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RESEARCH REGARDING THE COMPRESSION BEHAVIOUR OF FERROUS BRIQUETTES

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Original scientific paper

The paper presents the research on and the results related to the use of briquetted wastes, particularly small size and powdery ferrous ones. In order to produce the briquettes, we used scales and steel plant slag as small-grain ferrous materials, and electric steel plant dust, blast furnace-agglomeration slag and red slime from the alumina plants as powdery ferrous wastes. The research aimed at establishing recipes so that the contents of carbon may grant, on the one hand, the advanced reduction of iron oxides in the process of briquette hardening and on the other hand, high values of fissuring and crushing resistance.

Keywords: *blast furnace dust, briquettes, crushing time lag, scales, steel plant dust, resistance to crushing, resistance to fissuring*

Istraživanje kompresijske izdržljivosti briketa na bazi željeza

Izvorni znanstveni članak

U radu se predstavlja istraživanje i rezultati istraživanja korištenja briketiranog otpada, naročito onoga malih dimenzija i u obliku praha na bazi željeza. Za proizvodnju briketa smo koristili željeznu strugotinu i trosku iz željezara u obliku zrna, kao materijale na bazi željeza, te praškasti otpad iz željezara, šljaku visokih peći i crveni mulj iz tvornica aluminija kao praškasti otpad na bazi željeza. Cilj je istraživanja bio pronaći recepte kako bi sadržaj ugljika mogao omogućiti, s jedne strane, veće smanjenje željeznih oksida tijekom skrutnjivanja briketa i, s druge strane, visoke vrijednosti otpornosti na lomljenje i drobljenje.

Ključne riječi: *brikete, otpornost na lomljenje, prašina iz visokih peći, prašina iz željezara, usporavanje drobljenja, željezna strugotina*

1 Introduction

We are going to present the results of our research aimed at determining the influence of the weight of materials to be recycled upon the resistance of the briquettes made of these materials. In this case, we studied the dependence of briquette resistance on the quantity of steel plant dust particles, rolling scales and blast furnace agglomeration slam in their chemical composition, lime and bentonite being used as binders. In order to estimate the briquette quality characteristics of resistance to manipulation and transport, we determined by experiments three technological characteristics:

a) Resistance to fissuring:

$$R_f = \frac{F_f}{A},\ \text{kN/cm}^2, \tag{1}$$

where:
F_f – fissuring force, kN
A – the surface of the (briquette) sample cross section, cm^2.

Fissuring force F_f is considered to be the force which determines the appearance of the first visually detectable fissures. After a large enough number of preliminary trials and on the basis of the data in the reference literature, we concluded that this force has the value recorded at $t = 2$ s.

b) Resistance to crushing:

$$R_s = \frac{F_s}{A},\ \text{kN/cm}^2, \tag{2}$$

where:
F_s – crushing force, kN
A – the surface of the (briquette) sample cross section, cm^2.

On the basis of the reference literature data, and of the preliminary observations, we concluded that the crushing force should be the one recorded at $t = 12$ s.

c) The crushing time lag:

$$I_s = R_s - R_f,\ \text{kN/cm}^2. \tag{3}$$

2 Laboratory experiments

The wastes we took into consideration during the laboratory experiments were processed using several installations and equipment from the laboratories of University Politehnica of Timişoara – The Faculty of Engineering of Hunedoara or of our partners (University Politehnica of Bucharest – The Faculty of Science and Engineering of Materials, respectively the Center of Research and Production of Refractory Materials of Alba Iulia) [1]. Thus, we used an installation belonging to the class of laboratory vibration screening, a Sartorius analytical technical scales, a homogenizing drum, the laboratory experimental installation for waste briquetting, a hardening bar furnace, all of which are shown in Fig. 1.

Figure 1 Facilities and equipment used during the laboratory experiments

As to quality characteristics, we determined the fissuring and crushing resistance, and we also calculated the time lag of experimental briquettes crushing. The data we obtained were fed into the Matlab program and the resulting dependencies demonstrated the influence of the content of briquetting charge upon these indices [2 ÷ 4].

The briquettes were produced according to the recipes shown in Tab. 1, their diameter being d = 45 mm and their height h = 15 ÷ 40 mm.

Table 1 Recipe content

No	Waste used	Recipe content / %									
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
1	*AF*	18	17	16	15	14	13	12	11	10	9
2	*EP*	66	67	68	69	70	71	72	73	74	75
3	Scale	5	5	5	5	5	5	5	5	5	5
4	Lime	4	4	4	3	3	3	5	5	5	5
5	*C*	7	7	7	8	8	8	6	6	6	6

We will further present both graphically and analytically the dependence of the crushing resistance, R_s, of the fissuring resistance R_f and of the crushing time lag I_s on the percentage quantity of blast furnace agglomeration dust (*AF*), steel plant dust (*EP*) and cement (*C*).

Using Microsoft Office Excel we show in Fig. 2 the dependence of the three parameters R_s, R_f and I_s, on the percentage of blast furnace dust (*AF*).

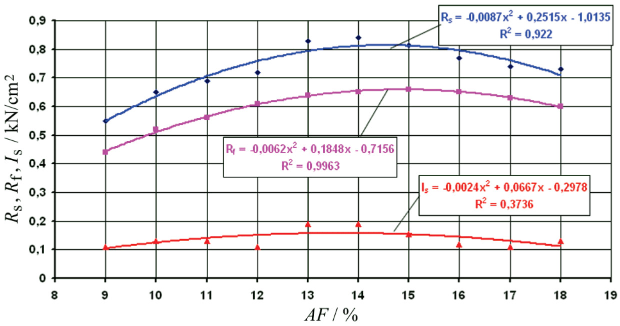

Figure 2 The dependence of the three parameters R_s, R_f and I_s, on the percentage of blast furnace dust (*AF*)

We show in Fig. 3 the dependence of the three parameters R_s, R_f and I_s, on the percentage of steel plant dust (*EP*) and Fig. 4 shows the dependence on the cement structure (*C*).

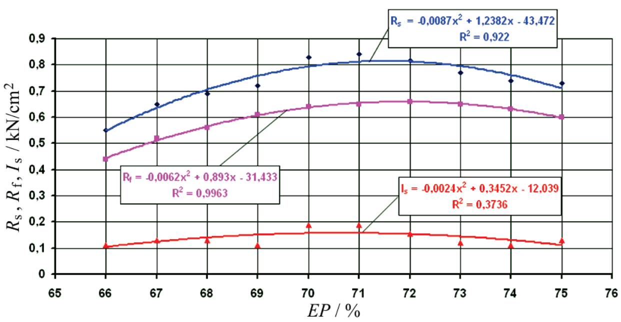

Figure 3 The dependence of the three parameters R_s, R_f and I_s, on the percentage of steel plant dust (*EP*)

We will further present both graphically and analytically the dependence of fissuring resistance R_f, crushing resistance R_s and the crushing time lag I_s on the percentage of blast furnace dust (*AF*), steel plant dust (*EP*) and cement (*C*).

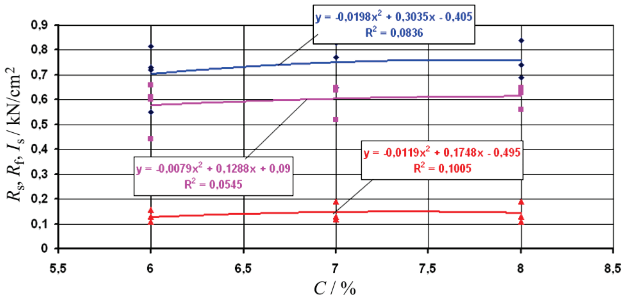

Figure 4 The dependence of the three parameters R_s, R_f and I_s, on the cement structure (*C*)

In order to determine the optimal *EP*, *AF*, C, values in the briquettes structure, it is necessary to graphically represent R_s, R_f and I_s, in Matlab, as functions of *EP*, *AF*, *C* and to give the analysis of the diagrams resulting from the horizontal projection of the contour lines, thus obtaining the optimal percentage of *EP*, AF and *C* [5]. Using Matlab, for R_s, the equation of the regression hyper surface is given by the following relation:

$$\begin{aligned} R_s &= -0{,}0139 \cdot AF^2 - 0{,}0004 \cdot EP^2 - 0{,}0038 \cdot C^2 + \\ &+ 0{,}0053 \cdot AF \cdot EP - 0{,}0046 \cdot AF \cdot C + 0{,}0016 \cdot EP \cdot C \end{aligned} . \quad (4)$$

In order to graphically represent the briquette crushing resistance R_s as function of the three parameters, i.e. the percentages of blast furnace dust (*AF*), steel plant dust (*EP*) and cement (C), in equation (4), we replaced in turn all the three parameters by their mean values, thus obtaining three equations, (5), (6) and (7) and the R_s dependences on the above mentioned parameters, which will be graphically represented by means of Matlab. Thus, for the mean value of the blast furnace dust, AF_{med} = 13,0435 %, it results:

$$\begin{aligned} R_s &= -0{,}0004 \cdot EP^2 - 0{,}0038 \cdot C^2 + 0{,}0016 \cdot EP \cdot C + \\ &+ 0{,}0696 \cdot EP - 0{,}0601 \cdot C - 2{,}3643 \end{aligned} . \quad (5)$$

For the mean value of the percentage of steel plant dust EP_{med} = 70,0435 %, it results:

$$\begin{aligned} R_s &= 0{,}0139 \cdot AF^2 - 0{,}0038 \cdot C^2 - 0{,}0046 \cdot AF \cdot C + \\ &+ 0{,}3736 \cdot AF + 0{,}1153 \cdot C - 0{,}0270 \end{aligned} . \quad (6)$$

And for the mean value of the cement percentage C_{med} = 6,9565 % it results:

$$\begin{aligned} R_s &= -0{,}0139 \cdot AF^2 - 0{,}0004 \cdot EP^2 + 0{,}0053 \cdot AF \cdot EP - \\ &- 0{,}0320 \cdot AF + 0{,}0115 \cdot EP - 0{,}1817 \end{aligned} . \quad (7)$$

Using Matlab from R_f, the equation of the regression hyper surface is given by the following relation:

$$\begin{aligned} R_f &= +0{,}0094 \cdot AF^2 - 0{,}0003 \cdot EP^2 - 0{,}0071 \cdot C^2 + \\ &+ 0{,}0037 \cdot AF \cdot EP - 0{,}0045 \cdot AF \cdot C + 0{,}0023 \cdot EP \cdot C \end{aligned} . \quad (8)$$

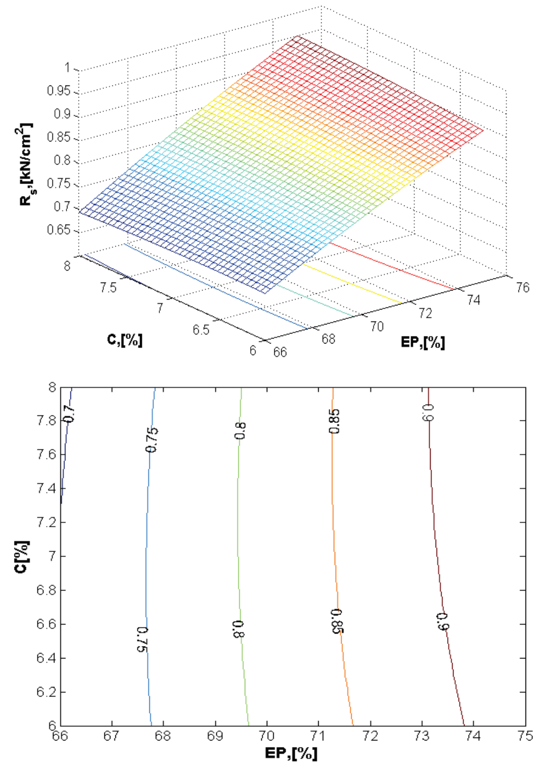

Figure 5 The briquette crushing resistance as function of the percentage of steel plant dust (*EP*) and cement (*C*) in the structure of the briquettes

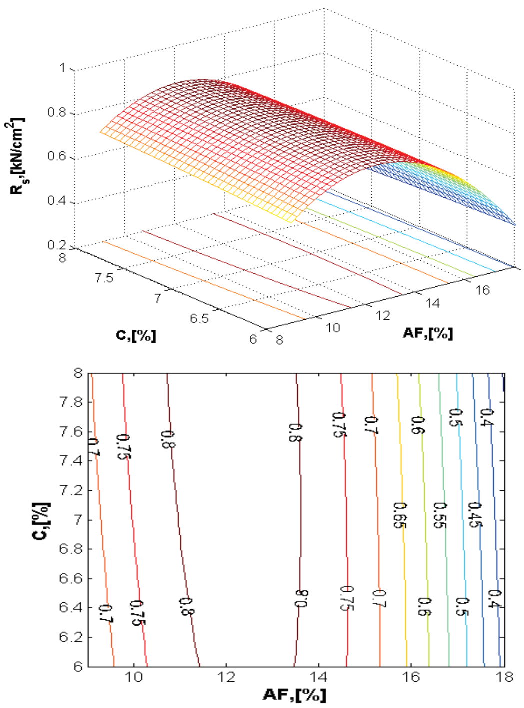

Figure 6 The briquette crushing resistance as function of the percentage of blast furnace dust (*AF*) and cement (*C*) in the structure of the briquettes

In order to graphically represent R_f as function of the three parameters, i.e. the percentages of blast furnace dust (*AF*), steel plant dust (*EP*) and cement (*C*), in parameters by their mean values, thus obtaining three equations (9), (10) and (11) and the dependences R_f on the parameters mentioned above, which will be graphically represented by means of Matlab. Thus, for the mean value of the percentage of blast furnace dust, AF_{med} = 13,0435 %, it results:

$$R_f = -0,0003 \cdot EP^2 - 0,0071 \cdot C^2 + 0,0023 \cdot EP \cdot C + 0,0485 \cdot EP - 0,0584 \cdot C - 1,6068 . \quad (9)$$

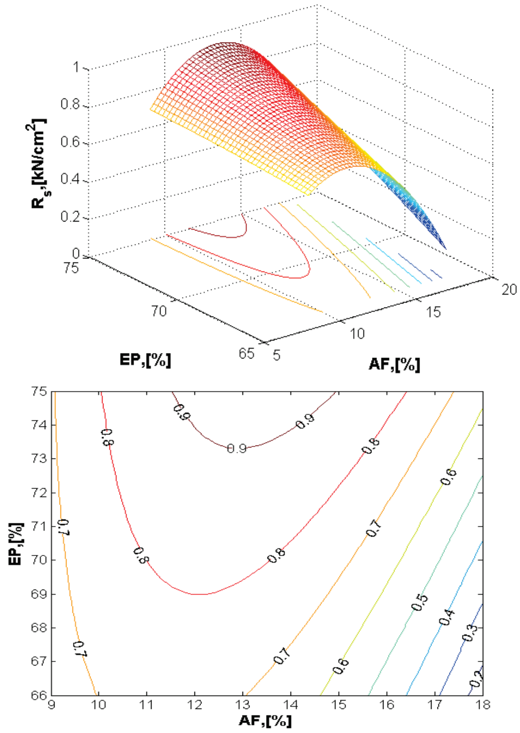

Figure 7 The briquette crushing resistance as function of the percentage of blast furnace dust (*AF*) and steel plant dust (*EP*) in the structure of the briquettes

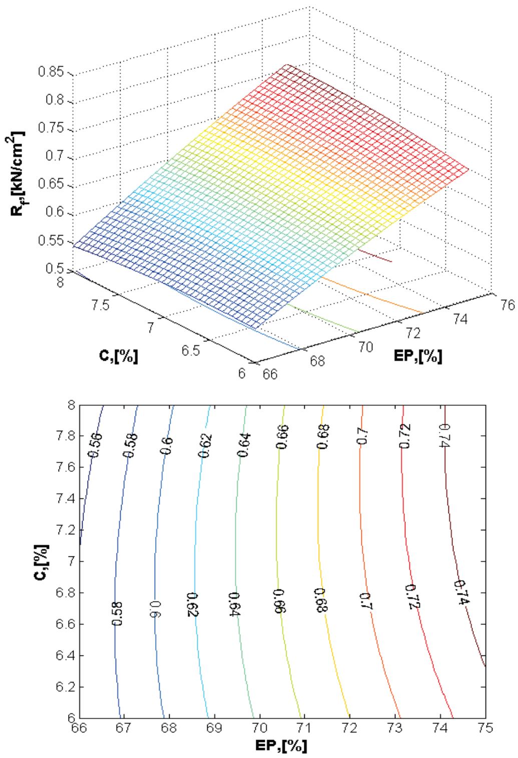

Figure 8 The briquette crushing resistance as function of the percentage of steel plant dust (*EP*) and cement (*C*) in the structure of the briquettes

For the mean value of the percentage of steel plant dust EP_{med} = 70,0435 % it results:

$$R_f = -0{,}0094 \cdot AF^2 - 0{,}0071 \cdot C^2 - 0{,}0045 \cdot AF \cdot C + \\ + 0{,}2605 \cdot AF + 0{,}1603 \cdot C - 1{,}5024 \quad . \qquad (10)$$

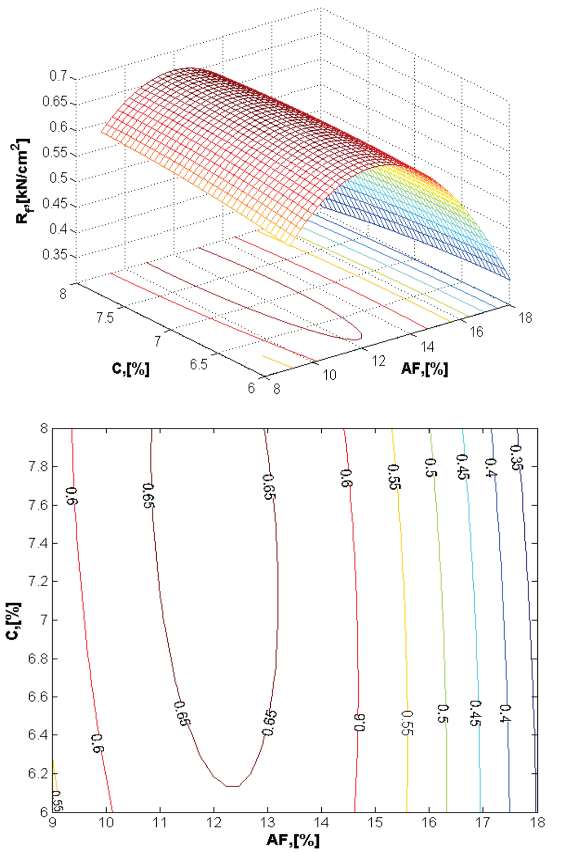

Figure 9 The briquette crushing resistance as function of the percentage of blast furnace dust (AF) and cement (C) in the structure of the briquettes

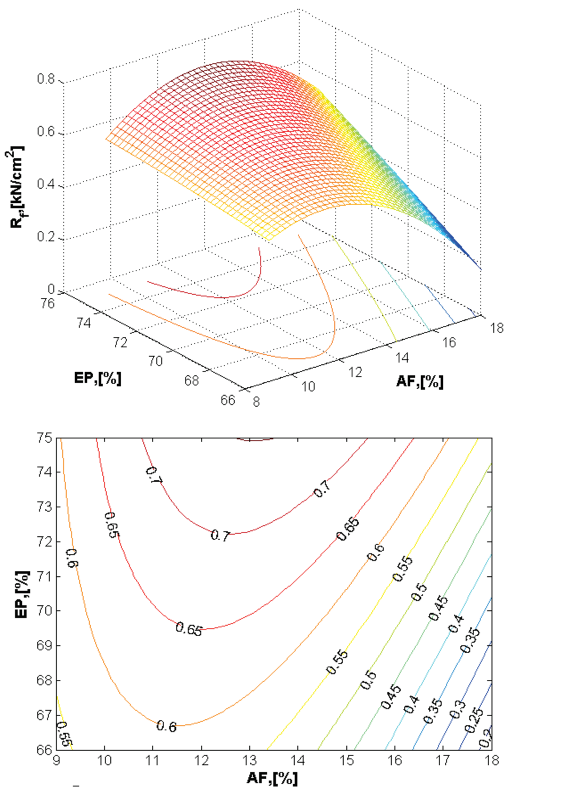

Figure 10 The briquette crushing resistance as function of the percentage of blast furnace dust (*AF*) and steel plant dust (*EP*) in the structure of the briquettes

And for the mean value of the cement percentage C_{med} = 6,9565 % it results:

$$R_f = -0{,}0094 \cdot AF^2 - 0{,}0003 \cdot EP^2 + 0{,}0037 \cdot AF \cdot EP - \\ - 0{,}0311 \cdot AF + 0{,}0159 \cdot EP - 0{,}0495 \quad . \qquad (11)$$

Using Matlab from I_s, the equation of the regression hyper surface is given by the following relation:

$$I_s = -0{,}0044 \cdot AF^2 - 0{,}0001 \cdot EP^2 - 0{,}0005 \cdot C^2 + \\ + 0{,}0017 \cdot AF \cdot EP - -0{,}0015 \cdot AF \cdot C + 0{,}0004 \cdot EP \cdot C \quad . \qquad (12)$$

In order to graphically represent I_s as function of the three parameters, i.e. the percentages of blast furnace dust (*AF*), steel plant dust (*EP*) and cement (*C*), in equation (8), we replaced in turn the three parameters by their mean values, thus obtaining three equations (9), (10) and (11) and the dependences I_s on the parameters mentioned above, which will be graphically represented by means of Matlab in Figs. 11 ÷ 13. Thus, for the mean value of the percentage of steel plant dust, EP_{med} = 70,0435 % it results:

$$I_s = -0{,}0044 \cdot AF - 0{,}0005 \cdot C^2 - 0{,}0015 \cdot AF \cdot C + \\ + 0{,}1208 \cdot AF + 0{,}0256 \cdot C - 0{,}6846 \quad . \qquad (13)$$

For the mean value of the percentage of blast furnace dust, AF_{med} = 13,0435 %, it results:

$$I_s = -0{,}0001 \cdot EP^2 - 0{,}0005 \cdot C^2 + 0{,}0004 \cdot EP \cdot C + \\ + 0{,}0225 \cdot EP - 0{,}0191 \cdot C - 0{,}7435 \quad . \qquad (14)$$

For the mean value of the percentage of cement C_{med} = 6,9565 % it results:

$$I_s = -0{,}0044 \cdot AF^2 - 0{,}0001 \cdot EP^2 + 0{,}0017 \cdot AF \cdot EP - \\ - 0{,}0102 \cdot AF + 0{,}0025 \cdot EP - 0{,}0035 \quad . \qquad (15)$$

On analysing Figs. 2 ÷ 4 one can see that, in the case of briquettes, the optimal R_s values (over 0,8 kN/cm^2), R_f values (over 0,6 kN/cm^2), I_s (over 0,15 kN/cm^2) are obtained for the blast furnace dust percentage (*AF*), ranging within 12 % and 15 %, the steel plant dust percentage (*EP*) ranging within 69 % and 72 % and the cement percentage (*C*), ranging within 6 % and 8 %.

Yet, in order to obtain more exact values for the percentage of blast furnace dust *AF*, the steel plant dust percentage *EP* and the cement percentage *C*, the data have been processed in Matlab. Thus, on analysing Figs. 5 ÷ 7, we find that R_s values above 0,8 kN/cm^2 are obtained for:

- in Fig. 5, for *EP* values between 69,5 % and 75 % and C values, between 6 % and 8 %.
- in Fig. 6, for *AF* values between 11,5 % and 13,5 % and *C*, values, between 6 % and 8 %.
- in Fig. 7, for *AF* values between 10 % and 16 % and *EP* values, between 69 % and 75 %.

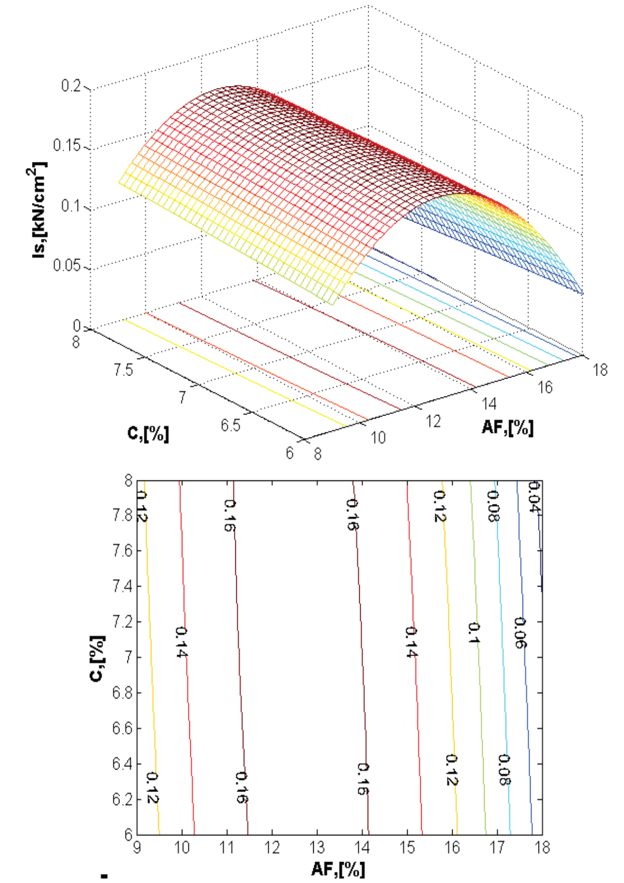

Figure 11 The briquettes crush time lag as function of the percentage of steel plant dust (*EP*) and cement (*C*) in the structure of the briquettes

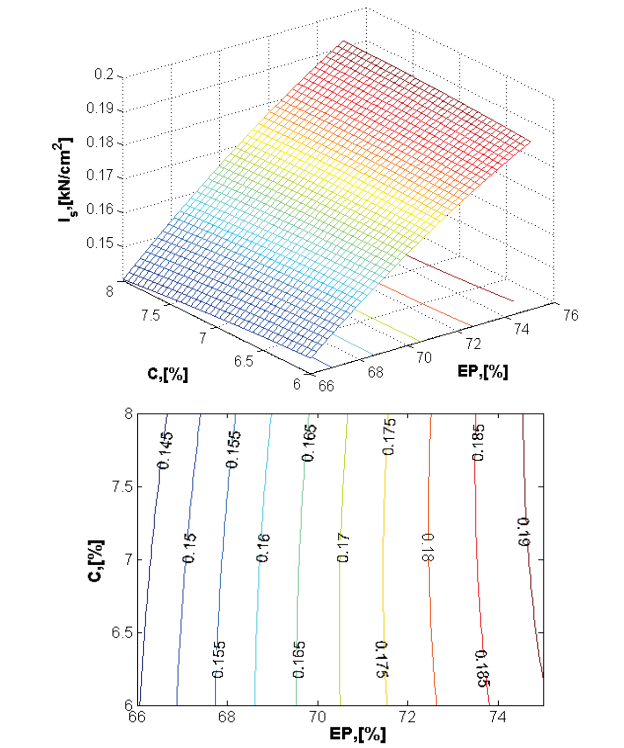

Figure 12 The briquette crushing time lag as function of the percentage of blast furnace dust (*AF*) and cement (*C*) in the structure of the briquettes

On analysing Figs. 8 ÷ 10 one can notice that R_f values above 0,6 kN/cm^2 are obtained for:

- in Fig. 8, for *EP* values between 68 % and 75 % and *C*, values, between 6 % and 8 %.
- in Fig. 9, for *AF* values between 10 % and 15 % and *C*, values, between 6 % and 8 %.
- in Fig. 10, for *AF* values between 9 % and 16 % and *EP* values, between 66,5 % and 75 %.

On analysing Figs. 11 ÷ 13, one can notice that I_s values above 0,16 kN/cm^2 are obtained for:

- in Fig. 11, for *AF* values between 11,5 % and 14,2 % and *C*, values, between 6 % and 8 %.
- in Fig. 12, for *EP* values between 69 % and 75 % and *C*, values, between 6 % and 8 %.
- in Fig. 13, for *AF* values between 11 % and 16 % and *EP* values, between 68,5 % and 75 %.

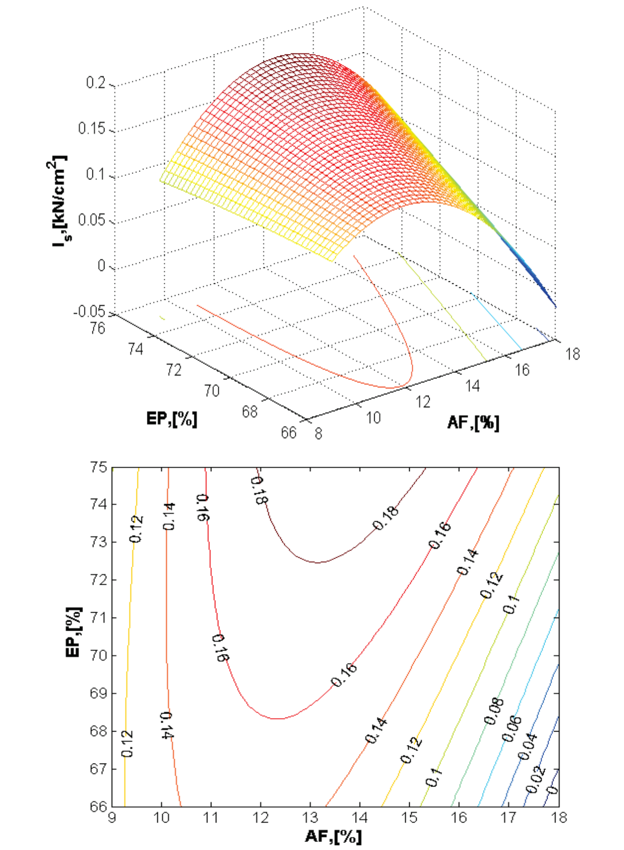

Figure 13 The briquette crushing time lag as function of the percentage of blast furnace dust (*AF*) and steel plant dust (*EP*) in the structure of the briquettes

3 Conclusions

Our research has lead to the following findings:

- for *AF* values between 11,5 % and 13,5 %, *EP* between 69,5 % and 75 %, *C* between 6 % and 8 %, R_f and R_s have maximum values
- for *AF* values between 11,5 % and 14,2 %, EP between 69 % and 75 %, *C* between 6 % and 8 %, I_s has maximum value
- in industrial processes, respectively in metallurgy and particularly in steel making, besides the main product several by-products, wastes result, which can be recycled;
- small size and powdery ferrous wastes in the industrial area of Hunedoara, the basic ones and those with carbon content can be recycled in steel making;
- the wastes under analysis can be processed through briquetting;

- the content of the recipes will be established in accordance with the available small size and powdery wastes and considering the destination of the processed material, respectively steel plants or blast furnaces;
- under the existing conditions, we consider it necessary to intensify the recycling of these wastes, as they represent a source of iron, a scarce raw material nowadays, for technological reasons and, last but not least, for ecological reasons;
- we consider that we can recycle both the wastes resulting directly from the technological fluxes and those already dumped.

4 References

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