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XXVII. vedecké sympózium s medzinárodnou účasťou

SITUÁCIA V EKOLOGICKY ZAŤAŽENÝCH REGIÓNOCH SLOVENSKA A STREDNEJ EURÓPY

The XXVII Scientific Symposium with International Participation

SITUATION IN ECOLOGICALLY LOADED REGIONS OF SLOVAKIA AND CENTRAL EUROPE

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APPLICATION OF MULTI-CRITERIA DECISION-MAKING METHODS FOR MANAGING QUALITY AND BENEFICIATION OF PELLETIZED FLY ASH

UPLATŇOVANIE VIACKRITÉRIOVÉHO ROZHODOVANIA PRI RIADENÍ KVALITY A OBOHACOVANIA PELETOVANÉHO POPOLČEKA

Marina Blagojev[1] – Rudolf Tomanec[2] – Slavica Mihajlović[1]

Abstract
The aim of this work is to analyze the impact and the potentials of multiple criteria decision-making methods (MCDM) especially focusing on its application in the field of sustainable solutions to waste problems. To demonstrate the applicability of MCDM methods in the field of mineral processing, the fly ash pellets selection problem was considered. Studies reported in this paper used three selected size fractions of pelletized fly ash, from power plant Nikola Tesla – B, Obrenovac, obtained at different amounts of the binder. Physical-mechanical properties of pellets samples were tested, afterwards the complex methods of multi-criteria decision making was presented, with the objective to determine adequate pellets for producing lightweight concrete. The criteria weighting was performed firstly, by AHP method, afterwards a decision model was applied, by using TOPSIS method. Fly ash pellets were ranked and the results obtained that the best pellet quality was archived for mean diameter (D_{50}) of 11.21 mm and 8.36 mm, with compressive strength of 6 MPa.

Keywords: *fly ash, pellets, decision analysis, TOPSIS.*

Introduction

According to the World Energy Council, energy demand is forecast to continue growing at an annual average rate of 1.6% between 2004 and 2030, therefore an increase in coal combustion by-products is also expected [González and Navia, 2009]. Utilisation of fly ash as an industrial by-product from coal-fired power plants has received a great deal of attention over the past decades and possibility of its application is considered for very important subject, frequently solved in scientific and technical papers [Hredzak et al., 2005; Blisset and Rowson, 2012]. According to that, ecologically loaded regions in Europe have a tendency to completely utilise produced fly ash, whereby the biggest current use for EF is either as a raw material or as an additive in the cement industry, in form of peletized fly ash (for production of lightweight concrete, mortar mixtures etc.) [Tomanec et al., 2013; Ahmaruzzman, 2010]. The aim of the present investigation is on the selection of pelletized fly ash aggregates for further application in the production of lightweight concrete. Multi-criteria decision-making methods (MCDM) were used for pellets ranking and selecting the most favorable alternative for its beneficial use. Namely, several MCDA methods have been proposed in recent years to help in selecting the best compromise alternatives rather than taking decisions based only on personal thoughts, views or experiences [Achillas et al, 2013; Kami and Werczberger, 1995]. Therefore, in this paper TOPSIS method was applied, along with AHP method for criteria weighting. Results of this investigation confirmed that MCDM are applicable for managing quality and beneficiation of peletized fly ash.

Materials and methods

Testing on the possibility for pellet production have been carried out on a representative sample of fly ash (total mass of 68 kg), which has been separated from the first zone of the electro filter in the

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power plant Nikola Tesla - B. The pelletizing of fly ash has been carried out discontinuously in a laboratory pelletizer Gustav Eirich TR-04 type, with power of 0.5 kW. Total of 40 experiments with different mixtures of fly ash and binders have been performed. Portland cement has been used as a binder, with mass fraction of 10, 12, 15, 18, 20, 25 and 30 %. Each sample, i.e. the experiment of pelletizing, has been classified into three to four size fractions. Physico-mechanical tests have been carried out on dried pellets (over 130 samples) with the aim to determine pellet resistance to pressure and pellet resistance to impact. Size fraction –11.2 +8.0 mm, as a selected size fraction, has been examined, while larger pellet grains (from the size fraction –16.0 +11.2 mm) have been examined for a certain number of experiments. The data have been statistically processed, and the matrix calculation method has been applied to the obtained results in order to demonstrate in the most obvious way / verify the multi criteria decision methods in the quality management of pelletized fly ash and precisely determine the best pellet production parameters.
The multi criteria decision method named TOPSIS (**T**echnique for **O**rder of **P**reference by **S**imilarity to **I**deal **S**olution) has been applied. This procedure requires the formation of an initial performance matrix X in which the alternatives A_i are set in rows, and the criteria C_i in the columns, with determining the criterion type - "min" or "max" (whether the aim is to use the maximum or minimum values of the criteria), as well as weight factors of the criteria $w_1, w_2, \dots, w_m$. The first step in applying this method is in the normalization ($\|X\| \rightarrow \|R\|$), according to equation 1, and the "weighting" ($\|X\| \rightarrow \|V\|$), of the initial matrix, according to equation 2.

$$R = \|R_{ij}\|_{m\,x\,n} \qquad r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad /1/$$

$$V = \|V_{ij}\| = \|W_j' \cdot r_{ij}\| \qquad W_j' = \frac{w_j}{\sum_{j=1}^{n} w_j}, \; v_{ij} = W_j' \cdot r_{ij} \qquad /2/$$

Then, ideal solution A^+ , and and anti-ideal solution A^- is formed, according to equations 3 and 4.

$$A^+ = \left\{ \left(\left(\underset{i}{MAX} v_{ij} \mid j \in K' \right) \right), \left(\underset{i}{MIN} v_{ij} \mid j \in K'' \right) \right\} = \{v_1, v_2, \dots, v_j, \dots, v_n\}, (i = 1,2, \dots, m) \qquad /3/$$

$$A^- = \left\{ \left(\left(\underset{i}{MIN} v_{ij} \mid j \in K' \right) \right), \left(\underset{i}{MAX} v_{ij} \mid j \in K'' \right) \right\} = \{v_1, v_2, \dots, v_j, \dots, v_n\}, (i = 1,2, \dots, m) \qquad /4/$$

At which point:
$K' \subseteq K \rightarrow K'$ is the subset of K , which is consisted of MAX criteria, and
$K'' \subseteq K \rightarrow K''$ is the subset of K , which is consisted of MIN criteria.

In the last step, using equations 5 and 6, the distance of each alternative from the ideal solution S_i^+ , or the anti-ideal solution, S_i^-, is calculated.

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2} \qquad /5/ \qquad S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2} \qquad /6/$$

Finally, the ranking is carried out based on the calculated relative proximity of each alternative to the ideal solution, C_i, according to equation 7.

$$C_i = \frac{s_i^-}{s_i^- + s_i^+}, \qquad 0 \le C_1 \le 1 \qquad /7/$$

Results and discussion

To demonstrate the applicability of TOPSIS method in conjection with the weighting method of AHP (**A**nalytic **H**ierarchy **P**rocess), the fly ash pellets selection problem was considered. After the determination of the weights of different criteria using the AHP method, the MCDM method was applied to the problem. The selected elements for forming the initial matrix *X* are shown in Table 1.

Table 1. Fly ash pellets for production of lightweight concrete

	Cement content, %	Bulk density, kg/m³	Total added water, %	Medium diameter, D_{50}, mm	Compressive strenght, MPa	Impact strenght of pellets/drop, n	Relative price
Pellet	K1 (min)	K2 (max)	K3 (min)	K4 (max)	K5 (max)	K6 (max)	K7 (max)
1	10	544	54.11	10.36	1.630	2.10	10
2	10	523	53.66	10.70	1.630	3.56	10
3	12	498	53.32	10.63	1.198	2.33	12
4	15	518	51.00	8.53	1.157	3.46	15
5	15	525	51.34	8.52	1.874	5.28	15
6	18	542	46.45	7.67	1.980	5.61	18
7	20	565	45.68	10.88	3.370	14.81	20
8	25	598	43.26	10.78	6.077	30	25
9	30	613	40.88	11.21	6.701	30	30
10	30	601	45.45	8.36	6.492	30	30

Criteria weighting

Weighting coefficients for different criteria estimations have been obtained by the AHP method. As criteria for fly ash pellet selection, for the needs of the construction industry in the production of lightweight concrete, the following parameters have been used: cement content (%); bulk density of pellets (kg/m^3); total added water (%); medium diameter (mm), compressive strenght of pellets (MPa); impact strenght of pellets/drop (n) and the relative price of pellets.

The decision hierarchy which is composed of three levels was structured as shown in Fig. 1. The aim of the decision process takes the first level of the hierarchy. The criteria and alternative materials are on the second and the third level of the hierarchy, respectively.

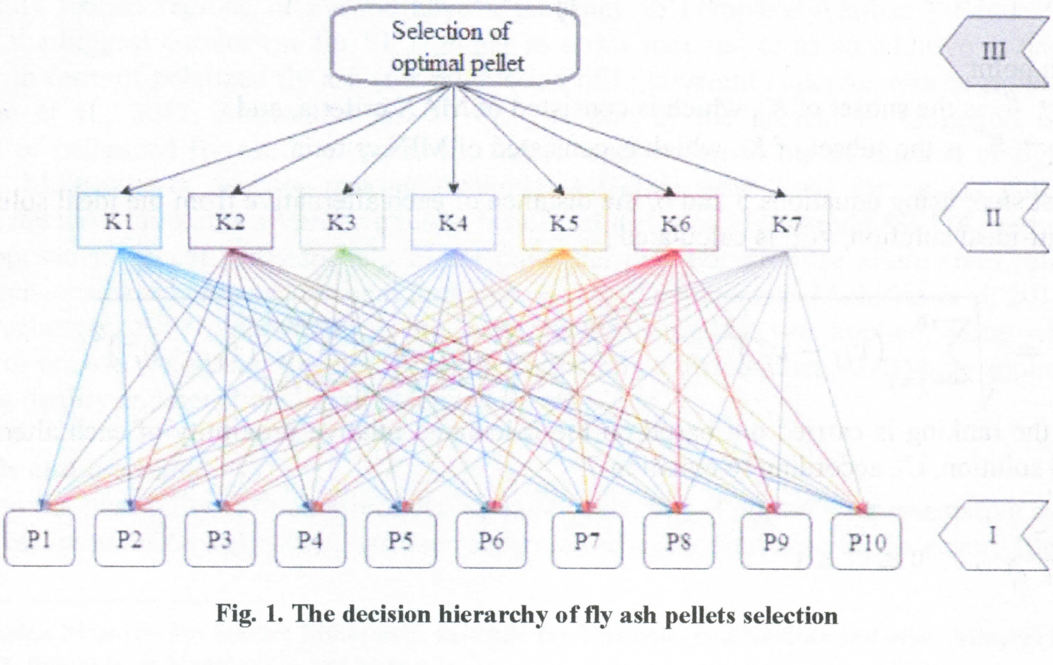
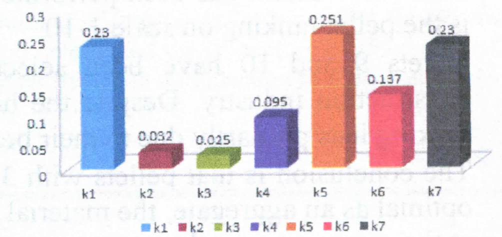


Fig. 1. The decision hierarchy of fly ash pellets selection

After structuring the hierarchy, it is approached to the element comparison by pairs at the same hierarchical level based on estimations founded on knowledge and own experience, which results in the formation of the comparison matrix. Saaty's value scale has been used to compare the elements [Saaty, 1980].
The final step in determining the weight coefficient vector is to summarize the matrix rows of the comparison results and normalize the obtained sums, as Saaty suggests [Saaty, 1996]. The weight coefficients (Wi) obtained by the AHP method are shown in Table 2.

Table 2. The pairwise comparison matrix for criteria weighting by AHP

	K1	K2	K3	K4	K5	K6	K7	ΣKi	Wi
K1	0.24	0.21	0.19	0.24	0.27	0.25	0.20	1.61	0.230
K2	0.03	0.03	0.06	0.02	0.04	0.02	0.03	0.22	0.032
K3	0.03	0.01	0.03	0.02	0.03	0.03	0.03	0.18	0.025
K4	0.08	0.12	0.14	0.08	0.13	0.06	0.05	0.67	0.095
K5	0.24	0.21	0.22	0.16	0.27	0.25	0.40	1.75	0.251
K6	0.12	0.18	0.14	0.16	0.13	0.13	0.10	0.96	0.137
K7	0.24	0.24	0.22	0.32	0.13	0.25	0.20	1.61	0.230



TOPSIS method

In this paper, TOPSIS is an applied method in solving the ranking problems and pellets selection with optimal characteristics for further usage in the construction industry, in the production of lightweight concrete. The method starts from the initial matrix given in Table 1. The normalized and weighting matrix is shown in Table 3. In addition, in Table 3, are shown calculated values of the ideal (A^+) and anti-ideal solution (A^-) as well as the deviations from the ideal solution (S_i^+) and negative ideal solution (S_i^-). The pellet ranking has been carried out based on the relative closeness of the ideal solution (C_i), from where it can be seen that according to this method, the pellet marked with number 10 with its characteristics is the most satisfactory for the use in the construction industry - for the production of lightweight concrete.

Table 3: Normalized and weighted decision matrix V_{ij} with calculated values S_i^+, S_i^-, C_i and final ranking of pellets

Pellet	K1	K2	K3	K4	K5	K6	K7	S_i^+	S_i^-	C_i	Rang
1	0.3663	5.4057	0.4751	0.3275	0.0543	0.0110	0.3663	0.9115	5.0044	0.1540	6
2	0.3663	4.9964	0.4672	0.3494	0.0543	0.0316	0.3663	0.5346	5.8334	0.0839	9
3	0.5274	4.5301	0.4613	0.3448	0.0293	0.0135	0.5274	0.3398	5.3667	0.0595	10
4	0.8241	4.9013	0.4220	0.2220	0.0274	0.0299	0.8241	0.7629	5.5717	0.1204	8
5	0.8241	5.0347	0.4277	0.2215	0.0718	0.0696	0.8241	0.8399	5.0207	0.1433	7
6	1.1868	5.3660	0.3501	0.1795	0.0801	0.0785	1.1868	1.4348	5.7009	0.2010	5
7	1.4651	5.8311	0.3386	0.3612	0.2321	0.5474	1.4651	2.1153	6.3232	0.2506	4
8	2.2893	6.5321	0.3037	0.3546	0.7547	2.2462	2.2893	4.1183	7.2142	0.3634	3
9	3.2965	6.8639	0.2712	0.3835	0.9176	2.2462	3.2965	5.3338	7.6999	0.4092	2
10	3.2965	6.5978	0.3352	0.2133	0.8613	2.2462	3.2965	5.2101	6.8991	0.4302	1
Ideal and anti-ideal solution											
A^+	0.3663	4.5301	0.2712	0.1795	0.0274	0.0110	0.3663				
A^-	3.2965	6.8639	0.4751	0.3835	0.9176	2.2462	3.2965				

Conclusion

- With the application of the MCDM methods in the example of pellet selection with optimal characteristics for the lightweight concrete production, the possibility of applying multi criteria decision analysis has been confirmed, based on the problems in the field of mineral processing since the research is always established on a large number of concentration tests.
- The importance of quality criteria selection on the basis of which optimal solutions are chosen has been highlighted, because the poorly defined criteria and their application without the previous analysis of mutual dependence can lead to the inadequate choice of the final variant.
- Defining values of weight coefficients was performed with the AHP method.
- Pellet assessment has been performed using the TOPSIS method, and the result of this method is the pellet ranking on scale 1-10.
- Pellets 9 and 10 have been selected as the most suitable for further application in the construction industry. Despite the high cost of their production, these pellets are the first on ranking lists primarily due to their best physically-mechanical characteristics.
- The conclusion is that pellets with 30% of cement and the compressive strength of 6 MPa are optimal as an aggregate, the material for lightweight concrete production, for further application in the construction industry.

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