InterCriteria Decision Making Approach for Metal Chips Briquetting

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Keywords: InterCriteria decision making, Index matrix, Impact briquetting.

Abstract: In the presented paper for the analysis purposes we have used experimental results of impact briquetting of grey cast iron chips. The presented multicriteria decision making method is based on two fundamental concepts: intuitionistic fuzzy sets and index matrices. We have named it 'InterCriteria' decision making approach, which utilizes the apparatus of index matrices and intuitionistic fuzzy sets - takes an existing multiobject multicriteria evaluation table and generates a new table that contains estimations of the pairwise relations among the set of evaluating criteria. Our goal is to increase the efficiency of the process of briquetting metal chips with good density and quality.

1 INTRODUCTION

Producing briquettes using metal chips and powder is an actual scientific problem which is reflected in a lot off publications. In paper (Bodurov et al., 2005) is proposed an original construction of die forging hammer propelled by industrial rocket engine. With this machine it is possible to work with controlled impact and with impact velocities from 4.5 [m/s] up to 20 [m/s]. Laboratory set-up for controlled impact, and the results of experimental study of metal chips briquetting by controlled impact with impact speed of 7 [m/s] are presented in paper (Gustavson et al, 2014). The potentiality to produce parts using such briquettes is also illustrated.

The technological effects of a controlled impact application in plastic deformation and briquetting of metal chips processes are discussed in (Penchev et al., 2013; Penchev et al., 2014; Penchev et al., 2014; Radeva et al., 2014). It was found that using a controlled impact increases the deformation up to 27% and the density of the briquettes up to 20% when compared to the ordinary impact. In (Penchev et al., 2014) is investigated the possibility of processing briquettes via plastic deformation of aluminum alloy chips (the density of the briquettes in this case is 93% of the density of the solid alloy). It was found that this is possible if stresses in the deformed body are compressive. In the presented paper for the analysis purposes we have used experimental results of impact briquetting of grey cast iron chips. In this study the parameters distance, speed, acceleration of the impacting bodies are analysed by means of high speed camera and the applicable software. They are part of the equipment of the Smart Lab at IICT.

The impact energy (E_y) and power (F_y) are calculated. To get more experimental data an Xray tomograph Nikon XTH 225 Compact Industrial CT Scanner has been used. This way the horizontal and vertical briquette sections have been investigated. The resolution of the obtained images is 5 [μm]. Based on these, we automatically determine the briquette diameter (D [mm]) and its height (H [mm]), with 4th decimal symbol accuracy.

In process of the metal chips briquetting, mechanical and hydraulic presses with nominal force of several hundred to several thousand kN are used. The goal is to obtain briquettes with good

Karastoyanov D., Doukovska L., Gyoshev S. and Kalaykov I.
InterCriteria Decision Making Approach for Metal Chips Briquetting.
DOI: 10.5220/0005888502970301
In *Proceedings of the Fifth International Symposium on Business Modeling and Software Design (BMSD 2015)*, pages 297-301
ISBN: 978-989-758-111-3

density - the ratio *H/D* for different materials vary within wide limits (*H*/*D* = 0.8 – 0.25), where H is the height, and *D* is the diameter of the briquette. The greater is the density of the briquettes, the smaller are the losses in the transport and melting. Basic data used to evaluate the effect of briquetting operation is the specific density of the briquette (ρ, [g/cm^3]), and specific contact pressure for briquetting (P, [MPa]).

Figure 1 shows the laboratory stand with a high speed camera and special lighting, for taking high-speed video recordings. Using the camera and software makes possible to determine the speed V_y and acceleration A_y and then to calculate the impact energy E_y and the power of impact F_y.

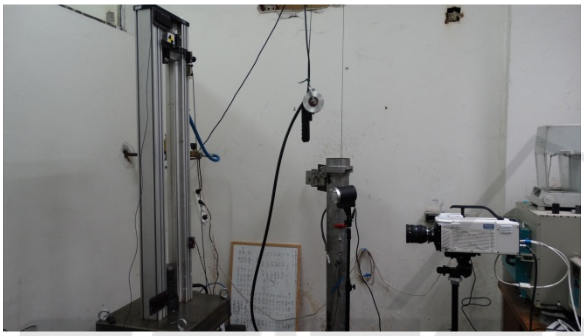

Figure 1: Laboratory stend for a complicated impact with high speed camera.

2 INTERCRITERIA DECISION MAKING APPROACH

The presented multicriteria decision making method is based on two fundamental concepts: intuitionistic fuzzy sets and index matrices. It is called 'InterCriteria decision making'.

Intuitionistic fuzzy sets defined by Atanassov (Atanassov, 1983; Atanassov, 1986; Atanassov, 1999; Atanassov, 2012) represent an extension of the concept of fuzzy sets, as defined by Zadeh (Zadeh, 1965), exhibiting function $\mu_A(x)$ defining the membership of an element x to the set A, evaluated in the [0; 1] - interval. The difference between fuzzy sets and intuitionistic fuzzy sets (IFSs) is in the presence of a second function $\nu_A(x)$ defining the non-membership of the element x to the set A, where:

$$0 \le \mu_A(x) \le 1,$$

$$0 \le \nu_A(x) \le 1,$$

$$0 \le \mu_A(x) + \nu_A(x) \le 1.$$

The IFS itself is formally denoted by:

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle \mid x \in E\}.$$

Comparison between elements of any two IFSs, say A and B, involves pairwise comparisons between their respective elements' degrees of membership and non-membership to both sets.

The second concept on which the proposed method relies is the concept of index matrix, a matrix which features two index sets. The theory behind the index matrices is described in (Atanassov, 1991). Here we will start with the index matrix M with index sets with m rows $\{C_1,\ldots,C_m\}$ and n columns $\{O_1,\ldots,O_n\}$:

$$M = \begin{array}{c|ccccccc}
 & O_1 & \ldots & O_k & \ldots & O_l & \ldots & O_n \\
\hline
C_1 & a_{C_1,O_1} & \ldots & a_{C_1,O_k} & \ldots & a_{C_1,O_l} & \ldots & a_{C_1,O_n} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
C_i & a_{C_i,O_1} & \ldots & a_{C_i,O_k} & \ldots & a_{C_i,O_l} & \ldots & a_{C_i,O_n} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
C_j & a_{C_j,O_1} & \ldots & a_{C_j,O_k} & \ldots & a_{C_j,O_l} & \ldots & a_{C_j,O_n} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
C_m & a_{C_m,O_1} & \ldots & a_{C_m,O_j} & \ldots & a_{C_m,O_l} & \ldots & a_{C_m,O_n}
\end{array},$$

where for every p, q ($1 \le p \le m$, $1 \le q \le n$), C_p is a criterion (in our case, one of the twelve pillars), O_q in an evaluated object, $a_{C_pO_q}$ is the evaluation of the q-th object against the p-th criterion, and it is defined as a real number or another object that is comparable according to relation R with all the rest elements of the index matrix M, so that for each i, j, k it holds the relation $R(a_{C_kO_i}, a_{C_kO_j})$. The relation R has dual relation $\overline{R}$, which is true in the cases when relation R is false, and vice versa.

For the needs of our decision making method, pairwise comparisons between every two different criteria are made along all evaluated objects. During the comparison, it is maintained one counter of the number of times when the relation R holds, and another counter for the dual relation.

Let $S^{\mu}_{k,l}$ be the number of cases in which the relations $R(a_{C_kO_i}, a_{C_kO_j})$ and $R(a_{C_lO_i}, a_{C_lO_j})$ are simultaneously satisfied. Let also $S^{\nu}_{k,l}$ be the number of cases in which the relations $R(a_{C_kO_i}, a_{C_kO_j})$ and its dual $\overline{R}(a_{C_lO_i}, a_{C_lO_j})$ are simultaneously satisfied. As the total number of pairwise comparisons between the object is $n(n-1)/2$, it is seen that there hold the inequalities:

$$0 \le S^{\mu}_{k,l} + S^{\nu}_{k,l} \le \frac{n(n-1)}{2}.$$

For every k, l, such that $1 \leq k \leq l \leq m$, and for $n \geq 2$ two numbers are defined:

$$\mu_{C_k,C_l} = 2\frac{S^{\mu}_{k,l}}{n(n-1)},\quad \nu_{C_k,C_l} = 2\frac{S^{\nu}_{k,l}}{n(n-1)}.$$

The pair constructed from these two numbers plays the role of the intuitionistic fuzzy evaluation of the relations that can be established between any two criteria C_k and C_l. In this way the index matrix M that relates evaluated objects with evaluating criteria can be transformed to another index matrix M^* that gives the relations among the criteria:

$$M^* = \begin{array}{c|ccc} & C_1 & \cdots & C_m \\ \hline C_1 & \langle \mu_{C_1,C_1}, \nu_{C_1,C_1} \rangle & \cdots & \langle \mu_{C_1,C_m}, \nu_{C_1,C_m} \rangle \\ \vdots & \vdots & \ddots & \vdots \\ C_m & \langle \mu_{C_m,C_1}, \nu_{C_1,C_m} \rangle & \cdots & \langle \mu_{C_m,C_m}, \nu_{C_m,C_m} \rangle \end{array}.$$

The final step of the algorithm is to determine the degrees of correlation between the criteria, depending on the user's choice of μ and ν. We call these correlations between the criteria: 'positive consonance', 'negative consonance' or 'dissonance'.

Let α, $\beta \in [0; 1]$ be given, so that $\alpha + \beta \leq 1$. We call that criteria C_k and C_l are in:

- (α, β) - positive consonance, if $\mu_{C_k,C_l} > \alpha$ and $\nu_{C_k,C_l} < \beta$;
- (α, β) - negative consonance, if $\mu_{C_k,C_l} < \beta$ and $\nu_{C_k,C_l} > \alpha$;
- (α, β) - dissonance, otherwise.

Obviously, the larger α and/or the smaller β, the less number of criteria may be simultaneously connected with the relation of (α, β) - positive consonance. For practical purposes, it carries the most information when either the positive or the negative consonance is as large as possible, while the cases of dissonance are less informative and can be skipped.

3 EXPERIMENTAL RESULTS

The metal chips briquettes preparation with good density and quality is of great importance for the efficiency of this industrial process. In the presented paper for the analysis purposes we have used experimental results of impact briquetting of grey cast iron chips.

Figure 2 shows obtained experimental results for the distance, the speed and the acceleration.

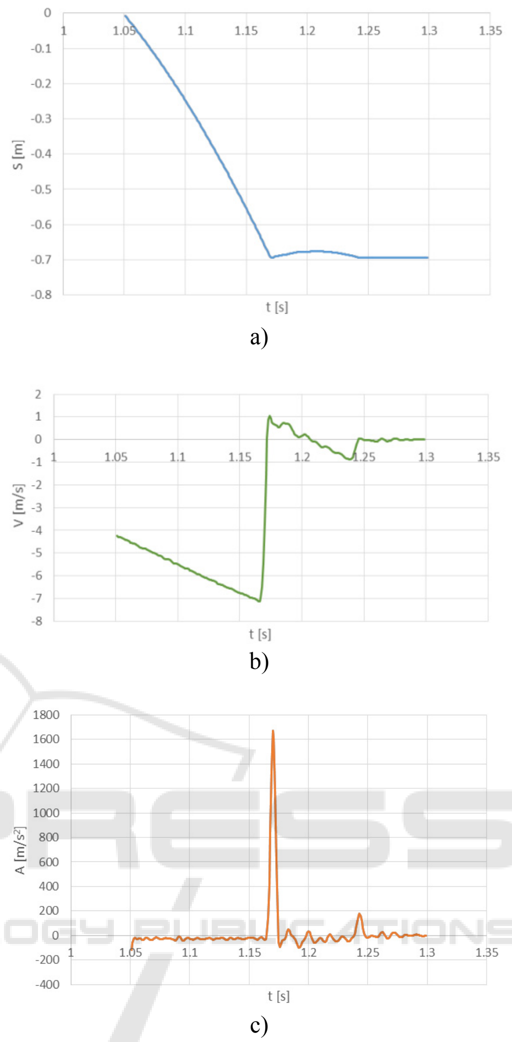

Figure 2: Distance (a), speed (b) and acceleration (c) diagrams in briquetting of grey cast iron chips.

In this paper are presented the results of impact briquetting of grey cast iron chips with rectangular shape. The average sizes are: length 25 [mm], width 15 [mm], thickness 1 [mm]. Diameter of the produced briquettes is 20 [mm], as it is the opening of the die for briquetting. Diameter of the punch is 19.6 [mm]. Density and quality of briquettes of these chips are compared with those obtained in another work of the authors using cast iron chips with smaller sizes. It has been found that if using a rectangular shape chips with a large size generates briquettes with a very low density and poor quality. From the photographs taken by X-ray tomography, it makes clear that the reason for this is the orientation of the chip in the peripheral wall of the briquettes, which does not allow of the air to escape from it. It was concluded that in order to obtain briquettes of cast iron chips with a large size, these chips must first be crushed, for example in a small ball mill. Preparation of metal chips briquettes with good density and quality is important for the efficiency of this process. The research conducted shows there is no difference in the density of the briquettes made from cleaned and not cleaned chips.

Based on the experimental research the values of eleven parameters of grey cast iron chips briquetting process have been obtained:

1 - V_y – Impact speed, [m/s];
2 - A_y – Impact acceleration, [m/s^2];
3 - H_Δ – Trimming height, [mm];
4 - H – Briquette height, [cm];
5 - D – Briquette diameter, [cm];
6 - V – Briquette volume, [cm^3];
7 - G – Briquette weight, [gr];
8 - ρ – Briquette density, [gr/cm^3];
9 - E_y – Impact energy, [J];
10 - E_c – Impact specific energy, [J/cm^3];
11 - F_y – Power of impact, [N].

Table 1: Membership pairs of the intuitionistic fuzzy InterCriteria correlations for the grey cast iron chips.

μ	1	2	3	4	5	6	7	8	9	10	11
1	1	0.6515	0.1969	0.7121	0.4090	0.6969	0.7121	0.3787	1	0.4848	0.6515
2	0.6515	1	0.51515	0.45454	0.34848	0.43939	0.48484	0.63636	0.65151	0.74242	1
3	0.1969	0.51515	1	0.24242	0.53030	0.22727	0.21212	0.66666	0.19697	0.62121	0.5151
4	0.71212	0.45454	0.24242	1	0.36363	0.95454	0.96969	0.36363	0.71212	0.19697	0.4545
5	0.40909	0.34848	0.53030	0.36363	1	0.40909	0.33333	0.28787	0.40909	0.42424	0.3484
6	0.69697	0.43939	0.22727	0.95454	0.40909	1	0.92424	0.31818	0.69697	0.18181	0.4393
7	0.71212	0.48484	0.21212	0.96969	0.33333	0.92424	1	0.39393	0.71212	0.22727	0.4848
8	0.37878	0.63636	0.66666	0.36363	0.28787	0.31818	0.39393	1	0.37878	0.71212	0.6363
9	1	0.65151	0.19697	0.71212	0.40909	0.69697	0.71212	0.37878	1	0.48484	0.6515
10	0.4848	0.7424	0.62121	0.19697	0.42424	0.181818	0.227273	0.712121	0.484848	1	0.7424
11	0.6515	1	0.51515	0.454545	0.348485	0.439394	0.484848	0.636364	0.651515	0.742424	1

These have been analysed applying InterCriteria decision making approach. The results are presented in Table 1.

The results show a strong relation between the parameter pairs: 1 (‘Impact speed‘) – 4 (‘Briquette height‘); 1 (‘Impact speed‘) – 7 (‘Briquette weight‘); 2 (‘Impact acceleration‘) – 10 (‘Impact specific energy‘); 4 (‘Briquette height‘) – 6 (‘Briquette volume‘); 4 (‘Briquette height‘) – 7 (‘Briquette weight‘); 4 (‘Briquette height‘) – 9 (‘Impact energy‘); 6 (‘Briquette volume‘) – 7 (‘Briquette weight‘); 7 (‘Briquette weight‘) – 9 (‘Impact energy‘); 8 (‘Briquette density‘) – 10 (‘Impact specific energy‘).

Part of these relations is due to the specific physical properties of the briquettes, which confirms the reliability of the proposed InterCriteria decision making approach. The benefit here is that this allows for finding strong dependencies as well as such where the relations are not so visible.

The geometrical visualisation of the InterCriteria correlations for the case of iron powder briquette onto the intuitionistic fuzzy interpretational triangle is shown on Figure 3.

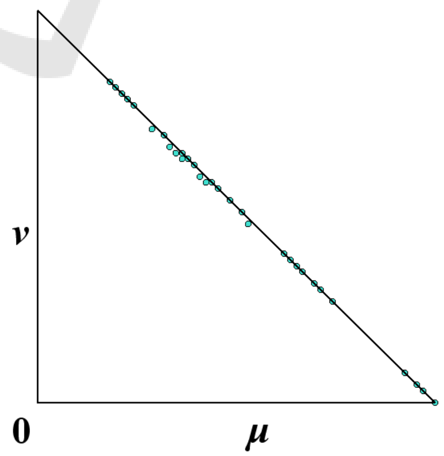

Figure 3: Geometrical visualisation of the InterCriteria correlations for the case of iron powder briquette onto the intuitionistic fuzzy interpretational triangle.

4 CONCLUSION

During the experiments it was seen that when briquetting grey cast iron chips increasing the impact specific energy to some point this increases the density, but further increase leads to a decrease in briquettes density. The conclusion that can be made is that this is being influenced by the content of carbon in the iron-carbon alloys.

The present paper proves the application of this original InterCriteria decision making approach, which eases the analysis if the relations between the criteria, giving better production quality.

ACKNOWLEDGEMENTS

The research work reported in the paper is partly supported by the project AComIn “Advanced Computing for Innovation”, Grant №316087, funded by the FP7 Capacity Programme (Research Potential of Convergence Regions) and partly supported under the Project № DFNI-I-02-5/2014.

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