An Analytical Way to Comparing the Affective Parameters on Iranian Pellet Strength

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Abstract

Iron ore pellets are the raw materials for direct reduction process of iron ore to sponge iron pellets and is an important step in the iron and steel production chain. Many of the defects in direct reduction and steel making processes could be identified in the iron ore processing stage. Therefore, the purpose of this study was to select the correct suppliers of iron ore pellets for direct reduction units based on criteria affecting the strength of cooked pellets, which played a key role in optimizing the production criteria of sponge iron and ultimately increasing production efficiency in the steelmaking stage which can be very effective. For this purpose, using the hierarchical analysis model, the parameters affecting the strength of pellets have been identified and studied by experts of several iron and steel production units, and finally, for example, several iron ore pellet production plants have been compared and ranked. According to AHP decision criteria, particle size is the most important parameter affecting the strength of cooked pellets.

1. Introduction

One of the most important issues in the iron and steel industry is the preparation and manufacture of pellets from iron ore concentrate and other additives that are first raw and then cooked and hardened, and to revive the traditional method of iron production in blast furnaces and Or several methods of direct reduction is used. Therefore, it seems necessary that all stages of pellet preparation, including mixing the concentrate with binders and additives, balling in pelleting machines, drying, preheating, cooking, should be carefully considered and the optimal conditions to perform each step, according to the initial composition. All mechanical, chemical, and thermal properties of pellets are strongly influenced by different criteria during the pelleting process and ultimately affect the quality of Reduction of iron ore pellets [1]. In particular, the optimal strength of pellets is a criterion for transportation, to prevent the formation of softness at low strengths or to reduce the recoverability at high strengths.

In the pelleting stage, a sufficient amount of water is added to the pellets to obtain the proper quality of pellets for spherization operations. A very common adhesive used to achieve the desired moisture is bentonite. Also, adding some lime or dolomite can be an effective factor in achieving the desired composition [2, 3]. Raw pellets have very little strength. The pellets become completely hard during cooking due to the recrystallization of phases, chemical reactions between additives and adhesives, the formation of glass phases, and other processes, so that they can be easily moved without being crushed. Or produce soft and dust [4]. Before obtaining usable pellets, the last stage of processing is to harden the dried pellets with the help of a kiln. To regenerate cooked pellets, they need to have the following properties:

- Good resilience with high efficiency and low energy consumption,
- Low tendency to inflation with good gas permeability,
- High mechanical strength in all stages of reduction at a temperature of about 1000 °C, including low degradation, low wear, and maximum strength, as well as high ability to pass gas; And
- Low tendency to crushing and uniformity for gas passage [4, 5].

By converting magnetite to hematite in the process of cooking raw pellets, the strength of the pellet increases, and in contrast, its porosity decreases. Other important parameters affecting the desired properties of pellets are temperature, time, and of course the initial composition of pellets [2].

Under normal conditions of Reduction in cooking kiln, mechanical strength may decrease by rising temperature from 500 to 1000 °C due to pellet swelling [6]. Additionally there are many factors that affect the properties and mechanical behavior of such polymers, and it is of high significance to evaluate chemical and combination of these materials [7-9]. In this research, an attempt has been made to rank the pellet production variables using the hierarchical decision-making method to achieve the maximum strength of domestically produced pellets. For this purpose, domestically produced pellets were ranked according to the manufacturers’ information in terms of strength.

2. Materials and research methods

2.1. Method of measuring the weight of criteria by Analytic Hierarchy Process (AHP)

It should be noted that some criteria are quantitative and some are qualitative. Each criterion also has its own measurement scale, which makes it difficult to compare the criteria. In any case, they all have to be measured in same way and eventually converted to a comparable value for calculation. In order to do that, in this section we will achieve the measured criteria by experts are presented, and in the next sections, we will discuss how to quantify the criteria and convert the measured values from each criterion to a value comparable to other criteria. Measurement scales are divided as follows, which depending on the nature of the problem, we use these scales for measurement.

The first step in solving multi-characteristic problems is to define the exact purpose of the problem. After defining the problem accurately, we must determine the criteria that affect the purpose of the problem, from which it is possible to collect information. After determining the criteria, we must follow the steps to identify them more accurately. Criteria are either quantitative or qualitative or positive (are criteria that we want to increase in the model) or negative (are criteria that we want to reduce in the model). Qualitative criteria need to be converted to a small amount to be able to make multi-criteria decision calculations on them. The main criteria have rank scales that can be converted to quantitative numbers using the spectroscopy method.

The alternatives either are already known and only need to be decided upon, although they are identified by research into the scope of the problem and among them are alternatives that can be collected about Decisions are made. After determining the alternatives and decision criteria, we must decide on how to rate the criteria. Hence a matrix consisting of alternatives and criteria that alternatives are usually placed in a row and criteria in its columns. In each of the matrix cells, the decision-maker enters the desired quantity for the quantitative criteria and his preference for the qualitative criteria.

Table 1. Decision matrix [10].

| Alternatives - Criteria | Criteria 1 \( (x_1) \) | Criteria 2 \( (x_2) \) | Criteria n \( (x_n) \) |
|-------------------------|------------------------|------------------------|------------------------|
| Alternative 1 \( (A_1) \) | \( r_{11} \) | \( r_{12} \) | \( r_{1n} \) |
| Alternative 2 \( (A_2) \) | \( r_{21} \) | \( r_{22} \) | \( r_{2n} \) |
| Alternative m \( (A_m) \) | \( r_{m1} \) | \( r_{m2} \) | \( r_{mn} \) |

In this method, instead of using the decision matrix, the decision-maker enters her relative preferences relative to each of the criteria in the form of a matrix called the pairwise comparison matrix according to the table below.

Table 2. Matrix of pairwise comparisons [10].

| Purpose of the decision | Criteria 1 \( (x_1) \) | Criteria 2 \( (x_2) \) | Criteria n \( (x_n) \) |
|------------------------|------------------------|------------------------|------------------------|
| Criteria 1 \( (x_1) \) | \( x_{11} \) | \( x_{12} \) | \( x_{1n} \) |
| Criteria 2 \( (x_2) \) | \( x_{21} \) | \( x_{22} \) | \( x_{2n} \) |
| Criteria m \( (x_m) \) | \( x_{m1} \) | \( x_{m2} \) | \( x_{mn} \) |
Table 3. Preference values of criteria [10].

| The degree of importance | definition          |
|--------------------------|---------------------|
| 1                        | Equal importance    |
| 2                        | Relatively preferred|
| 5                        | High preference     |
| 7                        | High preference     |
| 9                        | Extremely high preference |
| 2, 4, 6, 8               | Intermediate values in judgment |

Because the results of the pairwise comparison methods are more accurate in weighing stage of criteria, the weight of the criteria can be obtained by using the pairwise comparison matrix method. If the decision is made using the pairwise comparison method, then in the above pairwise comparison matrix, we form a matrix for each criteria and compare different alternatives, which is the same method of hierarchical analysis (AHP), which is we will talk about it in detail later.

So, determining the criteria and alternatives and choosing the method of scoring the criteria, we will evaluate them. Each of the quantitative criteria has its measurement scale, which makes it impossible to compare their values with each other, so they must be measured independently of the unit to perform the comparison. There are three ways to do this. In non-scaling by soft method, we divide each element of the decision matrix by the square of the sum of the squares of the elements of each column:

\[
n_{ij} = \frac{a_{ij}}{\sqrt{\sum_{m=1}^{m} a_{ij}^2}}\]  

(1)

The scaled circuit is an alternative i of the criteria J.

After scaling the values of each criteria, we must determine the relative importance of the criteria relative to each other. To do this, the Shannon entropy method is used.

The weighting of the criteria is done using the Shannon entropy method. To calculate the weights of the criteria, we do the following (m is the number of alternatives).

\[
p_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}; \forall i, j\]

(2)

\[
k = \frac{1}{\ln(m)}\]

(3)

\[
E_j = -k \sum_{i=1}^{m} [p_{ij} \ln p_{ij}]; \forall j\]

(4)

Shows the entropy value of my criteria.

\[
d_j = 1 - E_j; \forall j\]

(5)

Expresses the amount of uncertainty or degree of deviation for my criteria, and since the Shannon entropy method gives the most weight to the criteria with the highest degree of deviation, we will have:

\[
w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}; \forall j\]

(6)

And if the decision-maker already considers certain weights for the criteria, then the adjusted weight will be as follows:

\[
\hat{w}_j = \frac{\lambda_j w_j}{\sum_{j=1}^{n} \lambda_j w_j}; \forall j\]

(7)

First, we calculate the values, then we calculate the value of the constant-coefficient K.
3. Review the results

3.1. Calculating the weight of criteria and final ranking using AHP method

The impact strength of plate pellets is one of the important and significant points of this important industrial material. Important parameters affect the quality and especially the reasons for the strength of plate pellets, which are:

A) Cooking temperature in kiln
B) Cooking time in kiln
C) Particle size
D) Moisture
E) The amount of binder
F) Disk rotation speed in pelletizing stage
G) Disc rotation angle in pelletizing stage.
H) The amount of charged material to pelletizing disk [11]

The exact amount of impact strength of plate pellets is obtained from the following equation:

\[
\text{Impact strength} = \frac{\text{Weight of unbroken bullets}}{\text{Weight of primary bullets}}
\]  

(8)

In order to facilitate the discussion and perform better calculations, each of the mentioned parameters is named:

| Table 4. Naming process parameters. |
|------------------------------------|
| Cooking temperature | Cooking time | Particle size | moisture | The amount of glue | Disk rotation speed | Disk rotation angle | The amount of material charged |
| A                    | B            | C            | D        | E                | F                  | G                      | H                          |

3.1.1. Specifying the rating for two-to-two preference

The first step in selecting based on AHP criteria is to rate the process parameters based on their importance, which is well explained in Table 4.

| Table 5. Weighting of two-to-two preferences in the AHP method [12, 13]. |
|------------------------------------------------------------------------|
| Definite importance | Phase importance | Linguistic equivalent | Meaning                                                                 |
| 1 | (1,1,1) | Equal | The equal importance of criteria to each other (main diameter of the matrix) |
| 2 | (1,2,4) | Mediocrity | Poor importance of one criterion over another                          |
| 3 | (1,3,5) | Important | Slightly more important one criterion than another                       |
| 4 | (2,4,6) | Mediocrity | One criterion is more important than another                           |
| 5 | (3,5,7) | More importantly | The strong importance of one criterion over another                     |
| 6 | (4,6,8) | Mediocrity | The importance of one criterion is very strong compared to another    |
| 7 | (5,7,9) | Very important | The very importance of one criterion over another                  |
| 8 | (6,8,10) | Mediocrity | The very importance of one criterion over another                     |
| 9 | (7,9,11) | Wonderful | One criterion is more important than another                           |

Based on this, the rules of iron ore reduction, pelletizing, multi-criteria decision criterion, and according to tables 3 and 4 parameters are scored. Temperature and time play a very important role in cooking pellets to achieve maximum impact strength. Because moisture comes out of the pellet after cooking and makes it porous, porosity is directly related to strength. Among these, production parameters along with nature parameters are less important. In the same way, all parameters are scored [13, 14].
3.1.2. Formation of the relative weight matrix

After weighting, we give the criteria relative to each other in pairs in a relative weight matrix.

\[
\begin{bmatrix}
A & B & C & D & E & F & G & H \\
1 & 9 & 9 & 9 & 9 & 3 & 9 & 9 \\
7 & 5 & 5 & 5 & 2 & 2 & 2 & 2 \\
B & 7 & 1 & 7 & 1 & 7 & 7 & 7 \\
9 & 5 & 2 & 3 & 2 & 2 & 2 & 2 \\
C & 5 & 5 & 1 & 5 & 5 & 5 & 5 \\
9 & 7 & 2 & 3 & 2 & 2 & 2 & 2 \\
D & 7 & 1 & 7 & 1 & 7 & 7 & 7 & 7 \\
9 & 5 & 2 & 3 & 2 & 2 & 2 & 2 \\
E & 2 & 2 & 2 & 2 & 1 & 2 & 1 & 2 \\
9 & 7 & 5 & 7 & 3 & 3 & 3 & 3 \\
F & 3 & 3 & 3 & 3 & 1 & 3 & 3 & 3 \\
9 & 7 & 5 & 7 & 2 & 2 & 2 & 2 \\
G & 2 & 2 & 2 & 2 & 1 & 2 & 1 & 2 \\
9 & 7 & 5 & 7 & 3 & 3 & 3 & 3 \\
H & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
9 & 7 & 5 & 7 & 2 & 2 & 2 & 2 \\
\end{bmatrix}
\]

(9)

Then we normalize the above matrix for simplicity of comparisons. Then in the second matrix on the next page, we calculate the average of each criterion relative to the other criteria [13].

\[
\begin{bmatrix}
A & B & C & D & E & F & G & H \\
1 & 1.28571429 & 1.8 & 1.28571429 & 4.5 & 3 & 4.5 & 9 \\
B & 0.77777778 & 1 & 1.4 & 1 & 3.5 & 2.33333333 & 3.5 & 7 \\
C & 0.55555556 & 0.71428571 & 1 & 0.71428571 & 2.5 & 1.66666667 & 2.5 & 5 \\
D & 0.77777778 & 1 & 0.14 & 1 & 3.5 & 2.33333333 & 3.5 & 7 \\
E & 0.22222222 & 0.28571429 & 0.4 & 0.28571429 & 1 & 0.66666667 & 1 & 2 \\
F & 0.33333333 & 0.42857143 & 0.6 & 0.42857143 & 1.5 & 1 & 1.5 & 3 \\
G & 0.22222222 & 0.28571429 & 0.4 & 0.28571429 & 1 & 0.66666667 & 1 & 2 \\
H & 0.11111111 & 0.14285714 & 0.2 & 0.14285714 & 0.5 & 0.33333333 & 0.5 & 1 \\
\end{bmatrix}
\]

(10)

\[
\begin{bmatrix}
\text{Sum} & 4 & 5.15 & 7.2 & 5.15 & 18 & 12 & 18 & 36 \\
\end{bmatrix}
\]

(11)

After calculating the above matrix, we weigh each of the parameters. Accordingly, the weight of each parameter is included in the average of other scores [13].

As can be seen, particle size plays an important role in the final strength of plate pellets. Then, production information was obtained from five domestic pellet production companies.

Based on the moral obligation, we are exempt from mentioning the names of those companies and publishing this received information. Based on this information and the previous calculation process, the following matrix is provided:
Table 6. Final weight of pellet production parameters.

| Parameter                                      | Weight |
|------------------------------------------------|--------|
| The final weight of the cooking temperature    | 0.22   |
| The final weight of cooking time               | 0.19   |
| The final weight of the particle size          | 0.28   |
| The final weight of moisture                   | 0.19   |
| The final weight of the adhesive               | 0.05   |
| The final weight of the disk rotation speed    | 0.08   |
| The final weight of the disk rotation angle    | 0.05   |
| The final weight is the amount of material     | 0.02   |

Table 7. Normalized matrix of effective criteria for 5 pelletizing companies.

|                   | A       | B       | C       | D       | E       |
|-------------------|---------|---------|---------|---------|---------|
| Pellet making company A1 | 0.0565  | 0.4874  | 0.5074  | 0.0474  | 0.0339  | 0.5744  |
| Pellet making company A2 | 0.1184  | 0.1187  | 0.0352  | 0.5440  | 0.4600  | 0.1898  |
| Pellet making company A3 | 0.1184  | 0.1187  | 0.0670  | 0.2075  | 0.2223  | 0.9400  |
| Pellet making company A4 | 0.4547  | 0.0287  | 0.1297  | 0.0339  | 0.0594  | 0.1193  |
| Pellet making company A5 | 0.2518  | 0.2459  | 0.2605  | 0.1655  | 0.2223  | 0.0767  |

Following the calculation process of that section and the matrix information above the following table is obtained:

Table 8. Rankings of pellet production companies in the country.

| Alternative                | Final ranking |
|----------------------------|---------------|
| Pellet making company A1   | 0.146         |
| Pellet making company A2   | 0.265         |
| Pellet making company A3   | 0.145         |
| Pellet making company A4   | 0.222         |
| Pellet making company A5   | 0.218         |

As it can be shown, according to the criteria studied in this research and the calculations performed, in terms of AHP theory, the plate pellets produced in A2 pelletizing have the highest strength compared to other factories.

4. Conclusion

The following results are obtained from the present study:

1. AHP process can be performed to select the most important parameter of pellet production.
2. Based on the results of this research and industrial experiences, the innate parameters of pellets are more important than the technological parameters of production.
3. According to AHP criteria, the parameters of pellet production are important in order of:
4. Particle size, sintering temperature, sintering time, moisture, disk rotation speed, adhesive mass, disk rotation angle, and finally the amount of charged material.
5. According to the AHP decision criterion, particle size is the most important parameter, while in industry, temperature and sintering were the most important factors, and at the same time, the role of these factors can be done experimentally in the form of research.
6. According to the calculations, the pellets produced in A2 pellets have the highest strength compared to other compared manufacturers.
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