

Modeling of Steel Oxidation Resistance for Furnace Bars of Conveyor-Type Machine for Iron-Ore Pellets Roasting

M. M. Gasik¹, A. N. Panchenko²

¹*University Fund "Aalto", Finland*

P.O. Box 6200, 02015 TKK, Espoo, Finland

²*National Metallurgical Academy of Ukraine*

4 Gagarin Ave., Dnipropetrovsk, 49600, Ukraine

Results of mathematical modeling of oxidation resistance of complex-alloyed steels and alloys by self-organising maps method are presented based on experimental data of mass variation in the process of oxidation. Constructed statistical metamodel enables to forecast oxidation resistance of steels 24Cr-12Ni-Si, 28Cr-2Ni-Si and 14Cr-8Mn-2Al for cast furnace bars of roast machines.

Keywords: HEAT-RESISTANCE, STEEL, FURNACE BARS, ROAST MACHINES, MODELING, MASS VARIATION, METAMODEL

Introduction

Selection of sparingly alloyed heat-resistant steels for furnace bars is one of actual problems related to maintainability of burning and sintering machines. Now furnace bars for iron-ore pellet roasting are made of expensive hard-alloyed steels. High operating temperatures, presence of oxides of alkali metals, oxidizing atmosphere and abrasive-mechanical deterioration reduce durability of furnace bars to several months and lead to loss of their weight to 50 % [1, 2]. Along with usual oxidation, oxides of alkali metals form compounds and low-melting compositions with oxides of chromium and iron which leads to accelerated fracture of material. It was shown on the example of analysis of scaling on furnace bars in machine Lurgi-552 unfit for further service because of chemical and abrasive damage [1-3]. In such conditions the problem of definition of steel heat-resistance is rather difficult because of large number of cofactors, from which not all are well studied.

The problem of definition of steel heat-resistance only under conditions of oxidation where material sample mass variation due to formation of oxides can be such criterion of heat-resistance is considered in present research. To

simplify the problem we did not consider the factors of "hot corrosion" (in particular, interaction with alkaline oxides) and abrasive damage.

Results and Discussion

Comparative analysis of heat-resistance of steels

Many criteria were suggested to compare heat-resistance of steels and alloys. Method of incomplete factorial experiment was widely used earlier. Owing to complicated dependences between content of alloying elements, oxidation conditions (temperature, time, composition and gas flow velocity), good correlation dependences are almost impossible to determine as it requires a great number of experiments with variations on each parameter [4, 5].

We used statistical method based on several tens of experiments in present work. Obtained results of dependence of sample weight increment on alloy composition, temperature, oxidation time (to 1000 hours) and gas phase composition [5, 6] were used in the form of table. The statistical metamodel constructed on the basis of obtained results enables to forecast "optimum" composition of steel and mass variation of other steel samples which were not used in the initial experiments.

Experimental data [6] included steels 20X12M (X20), 10X18H12Г2H6 (347HFG), X26H20ГH6 (HR3C), X24H24B5Д3 (Sanicro 25) and also nickel high-temperature alloys X20H50K20M5T2 (A263 Nimonic) and X23H53K13M10Ю (A617 Inconel). A wide range of gas phase composition with various oxygen potential (from 3 to 20 % O, 15-60 % CO₂ and to 30 % H₂O) was investigated in [6]. Further we have analyzed only alloy composition and its effect on variation of sample mass after oxidation during 1000 hours at temperatures above 650 °C. This is because the specified composition of gas phase, gas-dynamic and temperature regime in furnace bar area are not clearly identified.

Experimental data were processed by self-organising maps method (SOM) developed at Helsinki Technological University in 1980s [7] (**Figure 1**). Each experimental point represents a vector covering composition of steel, gaseous atmosphere used in the experiments [6], temperature, time and mass variation per unit area. **Figure 1** shows all data on experiments [6] including points with low heat-resistance.

Idea of SOM maps consists in creation of artificial neural networks similar to brain neurons. The map represents a network of coupled neurons

in the set linear space (in this case, co-ordinates $x_1, x_2, x_3, \dots, x_n$ are all variables specified above). Random vectors of network with each iteration come closer to vectors of experimental data [7]. Unlike the correlation method, change of one neuron in the network affects the status of the next neurons. Besides, the nearest cells reflect affinity of original data vectors [7].

Taking into account this feature, this method enables to keep topological structure of initial multidimensional data having represented its two-dimensional map (it can be compared to cartography process when three-dimensional surface of the Earth in the form of globe is projected on a flat map - distortions are inevitable, however they can be minimized by means of selection of appropriate two-dimensional projection).

In the same way as on the geographical map, close arrangement of certain parameters means also their closer interconnection in the real space. For example, small maps for cuprum and tungsten in the left in **Figure 1** are almost equal by color spectrum and are located near but on the maximum distance from the map for change of sample mass. So we can assume that their effect on steel mass variation is similar and minimum simultaneously.

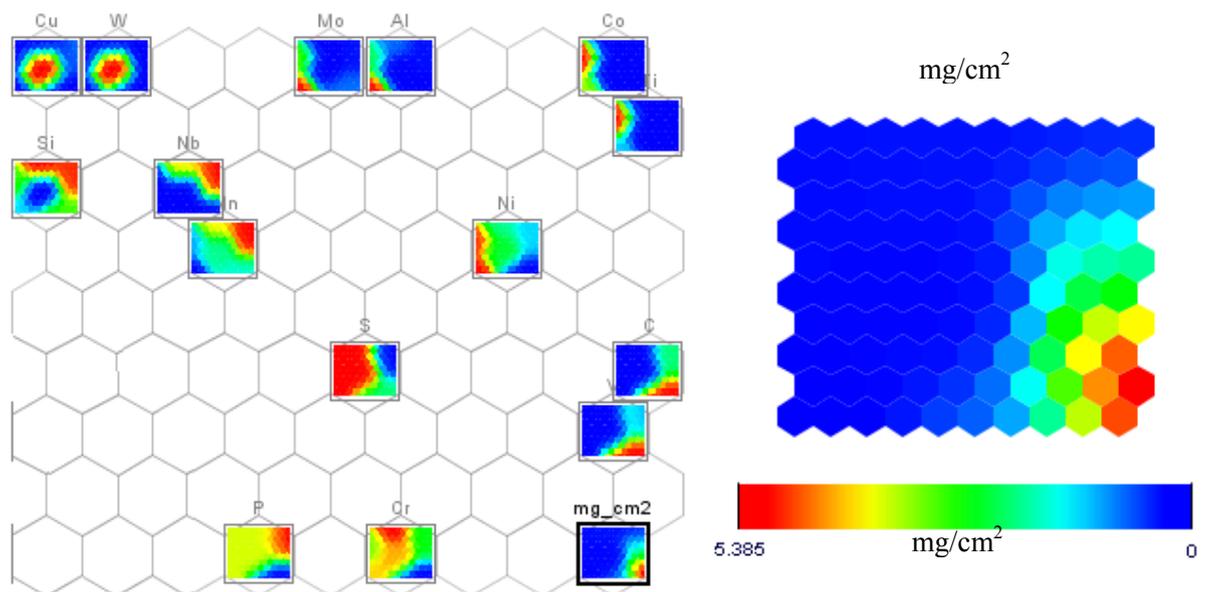


Figure 1. Self-organising map for sample mass increment (mg/cm^2) according to data in [6]

Alloys that could provide zero or very small gain in weight are of the greatest interest. If filter only those areas where weight increment for 1000 hours does not exceed 0.05 mg/cm^2 in **Figure 1**, the "optimum" alloy should be characterized by the following parameters, % mass.: Cr 20-25; C <0.1; Ni > 22; Nb <0.2; Si <0.25; Mn 0.1-0.8; Mo <5.5; Al <0.8. Such elements as Ti, Co, W, Cu almost do not have essential effect (role of vanadium is multiple-valued as there are no enough experimental data with more vanadium variation). It is necessary to note that such forecasts should be necessarily checked experimentally, however it was not the task of present research. In this case, we forecasted heat-resistance of other similar steels which have not been investigated in work [6].

Results of modeling of steel heat-resistance for furnace bars and their analysis

Now, steel grades 40X24H12CJI and 75X28H2CJI are used for furnace bars of roasting and sintering machines. Possibility of application of steel 30X14Г8Ю2JI is investigated also. Effect of basic elements (C, Cr, Ni, Al, Mn, Si) on heat-resistance of steel (mass variation during oxidation) is of theoretical and practical interest. The content of all other elements was at the minimum level and Principal Component Analysis (**Figure 2**) was carried out. As for self-organising maps, this analysis is related to minimization of information loss at projecting, however assumes

only linear transformation of co-ordinates. It is supposed that the linear combination of main elements content and heat-resistance will enable to define the basic trends for selection of "optimum" composition of steel.

Figure 2 illustrates the experimental points [6] in co-ordinates of the most important basic components PC1 and PC2 of vector (i.e. linear combination of initial parameters providing the best correlation). Arrows for corresponding variables are proportional to their contribution to values PC1 and PC2 (the longer the arrow, the more contribution). Collinearity of arrows shows their joint effect. It is possible to note that mass variation vector correlates with carbon and chromium the most while the effect of other elements is less significant. In other words, chromium and carbon (in these experiments) are the most important variables from the point of view of heat-resistance (oxidation).

In view of the above, a metamodel was developed with the use of special software that enables to forecast behavior (variation of material mass during oxidizing) for industrial steels. In this case we used method of radial basis functions [8]. This method is convenient for multifactorial forecasting as does not need interpolation and uses automatic normalization of data on the basis of algorithm of minimization of average error from consecutive exclusion of each experimental point from the analysis.

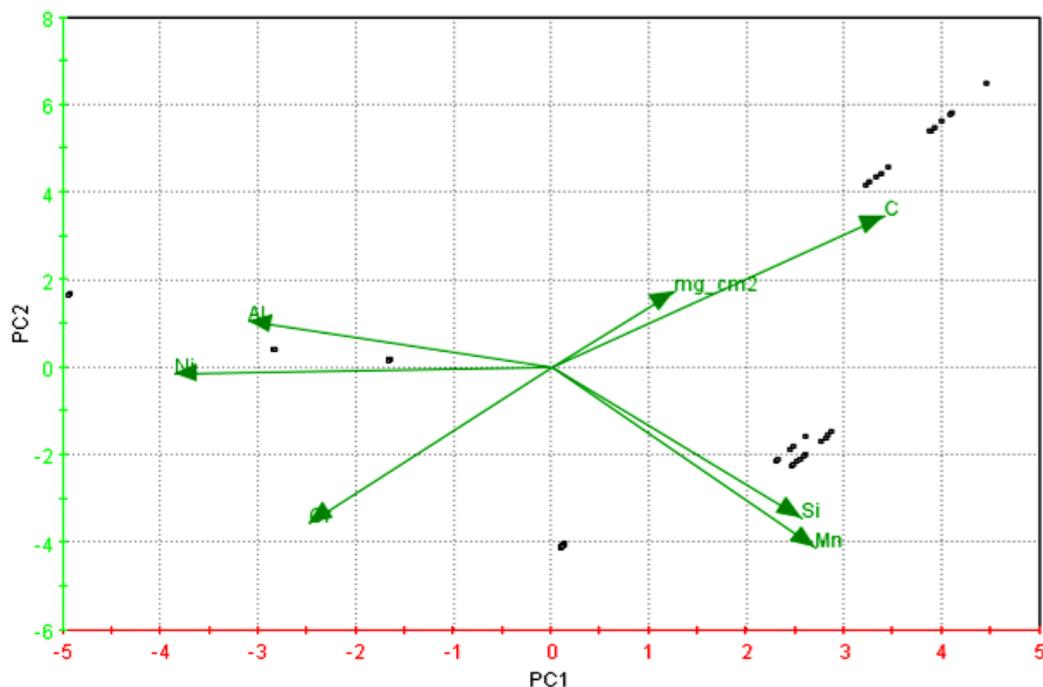


Figure 2. Experimental data [6] (points) in co-ordinates of their values

The limitation of the method is that it is hard to obtain direct functional dependence as in each case it is necessary to make numerical but not analytical calculation. The example of three-dimensional diagram of response function (i.e. expected variation of sample mass after 1000 hours of oxidation at temperature above 650 °C) is shown in **Figure 3** as function of nickel and chromium content on silicon concentration to 1 %. It follows from **Figure 3** that chromium and nickel content increase leads to drop of heat-resistance (smaller increase of sample mass is expected). The similar model is shown in **Figure 4** for nickel-free steel with 14 % of chromium as a function of content of manganese and aluminum. From here we can conclude that manganese addition in steel with 14 % of chromium is the most effective for high-temperature strength raise at small contents of aluminum. If concentration of aluminum exceeds

3 %, manganese has a little effect on heat-resistance of 14 % Cr steel.

The higher expected heat-resistance of steel with lower content of chromium (compare **Figures 3** and **4**) can be explained, for example, by that at high content of chromium and oxidation potential the formation of hexivalent chromium and chromates [3, 4] is observed. Using data of metamodel from **Figures 3, 4** it is possible to count the expected weight increment of steels after 1000 hours of oxidation: for 40X24H12CJI about 1.18 mg/cm², for 75X28H2CJI 1.5 mg/cm² and for 30X14Г8Ю2JI 0.32 mg/cm².

Thus, the latter steel grade is the most preferable in view of expected heat-resistance and more economic alloying elements. It is necessary to note that this conclusion should be confirmed also experimentally by measuring of oxidation without alkaline components and abrasive damage.

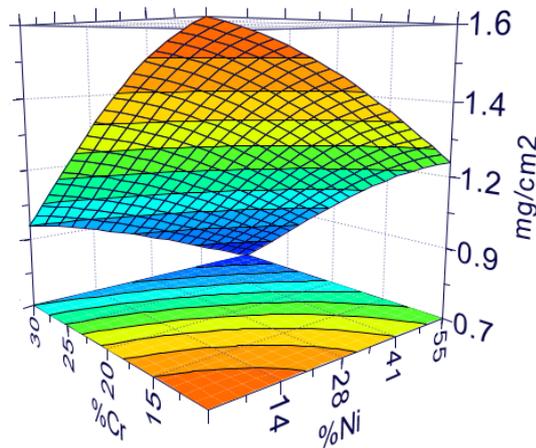


Figure 3. Metamodel of expected mass variation for steels Cr-Ni-1 % Si

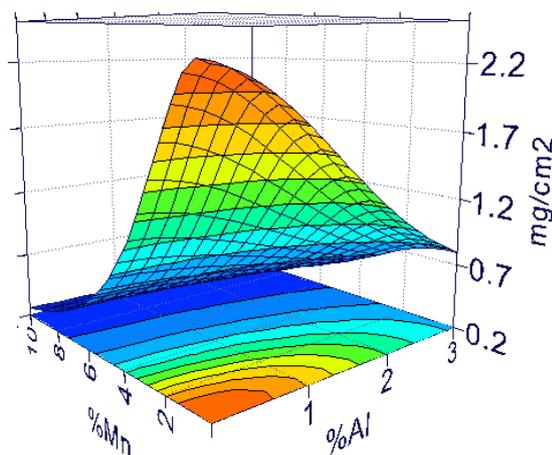


Figure 4. Metamodel of expected mass variation for steels 14 % Cr-Mn-Al

Conclusions

1. Statistical analysis is carried out and interrelations between various factors (composition, temperature, time) and sample mass variation with the use of self-organising maps and Principal Component Analysis are determined based on experimental data on heat-resistance of steels and alloys in gas environments CO₂-O₂-H₂O-N₂ for up to 1000 hours of oxidation.

2. The major effect of chromium and carbon on heat-resistance of steels in the investigated range is determined and behavior of heat-resistance of steels of other compositions with application of metamodelling on the system of radial basis functions is forecasted.

3. Using metamodel data, the probable weight increment of steels after 1000 hours of oxidation is counted: 40X24H12CJI 1.18 mg/cm², 75X28H2CJI 1.5 mg/cm², 30X14Г8Ю2JI 0.32 mg/cm². Thus, steel 30X14Г8Ю2JI is the most preferable in view of expected heat-resistance and more economic alloying. Further, behavior of steels taking into account alkaline components and abrasive damage can be investigated.

References

1. M. I. Gasik, A. D. Uchitel, A. N. Panchenko. *Metallurgicheskaya i Gornorudnaya Promyshlennost*, 2008, No. 1, pp. 55-61. *
2. M. I. Gasik, A. D. Uchitel, A. N. Panchenko. *Metallurgicheskaya i Gornorudnaya Promyshlennost*, 2008, No. 2, pp. 26-31. *
3. M. I. Gasik, A. D. Uchitel, A. N. Panchenko. *Stal*, 2009, No. 1, pp. 2-7. *

4. M. Gasik *Materials for Fuel Cells*, Woodhead Publ., UK, 2008, 512 p.

5. M. Malinina, M. Gasik. *World J. Eng.*, 2008, Vol. 5, No. 1, pp. 56-62.

6. K. Penttilä, H. Sommarström, K. Vänskä, M. Hämmäläinen, M. Gasik. *Research Report VTT-R-01279-10*, VTT, Espoo, Finland, 2010, 25 p.

7. T. Kohonen. *Biol. Cybern.*, 1982, No. 43, pp. 59-69.

8. M. D. Buhmann. *Radial Basis Functions: Theory and Implementations*, Cambridge University Press, UK, 2003, 274 p.

* Published in Russian

Received August 04, 2010

Моделирование жаростойкости сталей для колосников конвейерных машинах обжига железорудных окатышей

Гасик М.М., Панченко А.Н.

Изложены результаты математического моделирования жаростойкости группы сложнолегированных сталей и сплавов по методу самоорганизующихся карт на основании экспериментальных данных по изменению веса при окислении. Построена статистическая метамодель, позволившая спрогнозировать жаростойкость сталей 40X24H12CJI, 75X28H2CJI и 30X14Г8Ю2JI для литых колосников обжиговых машин.