Ferrous waste processing by pelletizing, briquetting and mechanically mixed

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Abstract**—** Industrial processes in steel making, energetic and mining are highly polluting. Steel making and energetic machinery release large quantities of gas and dust, the latter being retained by modern purification installations. As to the small size and powdery wastes resulting from the technological fluxes of the industrial branches mentioned above, this paper had as a main target to reduce pollution in industrial areas and to turn to good account the wastes containing iron, carbon and basic oxides, by their recycling in the steel making industry and, finally, to return the areas occupied at present by slag dumps or ponds to the natural environment. From the point of view of their chemical composition and granulometry, waste recycling proved profitable technologically, economically and ecologically.

Keywords**—**briquette, capitalization, ferrous waste, siderurgy, sustainable development.

I. INTRODUCTION

In the last decade, manufacturing technologies for metallic materials all over the world have reached a high performance level, demonstrating a high capacity to adapt to the changes due to conditions imposed on raw materials and energy, necessary to increase productivity and decrease specific use, as well as obeying to stricter environmental regulations. The remarkable results obtained in modern iron factories were possible through implementation of management systems into industrial activity, systems which imposed the analysis, evaluation and selection on changes at the level of technologies/equipments, respectively alternative technologies, from the perspective of its specific instruments, among which one of the most complex is undoubtedly the life cycle analysis [1].

For Romania the recovery of ferrous wastes represents a priority for the durable development strategy because the natural resources of some raw materials categories are poor or insufficient and the resources can substitute part of the raw materials with significant low costs. Comparatively with the practice and the world wide manifested tendencies, the Romanian industry registers gaps in the powder wastes collection, transportation and storage area, as well as in that of the recovery technologies area by their recycling or reusing [2]. Thereby, the approach of the superior recovery of small and powder ferrous wastes problem was considered necessary and convenient. Pulverous ferrous wastes are present in all cases in the form of oxides. For the recovery of iron, they must be objects in a reduction process, either in a furnace, case in which these wastes are components of the raw material (previously processed as pellets, briquettes or agglomerate), or in electric arc furnaces, as secondary material with a complex fusing - oxidizing character or as a slag foaming agent. In countries with a well-developed iron industry, pulverous ferrous wastes are recovered in a proportion of over 90% through re-introduction in the siderurgical circuit.

The works written of this theme state that this recovery is practised with several technologies, namely [3]–[10]:

- *Recovery through agglomeration* - in this processing technology, pulverous ferrous wastes (steel plants dust) compose the agglomeration charge in a proportion of 2-3% (sometimes together with other ferrous wastes like sunder, blast furnace flue dust, agglomeration dust, etc.). The obtained agglomerate is later used as raw material in furnace charge;
- *Recovery through pelletizing* - this technology involves using steel plant dust as unique component in the agglomeration charge, or in a mixture with pulverous ferrous ore or other pulverous wastes for producing pellets. The obtained pellets, according to their quality, determined mainly by the processing technology, can be used: in furnace charges, as raw material, together with agglomerate, and, eventually, ore; in reduction equipment charge, to obtain metalized pellets and use them as raw material in electric arc furnace; in charge of electric arc furnace as auxiliary material to form slag and correct the chemical composition, or as foaming agent;
- *Recovery through briquetting* - at this variant, generally the briquetting charge used more ferrous wastes, adding powders with high carbon and lime dust content. The obtained briquettes can be processed in reduction aggregates. We consider the Thyssen–Krupp Stahl Company’s technology extremely efficient: the fine and pulverous ferrous wastes are processed in the form of hexagonal briquettes, sized 100 mm, respectively 56 mm. After a hardening period of 5 days, they are charged in shaft furnaces (Hamborn type) with 15 t/h productivity;
- *Recovery through reduction without initial processing* - these technologies require iron reduction from powder wastes either with a gaseous reduction agent, or with carbon, obtaining iron sponge, used in electric arc furnace charge;

- *Recovery through the carboferrous method* - to produce it we use: tunder, laminating slime, steel plant dust, furnace dust, agglomerating slime, lime dust, coal dust etc. All over the world it is used to produce cast iron in furnaces, being blasted into the mixture with coal dust through the blast inlet of the furnace, as well as casting iron in electric arc furnace using it as a replacement for common slag foaming agents at electric arc furnaces provides both environmental and economical aspects. The environmental aspect is given by the considerable reduction of environmental pollution, both by the increase of recovery for pulverous wastes and reduction of depository spaces for these wastes. The economical aspect is reflected by transferring depositary expenses (55-110 €/tone of waste) to other purposes.

II. EXPERIMENTS IN THE LABORATORY PHASE

A. *Processing of waste by briquetting*

For the recovery in form of briquettes of the small and powder ferrous wastes accrued from the iron-and-steel industry we have taken into consideration the following wastes: dust from the electrical steel works, dust (pulp) from furnace-congestion, scum (pulp of scum) and as binder: lime and bentonite. The chemical compound of the 10 experimented receipts is presented in figure 1. The obtained product is presented in figure 2.

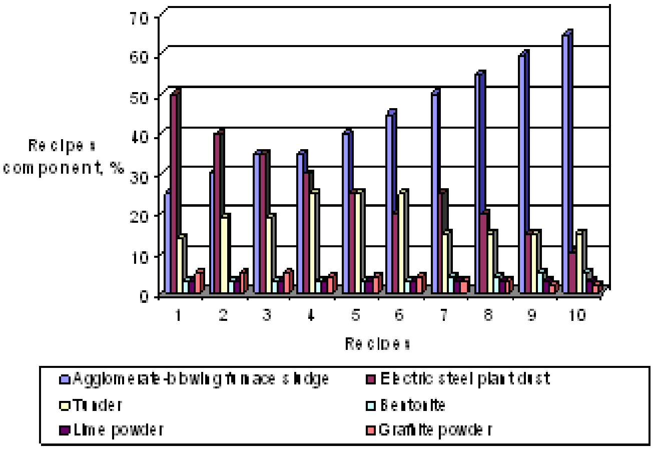

Fig.1. Experimental recipes component.

Fig.2. The briquettes.

Hereinafter, we present the results of the researches performed in order to produce and test cylindrical briquettes with 45mm diameter and 15-40mm height, along with the results of the resistance tests performed on the briquettes made of recyclable materials [11]:

- The changing of the briquette resistance according to the weight (in the preparation recipe) of the steel plant dust particles (EAF), rolling-mill scale, sintering-blast furnace sludge, lime, cement;
- The influence of some chemical compounds (found in the materials recycled through briquetting) on resistance.

To evaluating the resistance qualitative characteristics during handling and transportation of the briquettes, we determined, through experiments, three technological characteristics:

- Crack resistance (R_f);
- Crushing resistance (R_s);
- Crushing interval (I_s).

For a more complex assessment of the analyzed factors, the data has been processed in the computation program Matlab, resulting in multiple correlations, analytical expressed by equations and graphical by regression surfaces. Onwards the correlations obtained for the experimental lot are presented. Thereby, in figure 3-11 are presented both the regression surfaces as well as the level curves representing the dependencies between the resistance to cracking, resistance to breaking and the breakage interval and the proportions of steel works dust, dust (pulp) from furnace-congestion and scum, the correlations having as general form the equation:

$$z = a_1x^2 + a_2y^2+a_3xy+a_4x+a_5y+a_6 \tag{1}$$

where: z – dependent parameter;
x, y – independent parameters;
a_i – coefficient.

The equations that describe the regression surfaces are:

$$R_f = 0,0001 \cdot (FA)^2 + 0,0004 \cdot (CEA)^2 + 0,0002 \cdot (FA) \cdot (CEA) - 0,0051 \cdot (FA) - 0,0337 \cdot (CEA) + 1,1685 \tag{2}$$

$$R_f = - 0,0001 \cdot (FA)^2 + 0,0013 \cdot (T)^2 - 0,0001 \cdot (FA) \cdot (T) + 0,0109 \cdot (FA) - 0,0484 \cdot (T) + 0,8407 \tag{3}$$

$$R_f = 0,0001 \cdot (CEA)^2 + 0,0005 \cdot (T)^2 + 0,0001 \cdot (CEA) \cdot (T) - 0,0132 \cdot (CEA) - 0,0244 \cdot (T) + 1,0902 \tag{4}$$

$$R_s = - 0,0006 \cdot (FA)^2 - 0,0004 \cdot (CEA)^2 - 0,0016 \cdot (FA) \cdot (CEA) + 0,0958 \cdot (FA) + 0,0778 \cdot (CEA) - 2,1665 \tag{5}$$

$$R_s = - 0,0002 \cdot (FA)^2 + 0,0013 \cdot (T)^2 - 0,0002 \cdot (FA) \cdot (T) + 0,0154 \cdot (FA) - 0,0456 \cdot (T) + 0,9520 \tag{6}$$

$$R_s = 0,0004 \cdot (CEA)^2 - 0,0005 \cdot (T)^2 + 0,0005 \cdot (CEA) \cdot (T) - 0,0410 \cdot (CEA) + 0,0046 \cdot (T) + 1,4388 \tag{7}$$

$$I_s = - 0,0007 \cdot (FA)^2 - 0,0008 \cdot (CEA)^2 - 0,0017 \cdot (FA) \cdot (CEA) + 0,1009 \cdot (FA) + 0,1115 \cdot (CEA) - 3,3350 \tag{8}$$

$$I_s = - 0,0001 \cdot (FA)^2 + 0,0001 \cdot (T)^2 - 0,0001 \cdot (FA) \cdot (T) + 0,0044 \cdot (FA) + 0,0028 \cdot (T) + 0,1113 \tag{9}$$

$$I_s = 0,0003 \cdot (CEA)^2 - 0,0010 \cdot (T)^2 + 0,0004 \cdot (CEA) \cdot (T) - 0,0279 \cdot (CEA) + 0,0290 \cdot (T) + 0,3486 \tag{10}$$

where: CEA – electric steel plant dust;
FA – blast furnace agglomeration sludge;
T – tunder.

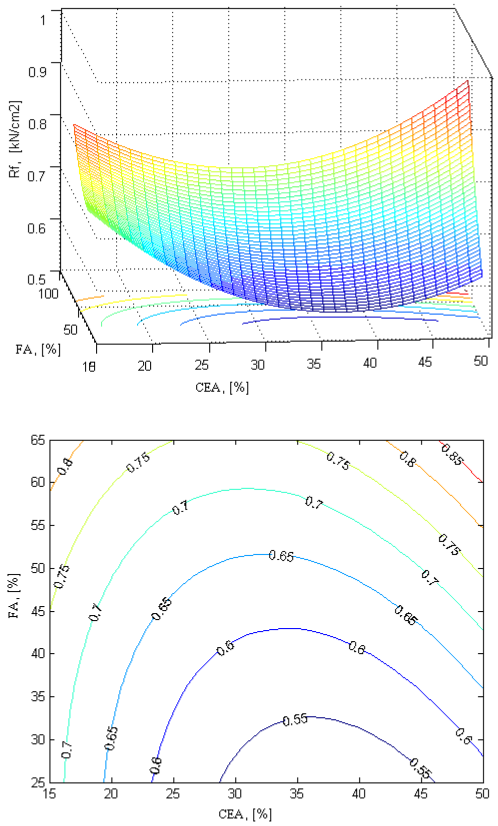

Fig.3. $R_f = f(FA, CEA)$

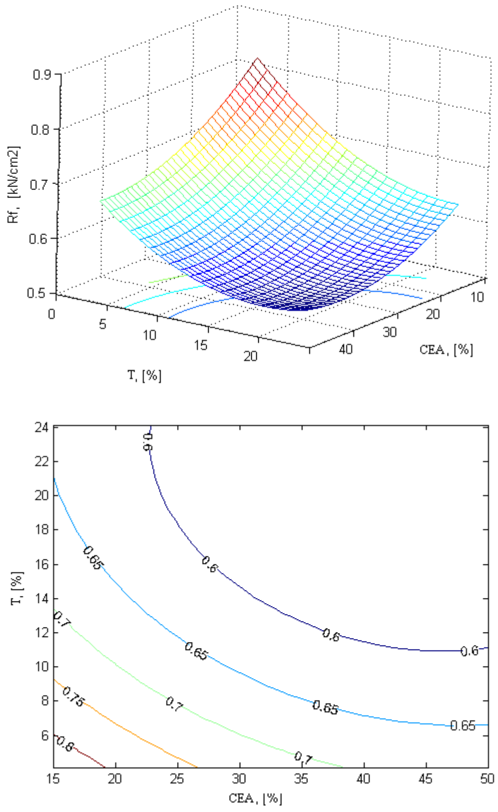

Fig.5. $R_f = f(T, CEA)$

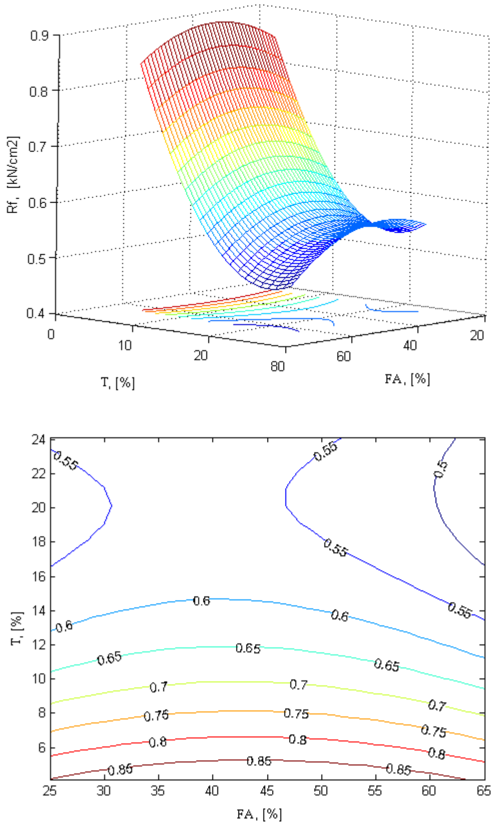

Fig.4. $R_f = f(T, FA)$

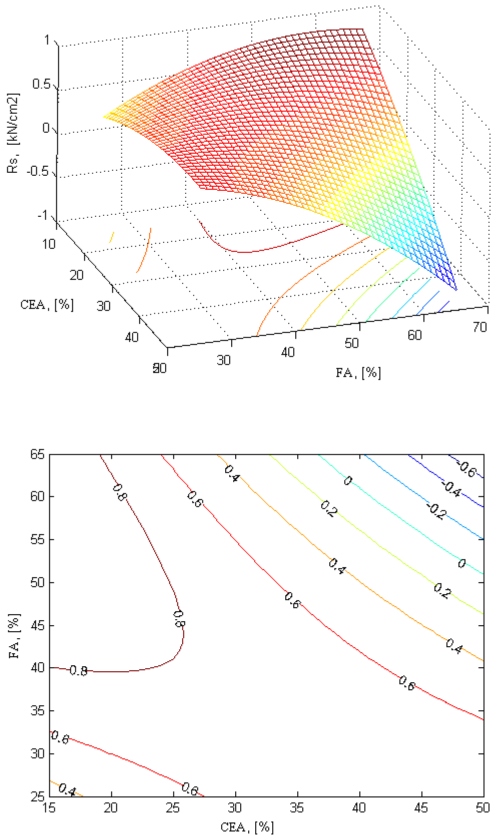

Fig.6. $R_s = f(CEA, FA)$

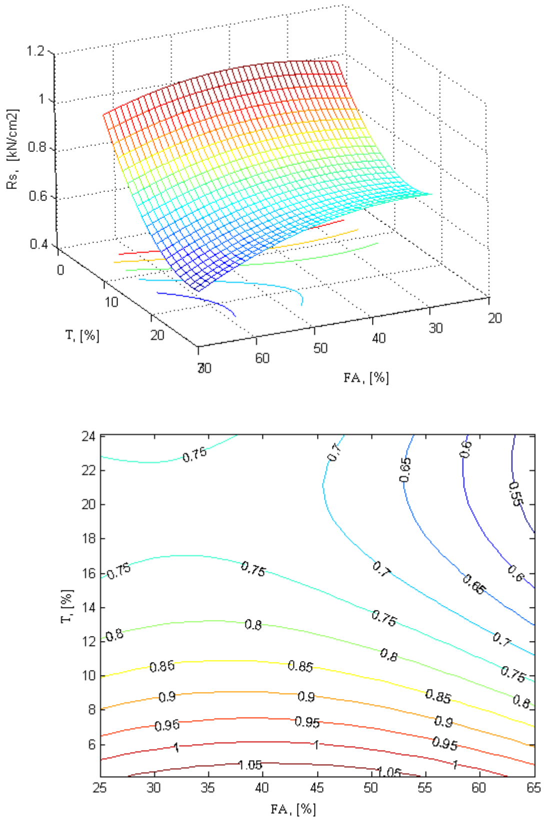

Fig.7. $R_s = f(T, FA)$

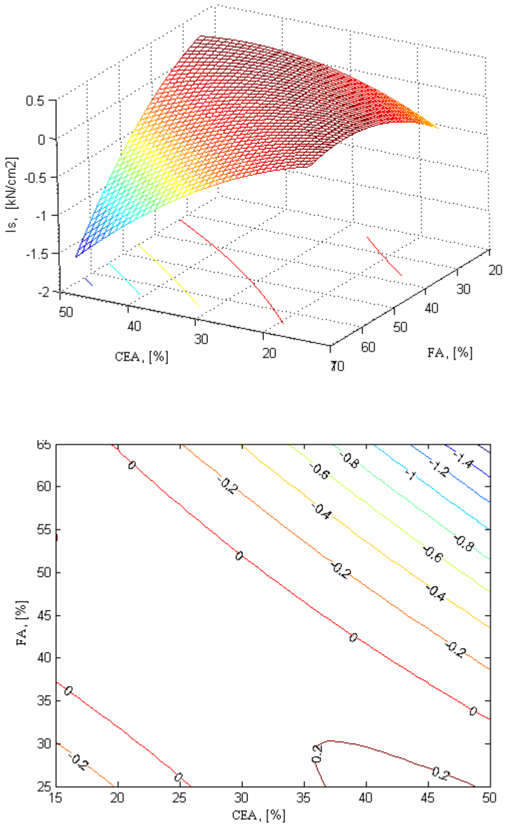

Fig.9. $I_s = f(CEA, FA)$

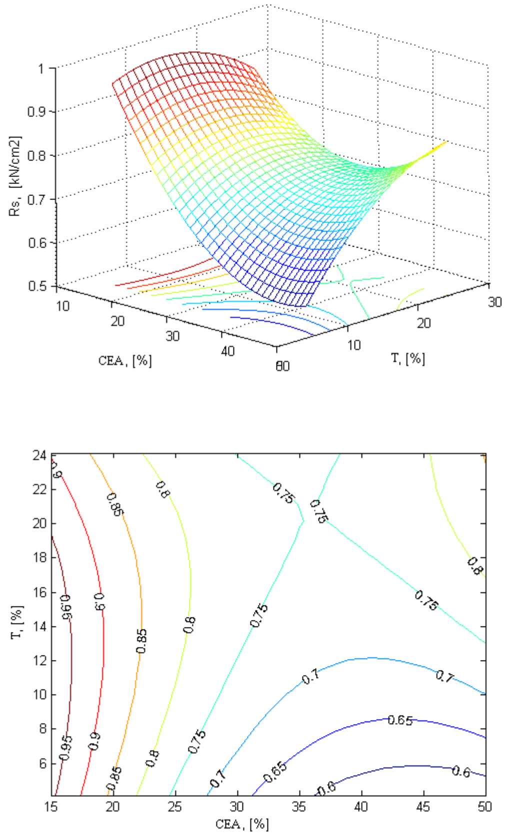

Fig.8. $R_s = f(CEA, T)$

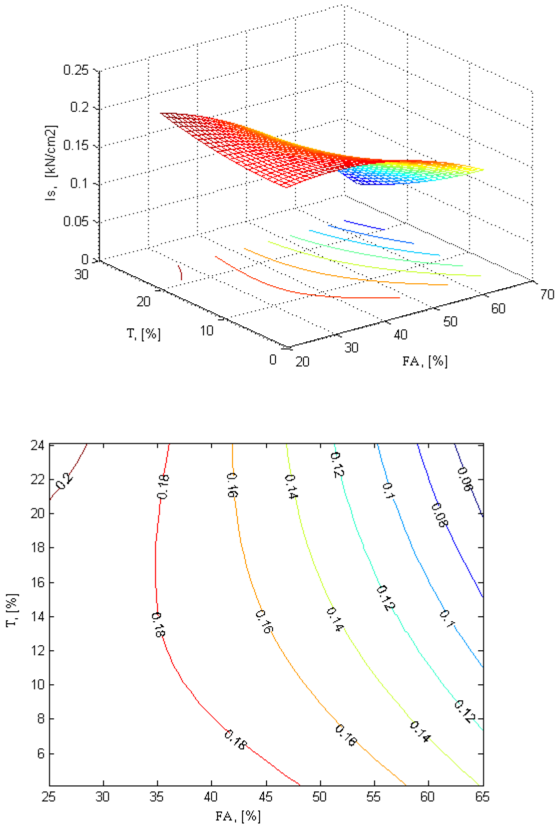

Fig.10. $I_s = f(T, FA)$

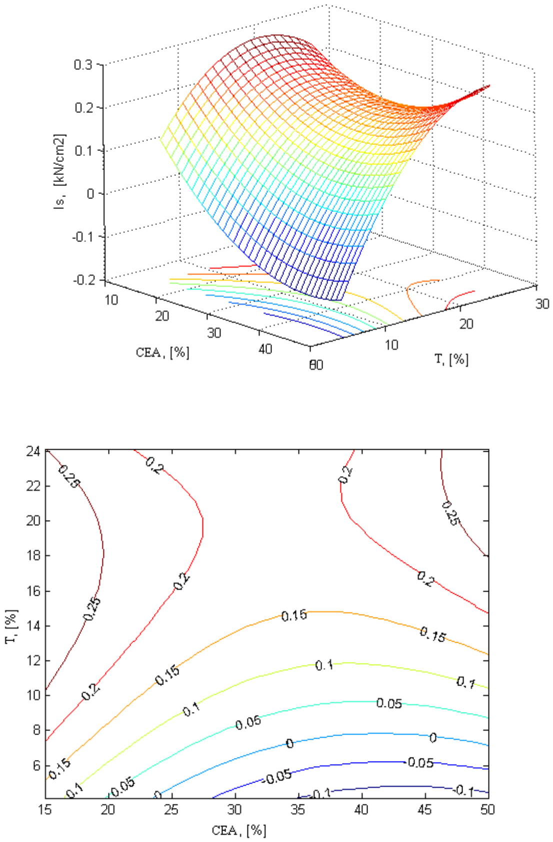

Fig.11. $I_s = f(CEA, T)$

Lighters have undergone experimental reduction by heating in the oven room type forced bars (figure 12) and Tammann oven (figure 13) to 1350^{o}C temperatures and kept at that temperature for 30min. Heating time was 60 min and thus keeping the total time in the oven resulted in 1,5 h.

We believe that the reduction process went well; we obtained high values for the degree of reduction, which is normal if we consider that they have higher carbon content than that required reduction.

Fig.12. Experiments in the furnace room type

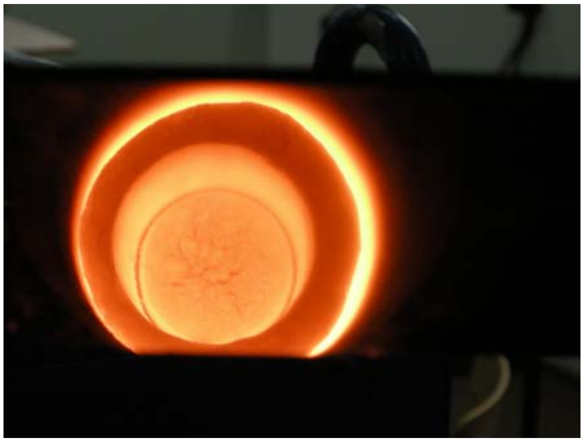

Fig.13. Experiments in the oven Tammann

B. *Processing of waste by pelletizing*

Wastes have been processed into micro-pellets, the resulting CARBOFER being recyclable both in the agglomeration process and in steel making, where it is used as slag foaming agent in the electric arc furnace. Micro-pelleting is a flexible process, which offers the possibility of choosing such recipes that may contain one or several waste types, depending on the chemical composition needed by the respective product, as well as on the amount of waste available in a given period [12]-[13].

The materials processed contain elements – Fe, C, Ca – that are useful in the steel making processes, their percentage in the finite product ranging within the following limits: Fe = 28,35% (from the steel plant dust, blast furnace agglomeration sludge, tunder, tunder sludge); Ca = 18,49% (from the steel plant dust, blast furnace agglomeration sludge); and C = 11,66% (from the blast furnace dust, coke, coal or graphite dust).

As to obtaining CARBOFER pellets, the recipes suggested for experiments in the pilot phase aimed at obtaining a recyclable product, usable both as slag foaming agent, in electric arc furnaces, and as component in the agglomeration charge [14].

The chemical compound of the 10 experimented receipts is presented in figure 14. The chemical composition of CARBOFER pellets is given in figure 15.

After pelletizing, for each particular charge we determined the following characteristics:

- the bulk mass of wet and dry micro-pellets [kg/dm^3];
- the humidity of the micro-pellets [%];
- the granulometric distribution of the pellets in a raw state.

Pellet formation, their granulometric distribution and resistance to handling are influenced by the amount of water used in the micro-pelletizing process, by the amount of calcium in the limestone dust used as a bonding element, giving the pellets resistance in handling, as well as by the content of carbon, more exactly the amount of coke dust in the recipe.

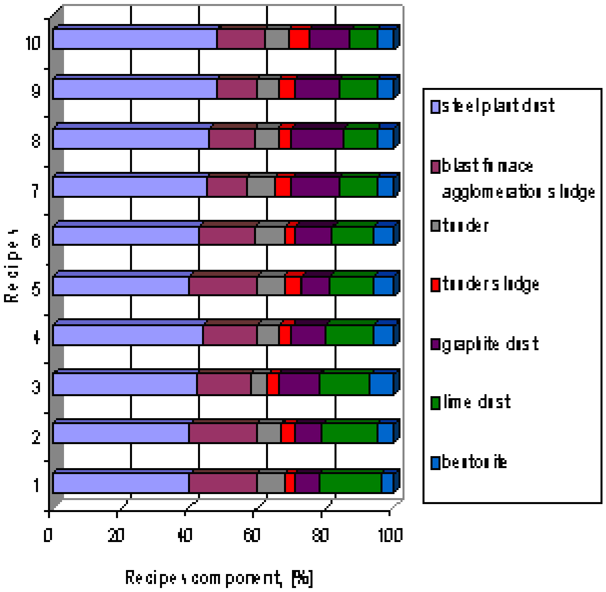

Fig.14. The chemical compound of recipes.

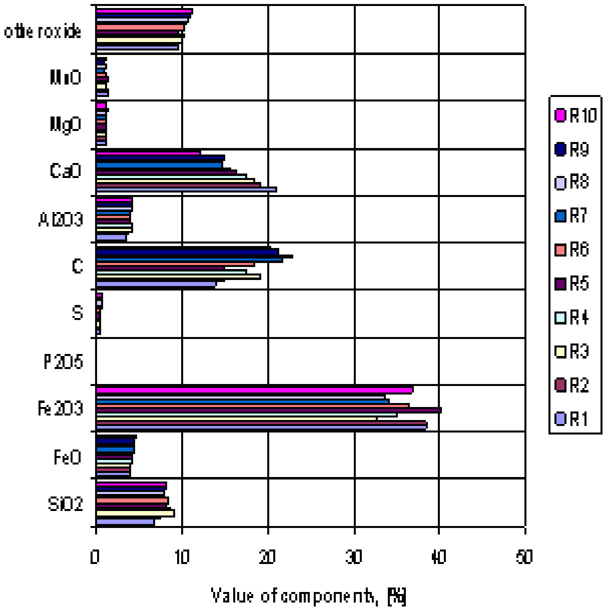

Fig.15. The chemical composition of CARBOFER pellets

The analysis of the results leads to the conclusion that the optimal recipes from the granulometric point of view, meeting the condition of evenness and preponderance in the range 1-3mm, a grain size recommended both in the process of electric arc furnace steel making, as slag foaming agent, and in the agglomeration process, are R3, R4, R6, R8.

From the point of view of the three main elements: Fe, C şi Ca, one can notice that the entire range of variation is covered, which proves the flexibility of the process, which allows us to choose from recipes that may contain one or several powdery wastes, depending on the chemical composition required by the place of recycling the product as well as on the amount of waste currently generated along a given period of time or existing in ponds.

Figure 16 shows aspects of the pelletizing process.

Fig.16. The aspects of the pelletizing process

Analyzing the results obtained from the pellets to obtain the best recipes was selected and tested their behavior in the heating process.

Burning was conducted in an oven with forced bars. It was found that starting at temperatures higher than 700^{o}C is formed due to intense flame combustion of carbon monoxide resulting from the combustion of iron oxides (Figure 17).

Fig.17. Aspects of the pellets during the combustion product CARBOFER

Combustion of iron oxide increased the temperature, leading to partial ccrossing the form of slag at CARBOFER pellets (the part came in contact with the flame, that top load) - figure 18.

Fig.18. Aspects of product during hardening pellets CARBOFER

C. Processing waste as mechanical mixture

CARBOFER is a mechanical mixture obtained out of various powdery wastes (tunder, rolling mill sludge, powders with a high content of carbon or limestone dust) whose content in iron, calcium and carbon, elements needed in steelmaking processes, is high enough to justify their valorization [15].

The chemical compound of the 10 experimented receipts is presented in figure 19.

The chemical composition of CARBOFER mechanical mixture is given in figure 20.

The CARBOFER mechanical mixture is present in figure 21

The classification of CARBOFER product (mechanical mixture) on the particle size classes is shown in Figure 22.

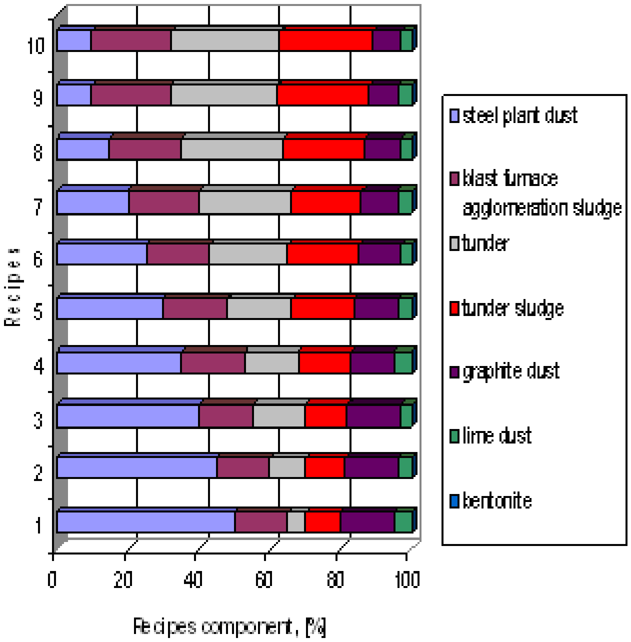

Fig.19. The chemical compound of recipes.

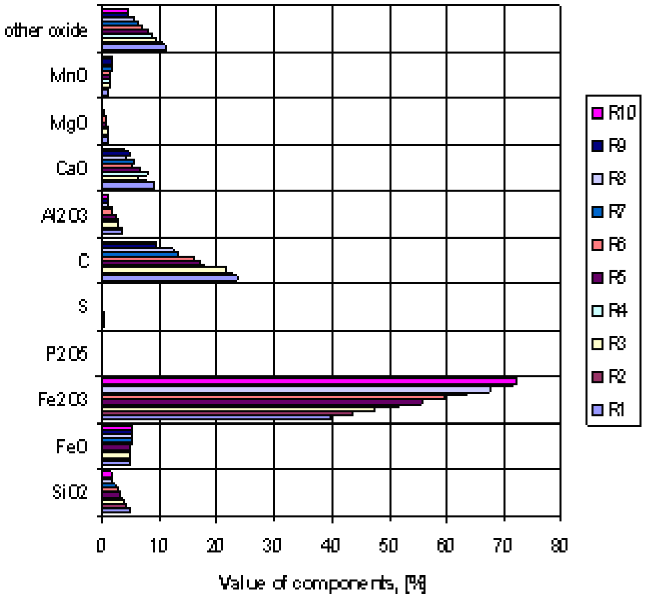

Fig.20. The chemical composition of CARBOFER mechanical mixture

Fig. 21. CARBOFER mechanical mixture

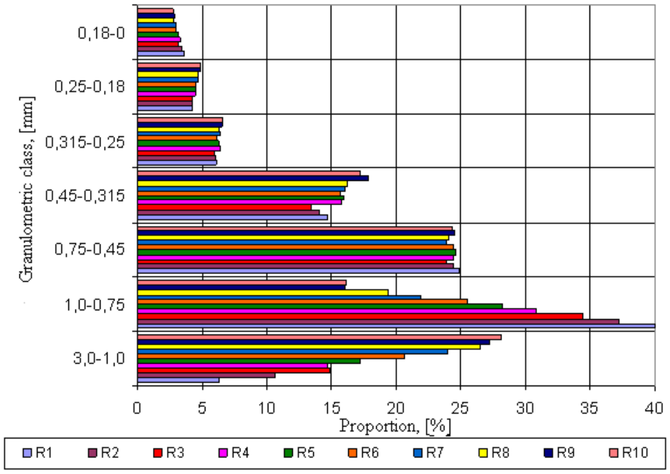

Fig.22. The classification by classes of CARBOFER product (mechanical mixture).

Experimental recipes were tested in an industrial-type electric arc furnace EBT 100 tons capacity. Additions were made at a rate of 5-7% of furnace capacity, as pursued by the addition of slag foaming capacity results. In figure 23 is presented the oven and the experiments were made during experiments in figure 24 issues.

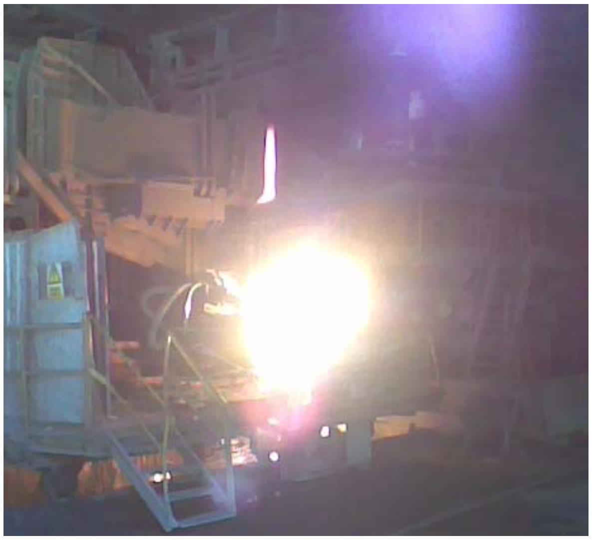

Fig.23. Electric arc furnace used in experiments

Fig.24. Aspects from industrial experiments

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III. RESULTS AND DISCUSION

Analyzing the achieved graphic and analytic correlations, it is observed that these have extreme points (maximum and minimum) and şea points.

From processing the experimental data and the respective regression surfaces of the level curves obtained it results that, to obtain briquettes with a breakage resistance higher than 0,6kN/cm^2 a receipt with the following composition is advisable: scum 10-12%, steel works dust of furnace-congestion 20-25% and dust of furnace-congestion60-70%. For this kind of limits briquettes with higher than 0,8kN/cm^2 crushing strength are obtained. Analogous values for these two resistances assure a good behavior of the briquettes during transportation and manipulation as well as during the technical process development.

The process of micro-pellet making, their distribution by granulometric classes, their resistance to handling and shipping are directly influenced by:

- the amount of water used in the process of micro-pelletizing, expressed by the humidity of the micro-pellets;
- the content of de CaO in the limestone dust and in the blast furnace agglomeration sludge which, alongside with the Al_2O_3, represent the bonding element, and confers to the pellets resistance in handling and in the technological process;
- the percentage of bentonite, determining the content of Al_2O_3, a bonding component, whose action is similar to that of lime;
- the content of carbon, determined by the amount of coal, coke, electrode or blast furnace dust used in the recipe, but mainly the coal dust which significantly influences the granulometric distribution of the micro-pellets, due to its hydrophobic behavior;
- the duration of the micro-pelletizing process;
- the type of pelletizing machine and its technological characteristics.

IV. CONCLUSION

Pursuant to researches and their results, we consider important the following conclusions:

- The scrap used to produce the briquettes has a good technological behaviour, the obtained briquettes having the required technical characteristics to be used in the iron-steel processes;
- The briquetting is advantageous because it allows the processing of a wide range of scrap, either from the chemical composition or granulometric point of view;
- We can obtain briquettes to be used both in the iron and steel making processes;
- In the industrial areas and especially in the iron & steel making areas, which are frequently subject to a strong economical restructuring, we consider the recovery through the fine scrap briquetting to be one of the most viable technological solution, suitable to be introduced in the economic circuit.

Analyzing the regression surfaces as well as presenting the level curves, respectively their values allows the establishing of some variation limits for the receipts` components so certain values for the dependent parameter can be obtained, in this case for the quality indicators of the briquettes.

The ecological advantages are clear, namely: cutting down the amount of powdery wastes by their continuous recycling, the diminishing of soil pollution with metallurgical waste by reducing the dumping areas, the valorization by recycling of these wastes, without any negative impact upon the environment.

Using CARBOFER site with high Fe content of C and we consider that it provides a better dissolution of FeO in the slag in a very short time and also very quickly establish equilibrium slag - metal bath, which provide good oxidation of C in the bathroom and an intense foaming slag, so make working with arc.

The economical advantages have both an immediate impact, i.e. transferring the depositing costs to other scopes, the obtaining of secondary raw materials, the low costs of processing by means of this procedure, as compared to others, and also long term advantages, such as cutting down costs by partial replacing of some raw materials. Considering that processing the powdery materials resulting from steel making in view of recycling and/or re-using them represents an issue with real ecological and economical implications we found it appropriate to carry out researches in the field of their superior valorization.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support of the present research by the Project no. 31-098/2007: Prevention and fighting pollution in the steel making, energetic and mining industrial areas through the recycling of small-size and powdering wastes, Program PN2 – Consortium – CNMP Romania, Responsable Prof. dr. eng. Teodor Heputƫ.

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