ADVANCED COMPUTING FOR HIGH SPEED BRIQUETTING OF METAL CHIPS AND POWDERS

СЪВРЕМЕННИ ПРЕСМЯТАНИЯ ЗА ВИСОКОСКОРОСТНО БРИКЕТИРАНЕ НА МЕТАЛНИ СТРУЖКИ И ПРАХОВЕ

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Abstract: *In the paper is investigated the possible to produce briquettes from chips of aluminum alloy and iron powder. Chips of different shapes and sizes are compared, some of which are free of water and oil (cleaned chips), while the rest are left without cleaning (soiled chips). Upsetting and reverse extrusion of the briquettes were studded. The results show that may be accomplished a large extent of deformation of the briquettes when using processes with predominant compressive stresses. Preparation of briquettes of metal chips with good density and quality is of great importance for the efficiency of this process. The results of impact briquetting of grey cast iron chips with rectangular shape and dimensions 15x25x1 mm are presented. 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 by using a rectangular chips with a large size are produced briquettes with a very low density and poor quality.*

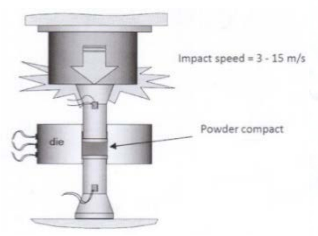
Keywords: IMPACT, IRON POWDER COMPACTING, POWDER METALLURGY, ROCKET ENGINE

1. Introduction

Obtaining of metal powder parts have a number of advantages over other methods of processing - use of 95% of the raw material (40% -50% in the other processing technologies), low energy consumption, producing of composite materials with large range of properties and these advantages of powder metallurgy increased by using impact and high velocity compacting (HVC). Research in this area in recent years have shown higher density and increase of the mechanical properties of the powder metallurgy parts [1]-[4].

In [1] is used hydraulic hammer for HVC (impact velocity 13.2 m/s). The density of the obtained cylindrical specimens using iron powder is 7.4 g/sm^3 (the density of monolithic material is 7.54 g/cm^3). This density is obtained with a pre-compaction to a density of 5 g/sm^3.

Fig.1 shows the scheme of HVC and Fig.2 shows the impact force change in HVC process [1]. From Fig.2 it can be seen that after first impact has 6 rebounds of the hammer to complete consumption of the impact energy. As a result part of the impact energy is spent on the rebound and this reduces the efficiency of the impact.



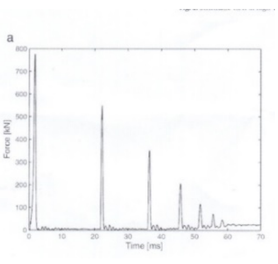


Fig.1. *Scheme of high velocity a HVC*

Fig.2. *Impact force change during compaction experiment with an impact energy of 2.7 kJ*

Controlled impact compacting (CIC) is an innovative technology that is possible when using a hammer propelled by industrial rocket engine [5]. The received force at work on a rocket engine (trust R) is R = 2000 kg when supplied with kerosene (hot rocket engine) and R = 300 kg in supplying with compressed air (cold rocket engine). The maximum impact energy is 35 kJ and impact velocity is 5-16 m/s. The opportunity to control the runtime of a rocket engine makes it possible to work with impact force Pi which changes in accordance with the lines 2-4 shown in Fig. 3.

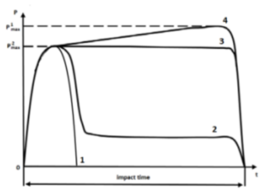


Fig.3. *Change of impact force P_i at the impact time: 1 – ordinary impact; 2, 3, 4 – controlled impact*

2. Methods

Iron powder AS29-100 is used. The distribution of particle size is shown in Fig. 4 (Fritch Analysette 22 Nano Tec+). For obtaining a better grip 1% zinc steatite is added.

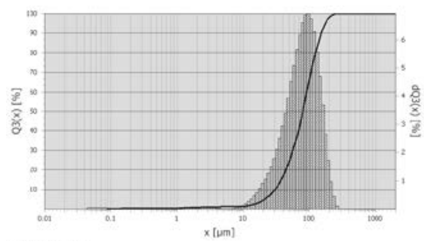
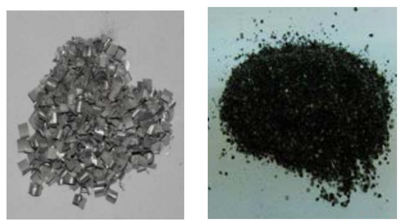


Fig. 4. *Distribution of iron powder particle size*



a) b)

Fig. 5. *a- chips used in present paper (type A); b – chips used in [8] (type B)*

The metal powder green body is with diameter of 20 mm. Used powder mass is 4, 3.5, 3 grams, as of each type were prepared 3 specimens. After compacting the specimens mass are measured on an analytical balance. The diameter and high of the specimens are measured with accuracy of 1 μ m (on X-ray 3D tomograph XTH 225) and the volume is calculated. Then the density ρ is determined by the ratio

$$\rho = \frac{m}{\Theta}, \quad \text{g/cm3}, \qquad (1)$$

where m is the mass and Θ is the volume of the specimen.The hammer impact velocity Vi is about 7 m/s and impact energy Ei is about 240 J. Change of the force Pi corresponds to the line 2 of Fig. 3 (R = 226 N).

To determine the impact force is used record of the impact process with high-speed camera Nac Memrecam HX6. Vicasso 2009 software is used for calculation of path S, velocity V and acceleration a. The force Pi is determined by the dependence

Pi = ai.m, N, (2)

where ai is the impact acceleration.

The specific impact energy ES is calculated by the ratio

$$E_S = \frac{E_i}{\Theta}, \quad \text{J/sm3}, \qquad (3)$$

where $E_i = MV_i^2/2$, and M is the mass of the hammer ram (M = 9.12 kg). This indicator can be used to compare the results when study the compacting process in different conditions.

In Fig.5 are shown used cast iron chips. Their average sizes are: length 25 mm, width 15 mm, thickness 1 mm. Diameter of the produced briquettes is 20 mm, as it is the hole of the die for briquetting. Diameter of the punch is 19.6 mm. The gap between the die and the punch is left out to ensure exit of the air that remains between the chips in the filling into the die. To account for the influence of the size and type of chips used in the present work (type A) are compared with those of work [7] (type B). In order to investigate the influence of the residual water and oil on the density of the briquettes produced by the impact briquetting part of the type A chips were cleaned (type AC) while others had been left uncleaned (type AUC). Both type of chips are from gray cast iron with 2.8 % C. In order to investigate chips density and structure the obtained briquettes are measured, weighed on an analytical balances and pictured on 3D X-ray tomography (Nikon XTH 225 Compact Industrial CT Scanner)–Fig. 6. [8], [9].

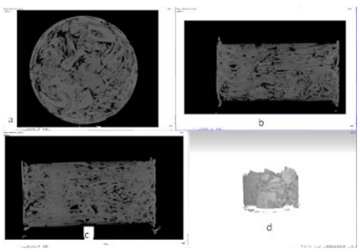


Fig. 6. *X-ray tomography images of gray cast iron briquettes a - cross-section in the middle of the briquette height; b, c - orthogonal vertical sections through the center of the briquette; d - 3-D image efficiency is higher when using controlled impact.*

Impact process is recorded with a high-speed camera NAC Memrecam HX6. The video is processed with the software Vicasso 2009 which defines impact speed (Vi) and acceleration (ai).

The impact force P_i and impact energy E_i are calculated by formulas

$$P_i = a_i m, \text{ N}, \qquad (4)$$

$$E_i = \frac{mV_i^2}{2}, \text{ J}, \qquad (5)$$

where *m* is the mass of the falling part, in kg.

The specific impact energy for briquetting is calculated by the formula

$$E_s = \frac{E_i}{\Theta}, \text{ J/cm}^3, \qquad (6)$$

where Θ, sm^3, is the briquette volume. The use of this indicator makes it possible to compare the results obtained under different conditions of briquetting.

3. Intercriteria decision making approach

The presented multicriteria decision making method is based on two fundamental concepts: intuitionistic fuzzy sets (9), (10) and index matrices (11). It is called 'InterCriteria decision making'.

Intuitionistic fuzzy sets (9) represent an extension of the concept of fuzzy sets (10), 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:

$$0 \le \mu_A(x) \le 1,$$
$$0 \le \nu_A(x) \le 1, \qquad (7)$$
$$0 \le \mu_A(x) + \nu_A(x) \le 1.$$

The IFS itself is formally denoted by:

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle \mid x \in E\}. \qquad (8)$$

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, [6]. Here we will start with the index matrix *M* with index sets with *m* rows $\{C_1,\ldots,C_m\}$ and *n* columns $\{O_1,\ldots,O_n\}$:

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

where for every p, q (1 ≤ p ≤ m, 1 ≤ q ≤ n), Cp is a criterion (in our case, one of the twelve pillars), Oq in an evaluated object, aCpOq 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(aCkOi, aCkOj). The relation R has dual relation $\bar{R}$, 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(aCkOi , aCkOj) and R(aClOi , aClOj) 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 $\bar{R}(a_{C_lO_i}, a_{C_lO_j})$ 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:

$$0 \le S^{\mu}_{k,l} + S^{\nu}_{k,l} \le \frac{n(n-1)}{2} \quad (9)$$

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

$$\mu_{C_k,C_l} = 2\frac{S^{\mu}_{k,l}}{n(n-1)}, \ \nu_{C_k,C_l} = 2\frac{S^{\nu}_{k,l}}{n(n-1)}. \quad (10)$$

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 Ck and Cl. 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:

$$M^* = \begin{array}{c|ccc} & C_1 & \cdots & C_m \\ \hline C_1 & \langle \mu_{C_1,C_1}, \nu_{C_1,C_1} \rangle & \cdots & \langle \mu_{C_1,C_m}, \nu_{C_1,C_m} \rangle \\ \vdots & \vdots & \ddots & \vdots \\ C_m & \langle \mu_{C_m,C_1}, \nu_{C_1,C_m} \rangle & \cdots & \langle \mu_{C_m,C_m}, \nu_{C_m,C_m} \rangle \end{array} . \quad (11)$$

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'. [6]

Let $\alpha, \beta \in [0; 1]$ be given, so that $\alpha + \beta \le 1$. 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.

4. Conclusions

The conducted study of briquetting of cast iron chips with controlled impact showed that the shape and size of the chips is essential for producing of high quality briquettes. Can be drawn the following important conclusions. It has been found that at impact briquetting of the chips with rectangular shape their location on the peripheral wall of the briquette is such that prevents Top of Form. Comparison with briquettes produced by impact of chips with small size indicates that by using of small size chips re produced briquettes with good density and quality. This means that large chips must first be ground to obtain chips with smaller dimensions.Depending on the trust R of the used rocket engine the process of compacting can be conducted in accordance with the curves 2,3,4 of Fig. 3. When operating in accordance with curve 2 ($R < P_i$) is observed reducing of the number of rebounds, which resulted in increasing of impact efficiency. When operating in accordance with curve 3 and curve 4 ($R \ge P_i$) it becomes possible to realize the impact without rebound (sticking impact) and increasing the time of action of the impact force. It is necessary to continue the research in this area using industrial rocket engines with a higher power.

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