SAATY'S METHOD AS A TOOL USED TO DETERMINE THE IMPORTANCE OF IRON ORE EVALUATION CRITERIA

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Abstract

The quality of ore raw materials significantly affects the technological aspects of the blast furnace process. The comparison of iron ores is complicated because of the wide range of parameters which can be used to evaluate the ores. In terms of categories, they may include physical, chemical, mechanical, and other properties. From a general point of view, current methodologies evaluating the quality of ore raw materials can be divided into two groups of methods. The first one tries to simulate the conditions which ore is exposed to when going down the stack. Another approach is based on single-purpose tests, designed to determine a selected indicator of metallurgical quality. Both of these approaches allow you to acquire a number of key information about the quality of ore raw materials and about the course of the blast furnace process. The application of these methods, however, does not provide complex information offering a global view of the total value of ore raw materials. The key factor of this process is to determine the weights of the individual criteria according to which the ore is evaluated. The determination of the weights is very inaccurate, provided that it is performed solely on the basis of an intuitive assessment of the importance of the criteria. An exact evaluation of the importance requires a utilization of some of the mathematical instruments. This article analyzes the use of Saaty's Method when determining the importance of the individual criteria used in the evaluation of the quality of iron ores.

Keywords: ore, iron, costs, technology

1. INTRODUCTION

Iron ore is one of the most widespread minerals. The resources of this raw material can be found in virtually all parts of the world. However, only selected sites contain raw material that is suitable for use in blast furnaces. The primary criterion will always be the content of iron. In rich magnetite and hematite ores, the metal content ranges from 57 to 65 %. In case of limonite ore, the Fe content may fall down to 38 %. Poor limonite and silicate ores may have a minimum metal content of 30 %. In exceptional cases, in large stocks and with suitable storage conditions, the acceptable Fe content varies in the range of 25 - 30 % [1]. With such a low metal content, however, the ore must also meet other conditions. One of them may be the adequate value of alkalinity coefficient ($B=CaO+MgO / SiO_2+Al_2O_3$). Recrements of Ca or Mg are welcome in iron ore, while excessive amounts of SiO_2 and Al_2O_3 have negative consequences [2]. Higher amounts of alkaline versus acidic recrements expressed by the coefficient of alkalinity thus increase the value of mined ore. The rating of quality of ore raw material is very complex and often inconsistent in different countries [3]. Apart from the above mentioned iron content and the coefficient of alkalinity, the evaluation may also include a number of other relevant criteria. Generally, these criteria can be divided into several categories:

- Chemical properties - which include mainly the iron content, alkalinity, but also the content of harmful substances (S, P, Cd, Zn, Pb, As, Na_2O, K_2O) [4].
- Physical properties - humidity, lumpiness, granulometric homogeneity, density, bulk properties, porosity, and magnetic properties.
- Technological properties:

- Strength characteristics - the strength of ore raw materials is determined by the tumbling test and is given by the percentage share of pieces of ore raw materials with size exceeding 6.3 mm after the test. The determined parameters also include abradability, which is determined by the percentages share of pieces of ore raw material with size smaller than 0.5 mm after the test (compressive strength on a pellet is tested in case of pellets) [4].
- Reducibility - is the summary of the raw material properties determining the rate of conversion of iron oxides to metal through the effect of the reducing agents. The measure of reducibility is represented by the weight loss of ore sample per unit of time due to the transition of oxygen to gas [5].
- Thermoplastic (properties) - are given by the initial softening temperature and the final softening temperature. The difference between these temperatures is referred to as the softening interval. The values of these temperatures are measured from the ore sample deformation under load with increasing temperature. The initial softening temperature should be as high as possible, while the value of the softening interval should be as low as possible.

The above enumerated properties of ore raw material clearly show that the evaluation will always require you to choose only certain relevant characteristics. The complexity of the evaluation is also influenced by the fact that a number of the so-called harmful elements may have different effect in different stages of the production of iron (later of steel) [6]. That is why only the classification of ores into the established categories (quality grades of ores) is used to simplify the evaluation of ores. There are three basic groups of ores, which are usually evaluated according to the following criteria: Content: Fe, SiO_2, Al_2O_3, P, S; humidity; grain size distribution (6 - 40 mm, above 40 mm, below 6 mm) [7]. Values for the three categories of ores are subsequently determined for all relevant criteria. This classification is sometimes supplemented by the aforementioned coefficient of alkalinity [8]. If you want to perform a complex evaluation of an ore raw material, you can use mathematical multi-criteria decision-making. However, in this case, it is first necessary to determine the importance (weight of the individual criteria). This can be performed in an exact manner by means of Saaty's Method.

2. PROBLEM FORMULATION

Saaty's Method is based on a quantitative pair comparison of criteria. When creating pair comparisons $S = (s_{ij})$, $i,j = 1,2,\ldots,k$, 1 - 9 scale and reciprocal values are often applied. The s_{ij} matrix elements are interpreted as the estimates of the share of the i-th criterion and the j-th criterion. Saaty's Method is thus based on the determination of the weights of the individual criteria based on the definition of mutual preferences [9]. A value of strength of the mutual preference is determined for each pair of criteria, which is subsequently written in the matrix. The evaluation is based on the use of point scale shown in **Table 1**.

Table 1 System of evaluation of the individual criteria

Definition of preferences	
Numerical	Verbal
1	The criteria are equally important
3	The first criterion is slightly more important than the other one
5	The first criterion is strongly more important than the other one
7	The first criterion is very strongly more important than the other one
9	The first criterion is absolutely more important than the other one

For a more sensitive definition of the preferences, it is also possible to use additional intermediate stages (2, 4, 6, 8, 10). The size of preferences of the *i*-th criterion compared to the *j*-th criterion can be arrange into Saaty's matrix whose elements s_{ij} represent the estimates of the shares of weights of the criteria (how many times one criterion is more important than the other), according to formula (1).

$$s_{ji} \approx \frac{v_i}{v_j}, i, j = 1,2,\ldots,n \tag{1}$$

Matrix *S* is the square order of *n* x *n* and its elements meet the equation:

$$s_{ji} = \frac{1}{v_j}, i, j = 1,2,\ldots,n \tag{2}$$

The matrix is therefore inherently reciprocal and its diagonal values are always one. This is due to the fact that each criterion in itself is equivalent. Normalized geometric mean of the lines of Saaty's matrix, presented in equation (3), is used to determine the final weights of each criterion.

$$w_i = \frac{\left[\prod_{j=1}^{n} s_{ij}\right]^{\frac{1}{n}}}{\sum_{k=1}^{n}\left[\prod_{j=1}^{n} s_{kj}\right]^{\frac{1}{n}}} \tag{3}$$

3. EXPERIMENTAL WORK

The following criteria have been selected for the evaluation of ore raw materials within the scope of the performed survey: K_1 - the price of ore, K_2 - the iron content, K_3 - the strength of ores after the tumbling test according to ISO (%), K_4 - lumpiness homogeneity (Vx, %), K_5 - amount of P (%), K_6 - reducibility (%), and K_7 - humidity (%). These were the criteria the Saaty's Method was applied for. All the criteria were evaluated against each other and the following Saaty's matrix was created:

$$S = \begin{pmatrix} 1 & 1 & 5 & 3 & 3 & 3 & 9 \\ 1 & 1 & 5 & 3 & 5 & 3 & 9 \\ 1/5 & 1/5 & 1 & 3 & 1 & 3 & 5 \\ 1/3 & 1/3 & 1/3 & 1 & 1/5 & 3 & 3 \\ 1/3 & 1/5 & 1 & 5 & 1 & 3 & 3 \\ 1/3 & 1/3 & 1/3 & 1/3 & 1/3 & 1 & 3 \\ 1/9 & 1/9 & 1/5 & 1/3 & 1/3 & 1/3 & 1 \end{pmatrix}$$

The values above the main diagonal thus represent the strength of preference (e.g. K_1 is preferred before K_3 as - strongly more significant = 5; written in *S* matrix in position a_{13}). The values below the diagonal represent the inverse values and they represent the strength of preference of, for example, K_3 before K_1 (1/5), according to equation (2). The same method was used to evaluate all pair comparison criteria included in the *S* matrix.

The final step is to determine the normalized geometric mean values of the lines using equation (3). This is the way used to determine the weights of all the criteria.

The example of calculation in case of criterion no. 1:

$$w_i = \frac{\left[\prod_{j=1}^{n} s_{ij}\right]^{\frac{1}{n}}}{\sum_{k=1}^{n}\left[\prod_{j=1}^{n} s_{kj}\right]^{\frac{1}{n}}} = \frac{2,7584}{9,4599} = 0,2916 \qquad (4)$$

The determination of the values of all weights is shown in **Table 2** and they are shown graphically in **Fig. 1**. The value of weight determines the importance of each criterion. The most important criterion determined using the Saaty's Method was criterion no. 2 (the weight of 0.3137), while the least important criterion was no. 7 (the weight of 0.0280). The advantage of the Saaty's Method is that it allows you to evaluate the mutual intensity of preferences among the individual criteria. This significantly increases the informative value of the determined weights. It is very useful to apply this method in the area of the evaluation of ores in situations, where an even higher number of criteria will be evaluated. They can be divided according to the character of the monitored variable.

Table 2 Weights of criteria used to evaluate ores determined by means of Saaty's Method

Criterion	K_1	K_2	K_3	K_4	K_5	K_6	K_7
$\left[\prod_{j=1}^{n} s_{ij}\right]^{\frac{1}{n}}$	2.7584	2.9672	1.0876	0.6789	1.1698	0.5334	0.2647
$\sum_{k=1}^{n}\left[\prod_{j=1}^{n} s_{ij}\right]^{\frac{1}{n}}$	9.4599	9.4599	9.4599	9.4599	9.4599	9.4599	9.4599
Criterion weight	0.2916	0.3137	0.1150	0.0718	0.1237	0.0564	0.0280

CONCLUSIONS

The evaluation of ore raw materials is very complicated because of the wide range of different criteria. If we want to find an effective evaluation system of the evaluation of raw materials, we must first establish a limited number of relevant criteria and their significance (weight). The values obtained for the monitored criteria are shown in **Fig. 1** and **Table 2**.

Saaty's Method allows you to set the weights of the individual criteria using the principle of pair comparison. All criteria are compared in this way according to a rating scale that classifies the relations of the individual criteria. The identified weights of all criteria can then be used for a complex evaluation of ore raw materials. Applying Saaty's Method is suitable if you want to determine the importance of the criteria, the number of which does not exceed twenty. With higher number of criteria, it is difficult to make a valid comparison using the pair method.

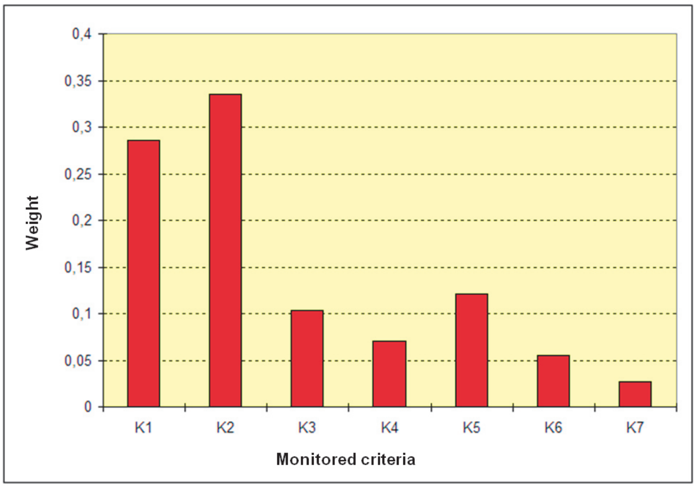

Fig. 1 The values of weights identified using Saaty's Method

The application of the methods of multi-criteria evaluation within the scope of the comparison of ore raw materials appears to be a convenient tool that allows you to achieve a global view of the overall value. The key factor will, however, always be an accurate and objective determination of the importance of the individual criteria. On the basis of the conducted research, we can clearly recommend the application of Saaty's Method in this process. An accurate determination of the value of ore raw material can have crucial impact on the choice of ore resources for the blast furnace process. At the same time, it may form the basis for effective negotiations with the suppliers.

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