2
Relevant parameters for end conditions in EAFs

Parameter	End condition			Parameter	End condition		
	1	2	3		1	2	3
Weight of materials in the charge mix (scrap, alloys, coke, slagformers)	x	x	x	Burner and lance practice (position and penetration depth)	x	x	x
Consumption of coal and oxygen via lances	x	x	x	Distribution of scrap in baskets and furnace		x	x
Consumption of gas, oil and oxygen via burners	x	x	x	Slag carry over		x	x
Weight and composition of the hot heel (metal and slag)	x	x	x	Slag foaming conditions	x	x	x
Thermal status of the furnace		x		Alloys and slagformers in ladle		x	x
Temperature of the charge material mix		x		Furnace and basket filling degree		x	
Heating profile	x	x	x	Power-on, power-off and tap to tap times		x	x

1—Chemical analysis, 2—energy consumption, 3—yield.